Final Report AO-2013-006: Misaligned take-off at night
Airbus A340, CC-CQF, Auckland Airport
18 May 2013

The Transport Accident Investigation Commission is an independent Crown entity established to determine the circumstances and causes of accidents and incidents with a view to avoiding similar occurrences in the future. Accordingly it is inappropriate that reports should be used to assign fault or blame or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

The Commission may make recommendations to improve transport safety. The cost of implementing any recommendation must always be balanced against its benefits. Such analysis is a matter for the regulator and the industry.

Final Report

Aviation inquiry AO-2013-006
Misaligned take-off at night

Airbus A340, CC-CQF
Auckland Airport
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Approved for publication: December 2015

Transport Accident Investigation Commission

About the Transport Accident Investigation Commission

The Transport Accident Investigation Commission (Commission) is an independent Crown entity responsible for inquiring into maritime, aviation and rail accidents and incidents for New Zealand, and co-ordinating and co-operating with other accident investigation organisations overseas. The principal purpose of its inquiries is to determine the circumstances and causes of occurrences with a view to avoiding similar occurrences in the future. Its purpose is not to ascribe blame to any person or agency or to pursue (or to assist an agency to pursue) criminal, civil or regulatory action against a person or agency. The Commission carries out its purpose by informing members of the transport sector, both domestically and internationally, of the lessons that can be learnt from transport accidents and incidents.

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Important notes

Nature of the final report

This final report has not been prepared for the purpose of supporting any criminal, civil or regulatory action against any person or agency. The Transport Accident Investigation Commission Act 1990 makes this final report inadmissible as evidence in any proceedings with the exception of a Coroner's inquest.

Ownership of report

Citations and referencing

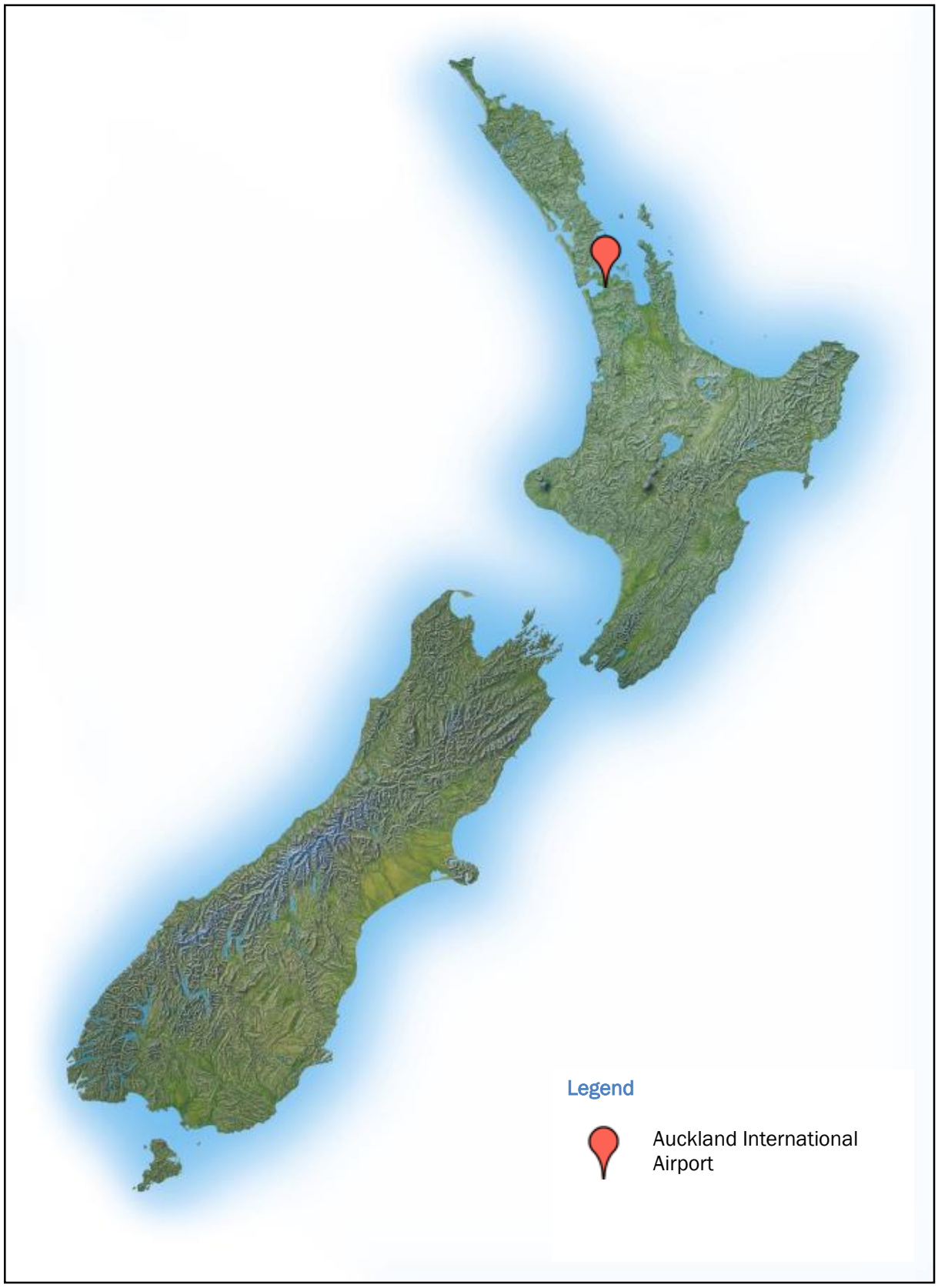
Information derived from interviews during the Commission's inquiry into the occurrence is not cited in this final report. Documents that would normally be accessible to industry participants only and not discoverable under the Official Information Act 1980 have been referenced as footnotes only. Other documents referred to during the Commission's inquiry that are publicly available are cited.

Photographs, diagrams, pictures

Unless otherwise specified, photographs, diagrams and pictures included in this final report are provided by, and owned by, the Commission.

LAN Airlines A340
(With permission from Emilio Zeininger)

Runway 23 Left, Auckland Airport,
viewed from the runway centreline



Source: mapsof.net

Location of incident

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Abbreviations

Airways	Airways Corporation of New Zealand
CAA	Civil Aviation Authority of New Zealand
Commission	Transport Accident Investigation Commission
Convention	Convention on International Civil Aviation
ICAO	International Civil Aviation Organization
m	metre(s)

Glossary

broken (cloud cover)	five to seven oktas (eighths) cloud cover, where zero oktas is a clear sky and eight oktas is fully overcast
candela	the intensity of light emitted in a particular direction. One candela is roughly equivalent to the intensity of light emitted from one candle
holding point	a line across a taxiway where aircraft must stop and wait until cleared to proceed
multilateration	a ground-based, three-dimensional position-determining system used by air traffic controllers. The system interrogates secondary radar transponders and measures the time delay of responses to multiple receiving stations
rolling take-off	a take-off in which the aeroplane is not brought to a stop before the pilot applies take-off thrust
scattered (cloud cover)	three to four oktas (eighths) cloud cover, where zero oktas is a clear sky and eight oktas is fully overcast
threshold	the start of a runway, marked by a group of parallel longitudinal stripes evenly spaced either side of the centreline across the full width of the runway

Data summary

Aircraft particulars

Aeroplane registration:	CC-CQF	
Type, serial number:	Airbus A340-313, 442	
Number and type of engines:	four CFM56-5C4 turbofan	
Year of manufacture:	2001	
Operator:	LAN Airlines, Chile	
Type of flight:	scheduled international passenger (Flight LAN 801)	
Persons on board:	10 crew, 196 passengers	
Pilots' details:	captain	first officer
licence:	airline transport pilot licence (aeroplane)	commercial pilot licence (aeroplane)
age:	64	36
flying hours:	32,336 hours (10,575 hours on the A340)	3,263 hours (756 hours on the A340)

Date and time 18 May 2013, 0619[1]

Location Auckland Airport

latitude: 37° 0.408´ S

longitude: 174° 48.270´ E

Injuries nil

Damage seven runway edge lights destroyed and two aeroplane tyres replaced

[1] Times in this report are New Zealand Standard time (co-ordinated universal time + 12 hours) and expressed in the 24-hour format.

1. Executive summary

1.1. On 18 May 2013 an Airbus A340 aeroplane operated by LAN Airlines, Chile was making an early-morning departure from Auckland Airport for a scheduled return flight to Sydney. In addition to the captain and the first officer, there were eight cabin crew and 196 passengers on board.

1.2. It was dark but the visibility was good. The captain taxied the aeroplane from the gate toward taxiway A1 for a take-off towards the west. As the aeroplane neared taxiway A1 the tower controller gave clearance for it to line up on the runway. As the aeroplane was entering the runway the tower controller gave clearance for it to take off.

1.3. The two pilots performed the remaining tasks and before-take-off checks while the aeroplane was taxiing. The captain then turned the aeroplane sharply to line up with what he thought were the runway centreline lights, but which were actually the right-hand runway edge lights, and applied take-off thrust.

1.4. While accelerating towards take-off speed, the captain realised that the aeroplane was not aligned with the runway centreline. He steered the aeroplane back onto the runway centreline and continued with the take-off. The pilots did not report the incident to air traffic control at the time.

1.5. A routine runway inspection later that morning found that seven of the elevated runway edge lights were damaged and required replacement. The runway was closed for 20 minutes while the debris was removed. When the aeroplane was inspected after it arrived in Sydney, two of the tyres were found to be damaged and had to be replaced.

1.6. The Transport Accident Investigation Commission (Commission) found that at some point while the pilots were conducting last-minute checks and tasks before the take-off, the captain lost awareness of precisely where his aeroplane was in relation to the runway centreline.

1.7. The Commission also found that three other factors contributed to the misaligned take-off: the potential illusion created by the illuminated manoeuvre area guidance signs parallel to the runway; no other means were used to confirm positively the aeroplane's position prior to take-off; and the rolling take-off which reduced the time available for either pilot to realise the error.

1.8. The Commission identified two broader safety issues relating to: the intensity settings for aerodrome lighting; and administrative errors and potential ambiguity in the way relevant International Civil Aviation Organization standards for airport design and operations might be interpreted. The Commission could not determine whether either of these safety issues contributed to the incident. Nevertheless, the Commission has made recommendations to the Director of Civil Aviation and the chief executive of Auckland International Airport Limited to address these safety issues.

1.9. Key lessons arising from this inquiry are:

- entering an active runway is a critical phase of flight. Pilots must give the manoeuvre their full attention and use all available means to confirm that they are lining up in the centre of the correct runway
- it is essential that pilots report as soon as practicable any suspicion that a runway is contaminated with debris.

2. Conduct of the inquiry

2.1. Auckland International Airport Limited notified the Transport Accident Investigation Commission (Commission) of the incident on the next day, 19 May 2013, by which time the aeroplane was about to return to Chile. The Commission opened an inquiry under section 13(1)(b) of the Transport Accident Investigation Commission Act 1990.

2.2. The cockpit voice recorder had been overwritten by the time the aeroplane reached Sydney, so no record was available of the cockpit conversation prior to the take-off at Auckland. The flight data in the quick access recorder was downloaded by LAN Airlines (the aeroplane operator) in Santiago several days after the incident and a copy forwarded to the Commission.

2.3. Two investigators travelled to Auckland on 29 May 2013 to inspect the airport in relation to the incident, gather evidence and interview the pilots[2]. The runway surface, markings, lights and signs were inspected during daylight and at night. Observations and photos were taken at approximately five metres (m) above the taxiway surface to replicate the pilots' view from the A340 flight deck.

2.4. Information was obtained from Airways Corporation of New Zealand (Airways), which provides air traffic control services and the airport lighting and signage, Auckland International Airport Limited (the airport operator) and the Civil Aviation Authority of New Zealand (CAA). A database search was made for similar incidents at Auckland and elsewhere, and local airline safety officers and individual pilots with some other operators of wide-bodied jets were asked if they had any concerns regarding the runway lighting or markings at Auckland Airport.

2.5. The taxiway and runway markings and lighting provided at Auckland Airport were compared with the international aerodrome design standards in the International Civil Aviation Organization (ICAO) Aerodrome Design Manual Doc 9157 AN/901, and Annex 14 of the ICAO Convention on International Civil Aviation (Convention), Aerodromes, Volume 1, Aerodrome design and operations.

2.6. On 14 June 2013 at the request of the Commission, Chile appointed a non-travelling Accredited Representative in accordance with Annex 13 to the Convention.

2.7. On 24 September 2015 the Commission approved a draft final report to be sent to interested persons for comment.

2.8. Submissions were received from three of the interested persons. The Commission has considered all submissions and any changes as a result of those submissions have been included in this final report.

2.9. The report was approved for publication by the Commission on 17 December 2015.

[2] The aeroplane operator made the pilots available in Auckland.

3. Factual information

3.1. Narrative

3.1.1. On 18 May 2013 an Airbus A340 operated by LAN Airlines was departing Auckland Airport for a scheduled return flight to Sydney. There were 10 crew and 196 passengers on board. The captain, the 'pilot flying' for the sector to Sydney, was in the left-hand seat and the first officer was in the right-hand seat.

3.1.2. The departure was 30 minutes before the beginning of daylight, so it was still dark. There were showers in the vicinity and the runway surface was damp[3]. Cloud was 'scattered'[4] at 3,000 feet [5] and 'broken'[6] at 5,000 feet , with 20 kilometres' visibility.

3.1.3. At 0610 the aeroplane was cleared to leave the terminal. While taxiing to the holding point[7] on taxiway A1 for runway 23 Left[8] (see Figure 1), the pilots conducted the before-take-off checks. The aeroplane's 'runway turn-off' and 'taxi' lights were on. All of the aerodrome lights were on.

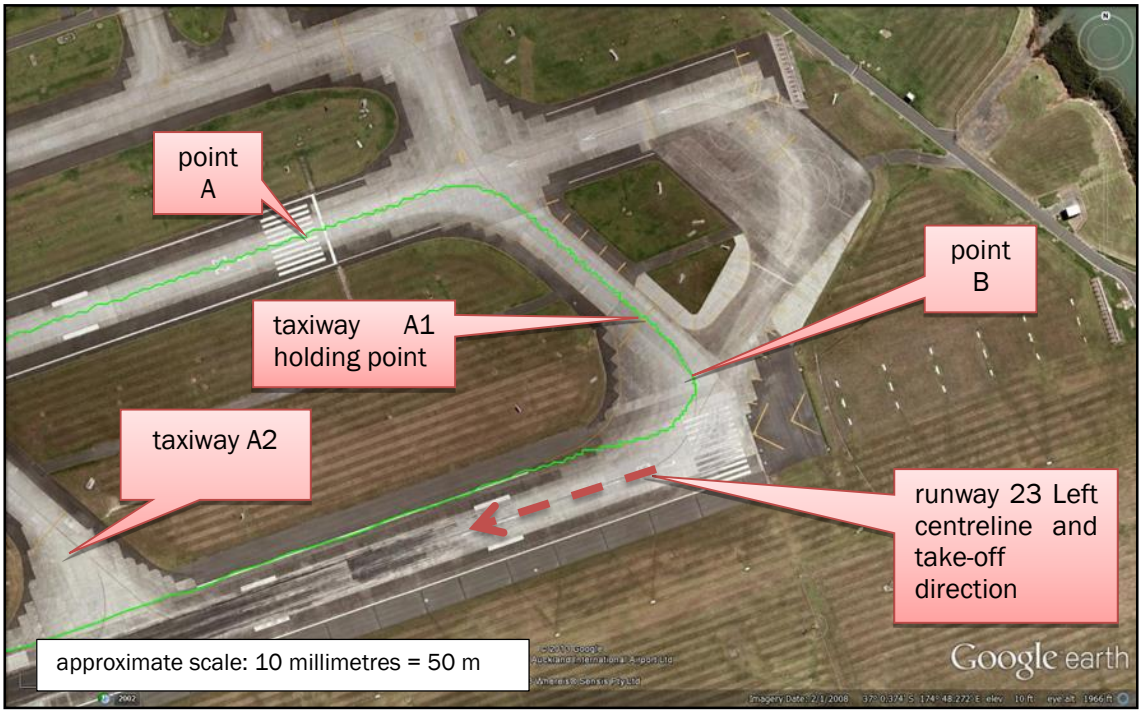

Figure 1
The aeroplane's taxi and take-off path
(The green line shows the aeroplane's track on the ground)

[3] The definition of 'damp' is that the surface had changed colour due to moisture.
[4] Scattered cloud cover is three to four oktas (eighths) cloud cover, where zero oktas is a clear sky and eight oktas is fully overcast.
[5] In the New Zealand aviation sector, altitude is expressed in imperial units.
[6] Broken cloud cover is five to seven oktas (eighths) cloud cover, where zero oktas is a clear sky and eight oktas is fully overcast.
[7] The holding point is a line across a taxiway where aircraft must stop and wait until cleared to proceed.
[8] The runway number is the magnetic heading of the runway to the nearest 10 degrees. Runway 23 Left was the left-hand runway of the two on that heading at this aerodrome.

3.1.4. The pilots completed the before-take-off checklist 'down to the line'[9] in preparation for a clearance to enter the runway. The last few items of the checklist, below the line, were to be completed after they had obtained clearance to move forward of the holding point.

3.1.5. At 0616, when the aeroplane was at point 'A' (shown in Figure 1), the tower controller asked if the aeroplane was ready for take-off. The first officer responded that they were, after which the controller cleared them to line up on runway 23 Left. The captain taxied the aeroplane towards the runway and called for the first officer to complete the remaining checks.

3.1.6. Before entering the runway the captain looked left to check that there were no approaching aircraft and the first officer looked right down the runway to ensure that it was clear.

3.1.7. The tower controller cleared the aeroplane for take-off near the time the aeroplane was crossing over the flush-mounted runway edge lights (point 'B' in Figure 1). The first officer acknowledged the take-off clearance. The captain turned on the aeroplane's landing lights and switched the taxi/take-off lights to the brighter 'take-off' position (see Figure 3 for the locations of these lights).

3.1.8. The captain could not recall seeing the taxiway lights leading onto the runway after he turned on the landing lights. He recalled seeing a line of bright lights and thinking that they marked the runway centreline. He then steered the aeroplane in a tight turn to line up with the line of bright lights and, without stopping, applied take-off thrust. A 'rolling take-off'[10] like this was a widely accepted and permitted practice.

3.1.9. The first officer said that he was looking inside the cockpit at the time. He glanced up and saw a single line of lights straight ahead then returned to monitor the engine instruments and the airspeed during the take-off.

3.1.10. During the take-off the captain realised that they were aligned on the right-hand runway edge lights instead of the centreline. He corrected the aeroplane to the runway centreline and continued with the take-off.

3.1.11. The first officer said later that he did not notice the runway misalignment but he did feel a small heading correction as the aeroplane accelerated on the runway. Neither pilot heard any unusual noises. The aeroplane travelled approximately 1,400 m while aligned with the right-hand edge lights.

3.1.12. The captain commented to the first officer during the climb that he thought he may have been lined up on the runway edge lights, but the first officer said he had not noticed anything unusual. The captain checked the electronic centralised aircraft monitor display for any indication of a possible tyre deflation, but all tyre pressures were normal.

3.1.13. The pilots did not advise air traffic control that they had been aligned with the edge lights. The controller did not notice anything unusual, because it was dark. The pilots of aeroplanes that subsequently took off or landed did not report any missing edge lights or debris on the runway. It was not until the next scheduled runway inspection near 0900 that seven broken edge lights were discovered. The runway was closed for 20 minutes while the debris was removed. The broken lights were replaced later that morning. The airport operator's staff identified from video records of runway activity which aeroplane had damaged the edge lights and advised the local agent for LAN Airlines.

[9] This line marked the end of the operator's checklist items that had to be completed before an aeroplane entered a runway.

[10] A rolling take-off is a take-off in which the aeroplane is not brought to a stop before the pilot applies take-off thrust.

3.2. Post-incident inspections

Aeroplane

3.2.1. When the aeroplane arrived at Sydney Airport, the ground engineer noticed a cut in the right nose wheel tyre and advised the captain. Together they inspected the aeroplane and found another cut on the centre undercarriage right tyre. The replacement of these tyres delayed the return flight to Auckland by 39 minutes. Upon the captain's return to Auckland, the airport operator contacted him about the damaged edge lights. The captain explained that with no indication of damage until the visual inspection at Sydney, he had decided there was no need to report the incident to the tower. He subsequently filed an occurrence report with the CAA.

3.2.2. Photographs taken by the maintenance engineer in Sydney showed tyre damage that matched the shapes of the broken edge lights (see Figure 2).

Figure 2
Tyre damage

Runway

3.2.3. The majority of the edge lights stand 300 millimetres above ground. They have a frangible base (built-in weak point) to allow them to break off cleanly if struck by an aeroplane, thereby minimising any damage to the tyres (see Figure 4). In this case the tyres did not deflate. Where taxiways intersect with a runway, the edge lights are flush-mounted with the surface, so that aeroplane tyres can roll over them. The runway centreline lights are also flush-mounted.

3.2.4. The first few edge lights encountered during the take-off were flush-mounted in the vicinity of taxiway A1 (see Figure 1). The next three edge lights before taxiway A2 were the elevated type, but they were undamaged. The first edge light to be damaged was an elevated light just after taxiway A2.

3.2.5. The aeroplane track (depicted by the green line in Figure 1) was determined using data obtained from the on-board GPS systems and the air traffic control multilateration surveillance system[11]. It showed that the aeroplane turned sharply as it came in line with the right-hand edge lights for runway 23 Left. The recorded track from that point matched the aeroplane's tyre tracks, which showed that the aeroplane was so accurately aligned with the runway edge lights that many of the elevated lights had passed between the double wheels of the nose undercarriage and the centre main undercarriage without being damaged.

[11] Multilateration is a ground-based, three-dimensional position-determining system used by air traffic controllers. The system interrogates secondary radar transponders and measures the time delay of responses to multiple receiving stations.

3.2.6. The wing undercarriage wheels on the A340 were 5 m from the centre wheels. Therefore, when the aeroplane was aligned with the runway edge lights, all of the main undercarriage wheels remained on either the runway or the strengthened shoulder. The outboard right-hand engine was over the grass and within 4 m of the row of movement area guidance signs. Figure 3 shows the position of the aeroplane in relation to the runway edge and lights when it was lined up for take-off.

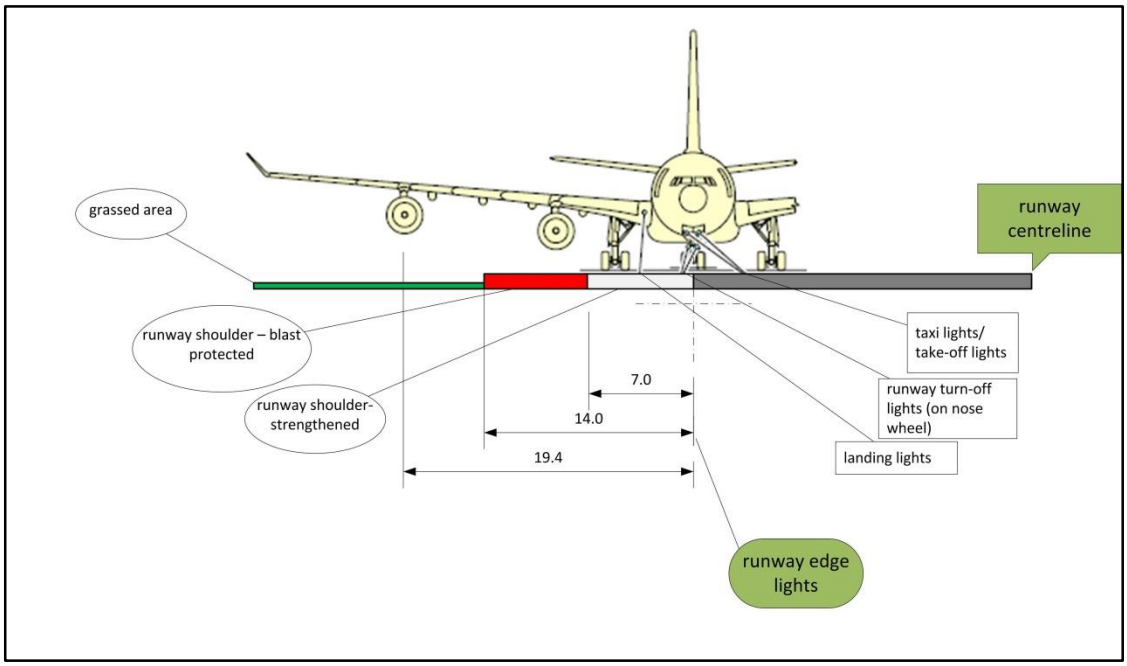

Figure 3
A340 position on runway (dimensions in metres)

3.2.7. The airport operator replaced seven damaged edge lights between taxiways A2 and A5. Some of the replacement and damaged fittings are shown in Figure 4.

Figure 4
Damaged runway edge lights

3.3. Aeroplane information

3.3.1. The Airbus A340 is a four-engine, two-pilot, fly-by-wire, wide-bodied passenger jet capable of carrying between 277 and 440 passengers depending on the selected seating configuration. The maximum take-off weight is 275,000 kilograms.

3.3.2. View angles from the pilot seats are determined when an aeroplane is designed, and provision is made for pilots to adjust their seat heights to ensure that they are at the design eye level. Both pilots said that they had adjusted their seat heights to achieve the correct eye level.

3.3.3. The aeroplane can be steered on the ground from either pilot's seat. The operator's policy was for only the captain to steer from the left-hand seat.

3.3.4. The aeroplane is fitted with three sets of lights to illuminate the forward path. The fixed-direction, forward-facing taxi/take-off lights are mounted below the nose and operate at low beam when selected to 'Taxi' and high beam when selected to 'Take-off'. A separate set of runway turn-off lights is mounted on the steerable nose wheel undercarriage to direct a light beam in the direction of a ground turn. A third set of high-beam landing lights that are mounted in the leading edge of each wing root has the dual purpose of illuminating the runway while landing or taking off and making the aeroplane highly visible from ahead.

3.4. Aerodrome information

3.4.1. Auckland Airport has one concrete runway in normal operation (see Figure 5 and Figure 6). It is 45 m wide with a 7 m strengthened shoulder on either side. The surface beyond the shoulder is protected from jet blast by a non-load-bearing asphalt surface for a further 7 m, giving a total sealed surface width of 73 m.

3.4.2. The taxiway and runway physical dimensions, markings and lighting installations on the aerodrome met the CAA design standards for an international airport that supported operations in conditions of very low visibility.

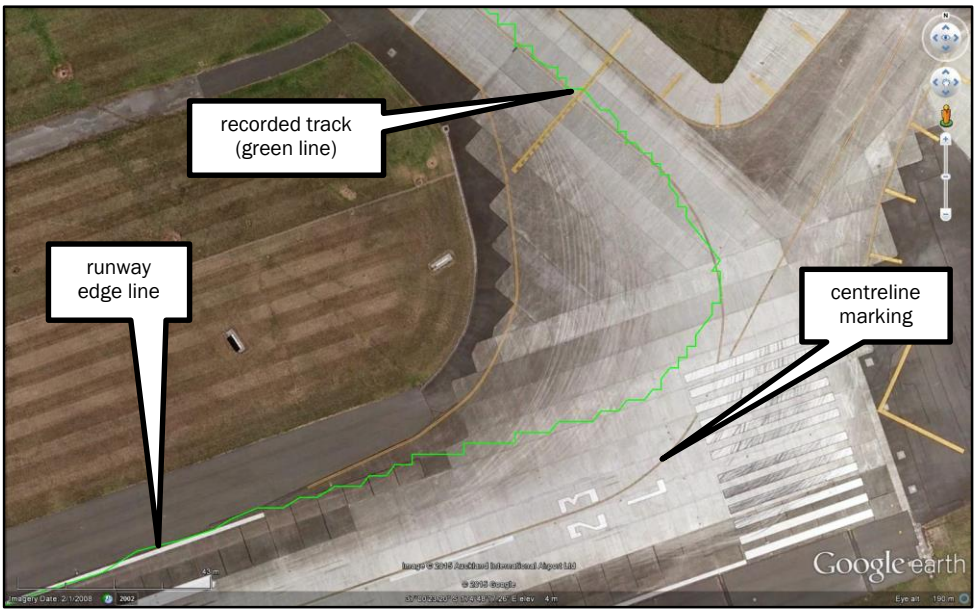

Figure 5
Runway 23 Left entrance

3.4.3. The taxiways were painted with edge and centreline markings. The centreline marking on taxiway A1 continued as a curved taxiway lead-in line to the runway centreline, passing

through the runway threshold marking[12] and the runway number[13]. Similarly, the right-hand taxiway edge marking curved around to join the right-hand runway edge marking. The taxiway centreline was marked with flush-mounted green lights for night operations.

3.4.4. The runway centreline was marked with flush-mounted white lights. The runway centreline and edge lights were differentiated by their spacing and intensity. The centreline lights were spaced 15 m apart and the edge lights at 60 m. The edge lights had focused beams that made them appear brighter than the centreline lights when viewed from the centre of the runway.

3.4.5. Each runway entrance and taxiway entry/exit was identified by an illuminated movement area guidance sign. These signs were installed in a line parallel to the runway and 23 m from the right-hand edge lights.

3.4.6. Tower controllers could alter the intensity of the runway and taxiway lighting through a range of preset steps. Tower controllers were recommended to use certain intensities for various conditions, but they had some discretion over the settings and these could be adjusted if a pilot requested a change. The brightness of the movement area guidance signs alongside the runway was linked to the runway edge light setting.

[12] The threshold is the start of the runway; the marking is a group of parallel longitudinal stripes evenly spaced either side of the centreline across the full width of the runway.
[13] The runway number is painted in large numerals.

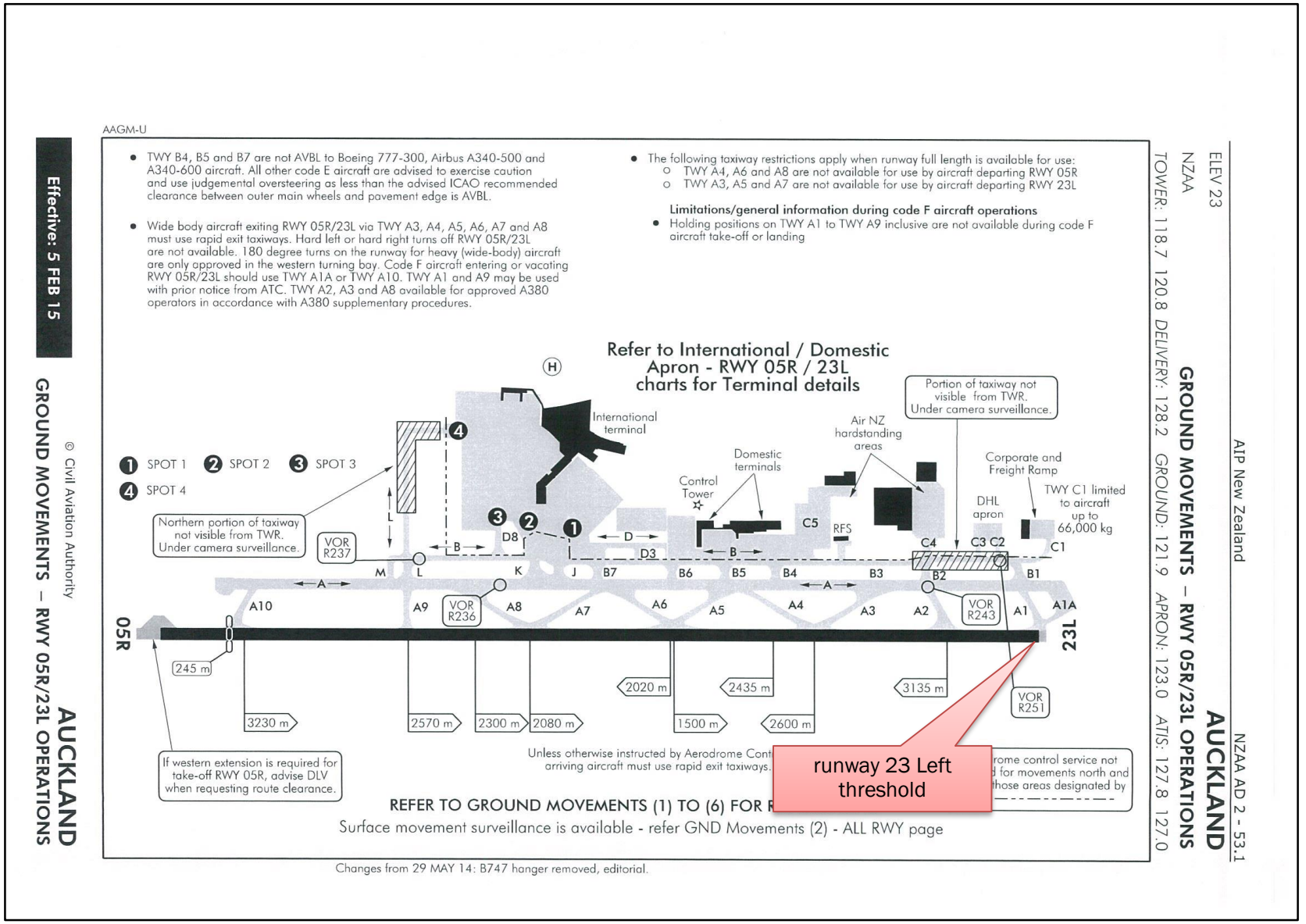

Figure 6
Auckland aerodrome layout

3.5. Personnel information

3.5.1. LAN Airlines operated a daily service between Santiago, Auckland and Sydney with Airbus A340s. The service had begun in 2002.

3.5.2. Four pilots were assigned as two crews for the 12-hour flight across the Pacific Ocean between Santiago and Auckland. One crew was responsible for the take-off and landing and the other responsible for the mid-Pacific phase. After arriving at Auckland, both crews would rest. On the next scheduled duty period, the mid-Pacific crew would fly the Sydney-return flight (two three-hour legs) while the other crew continued to rest. The crews would fly the return flight to Santiago on the next duty period for the same phase that they had had on the previous Pacific crossing.

3.5.3. The captain had approximately 32,000 hours' flying time, including 10,575 hours on the A340. He had flown 24 hours in the previous seven days and regularly operated into and out of Auckland. He had an airline transport pilot licence with current ratings for the A340 and was proficient in the English language to level 6[14]. His class 1 medical certificate was current and had a requirement that he wear corrective lens. He was wearing glasses with corrective lenses at the time of the incident.

3.5.4. The first officer had 3,263 hours' total flying time including 756 on the A340. He had flown 31 hours in the A340 during the previous seven days and was familiar with Auckland Airport. He had a commercial pilot licence with a current class 1 medical certificate. Three days prior to this incident he had completed a company 'line check' that included operations at Auckland[15].

3.5.5. The preceding duty periods[16] for both the captain and the first officer had included a three-day rest weekend in Santiago, a flight to Auckland covering only the mid-Pacific section, a three-day rest period in Auckland then this flight to Sydney and return. Both pilots felt that on the day of the flight they were well rested and alert.

3.6. Other runway misalignment incidents

3.6.1. In 2012 an Airbus A330 aeroplane commenced a take-off from Abu Dhabi International Airport while lined up with the left-hand edge lights of runway 31 Left (GCAA, 2012). The runway misalignment occurred at night in low visibility. The pilots stated that they had not been able to see the green taxiway lead-in lights as they entered the runway. The curved taxiway lead-in route was through a wide intersection that crossed the runway edge line at a shallow angle and did not cross the runway threshold. The pilots rejected the take-off due to the thumps heard as the aeroplane ran over the elevated edge lights.

3.6.2. In 2011 a Bombardier Challenger aeroplane lined up on the right-hand edge lights at Dubai International Airport (GCAA, 2011). The investigation report concluded that the pilots had been confused by the runway centreline and edge lights and had lost situational awareness due to being overwhelmed by activities within the cockpit as they were lining up.

3.6.3. A similar misalignment involved a Boeing 747 at Los Angeles International Airport in 2011. The incident was described in an internal company safety magazine article titled 'On the edge – runway misalignment at night'[17]. The article concluded that the experienced pilots had had an issue with their visual processing as they taxied into position for take-off from a displaced threshold.

3.6.4. In 2011 a Bombardier Q300 lined up on the left-hand edge lights at Auckland Airport on runway 23 Left after entering from taxiway A2[18]. The operator's report to the CAA concluded

[14] ICAO level 6 is expert standard.
[15] A line check is where the pilot is checked while conducting a scheduled flight.
[16] Based upon the Santiago time zone.
[17] Bradbury, Alan. On the edge – runway misalignment at night. Korusafe (Air New Zealand flight safety magazine), December 2011.
[18] The operator's occurrence report 0126-11.

that the pilot had not been familiar with new progressive lenses in his glasses and misjudged the turn onto the runway.

3.6.5. In 2006 an Airbus A319 lined up on the runway edge lights at McCarran International Airport in Las Vegas (TSB, 2006). The investigation report concluded that the taxiway centreline had curved around to join up with the runway edge line instead of the runway centreline and that the rolling take-off had reduced the pilot's time to recognise or correct the error.

3.6.6. In 2002 an Aerospatiale ATR 72-200 lined up on the runway edge lights at Dresden Airport in Germany (BFU, 2002). The investigation report concluded that "the pilot-in-command confused the runway centreline lighting of runway 22 with the left runway edge lighting" and the first officer had not noticed this.

3.6.7. The Australian Transport Safety Bureau carried out a systemic investigation into a group of runway misalignment incidents (ATSB, 2009) and concluded that the following factors increased the risk of a runway misalignment:

- night-time operations
- the runway and taxiway environment, including confusing runway entry markings or lighting, areas of additional pavement on the runway, the absence of runway centreline lighting, and flush-mounted runway edge lighting
- flight crew distraction or inattention
- bad weather or reduced visibility
- displaced threshold or intersection departure
- the provision of an air traffic control clearance when aircraft are entering the runway or still taxiing
- flight crew fatigue.

4. Analysis

4.1. Introduction

4.1.1. A misaligned take-off is a form of 'runway excursion', in which an aeroplane goes off the side or end of the intended runway. It is therefore a 'serious incident'. These events are rare, but the potential contributory factors identified in the Australian Transport Safety Bureau's study are often present and some were in this incident.

4.1.2. In this case the aeroplane's undercarriage remained on the strengthened runway shoulder, so there was no damage to the surface and therefore a low risk of major damage to the aeroplane. The principal risk was damage to some of the aeroplane's tyres and any consequences of that for the take-off and subsequent landing. In addition, the presence of unreported debris created a hazard for following flights.

4.1.3. Runway misalignments at Auckland at night have not been common. A database search revealed five events since 2005, mostly involving light, single or twin-engine domestic aeroplanes. Three of these occurred at the other end of the runway, and one on runway 23 Left but at taxiway A2. The fifth occurrence involved a medium-size aircraft at the same entry taxiway as for this incident. Auckland-based pilots of large aeroplanes had not reported through their operators' safety management systems any concerns for the runway-taxiway entry.

4.1.4. Both of the A340 pilots were experienced in their respective positions and both were familiar with night and day operations at Auckland.

4.1.5. The pilots were not fatigued. Both said they had slept well the night before and felt alert for the flight. Their workload in preparing for this flight had been normal. The flight commenced on schedule and the pilots were not in a hurry or under time pressure. They completed their checklists in good time to be ready for take-off as soon as the tower controller provided the take-off clearance. The air traffic movements were steady at near two-minute intervals.

4.1.6. The tower had previously cleared the aeroplane to line up on the runway and then gave clearance to take off just as the aeroplane began to follow the curve of the taxiway lead-in line to the runway centreline. The captain had anticipated the early take-off clearance, which gave him the option of making a rolling take-off. The operator considered a rolling take-off to be a normal procedure. Both pilots said they had not been distracted at that time by non-operational activities.

4.1.7. The following analysis discusses factors that may have contributed to the aeroplane being misaligned on the runway edge during the take-off. It also discusses the safety issue of not reporting an incident that results, or may result, in debris being left on the runway.

4.1.8. Also discussed are two safety issues that may or may not have contributed to the incident, but in the interests of transport safety should be addressed:

- differences between the intensity settings used on the night of this incident for runway and taxiway lights and the ICAO-recommended settings for similar conditions
- administrative errors were identified in the advisory circular AC139-6 current at the time of this incident, which had the potential to create ambiguity in the way the relevant ICAO standards and recommended practices for airport design and operations were interpreted.

4.2. The incident

4.2.1. The weather had no influence on the incident. The night was clear with 20 kilometres' visibility and the runway surface was damp from recent showers.

4.2.2. The captain said that at night and in low-visibility conditions he normally used the taxiway and runway lighting rather than the markings to guide him while taxiing. He was doing that when

the incident occurred. The painted markings were also visible at night with the aeroplane's lights.

4.2.3. Taxiway centreline lights are flush-mounted and green and have narrow light beams aligned with the taxiway centreline (Figure 7). On curved centrelines different fittings with wider beams are used. These are spaced more closely, with the centre of their beams toed in towards the centre of the curve radius, so that at least three lights are visible to a pilot as an aeroplane tracks around the curve.

4.2.4. Runway centreline lights are also flush mounted, but have white lights with narrowly focused beams aligned with the centre of the runway.

4.2.5. Runway edge lights are mounted on pedestals 300 millimetres above the runway surface, but where aeroplanes may roll over them they are flush-mounted. The elevated runway edge lights have narrow, high-intensity beams angled in towards the runway centre at three degrees from the edge line, and omnidirectional beams.

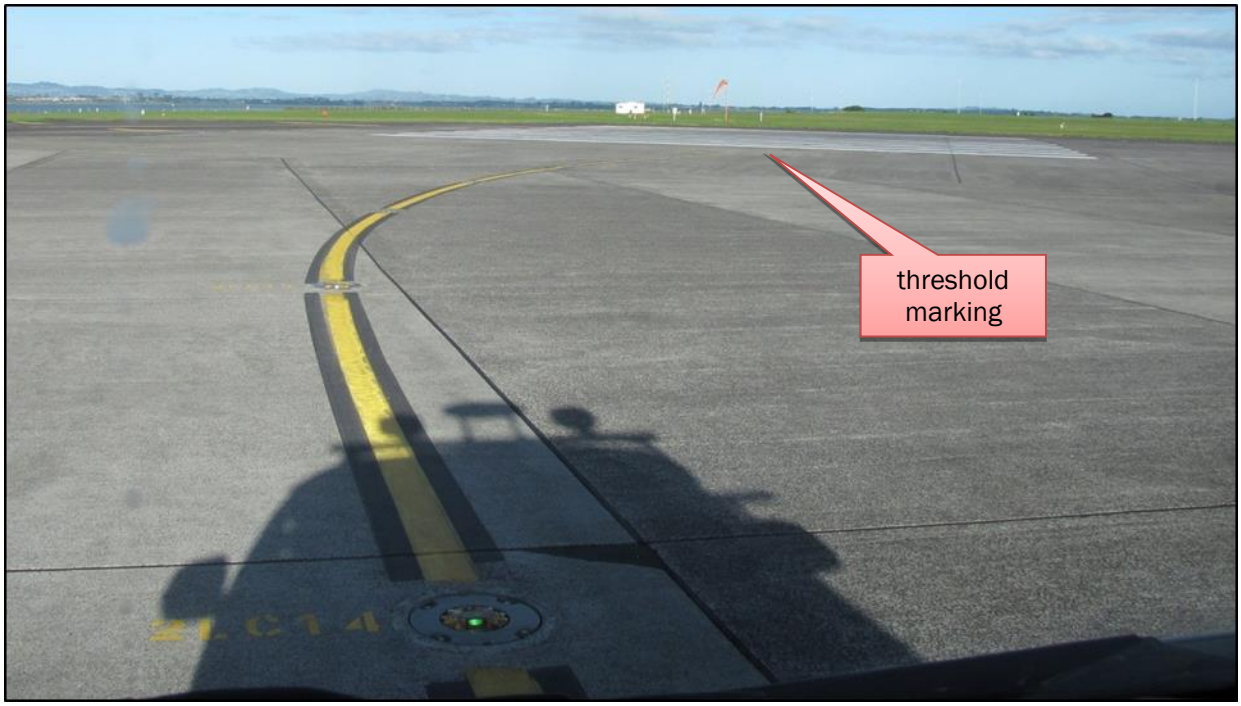

Figure 7
Daylight view of taxiway A1 centreline lights and
paint markings leading to runway 23 Left
(taken from 1.5 m above surface)

4.2.6. When an aeroplane is correctly aligned on the runway centreline, the runway edge and centreline lights appear as three white lines converging in the far distance, with the edge lights brighter than the centreline lights.

4.2.7. In this incident the captain accurately followed the taxiway centreline onto the runway, but then he made a sharp turn to line up on the edge lights. Figure 8 and Figure 9 give a daytime and night-time perspective of how the runway lights would have looked to the captain after he had lined up the aeroplane with the runway edge lights. The night-time view in Figure 9 could be slightly deceptive because the digital camera setting[19] required to get a clear picture would be different from the human eye's response to the scene.

4.2.8. The captain's attention to following the green taxiway lead-in lights would have been diverted when he looked outside for other traffic and then up to the overhead panel to turn on the

[19] ISO 1600, F2.8, with a one-second exposure time and taken at 1840 eight days after the incident.

landing lights. When he looked out again, the brighter landing lights reflecting off the concrete runway may have diminished the visibility of the taxiway centreline lights, although the paint marking would have become more visible.

4.2.9. ICAO's guidance to best practice on the flight deck from the Manual on the Prevention of Runway Incursions (ICAO, 2007, pp. App B-2) recommends planning the timing and execution of checklists to have 'all eyes outside' during entry to the runway. The operator's standard operating procedures gave the captain the choice of switching on the landing lights personally or requesting the first officer to do so. Best practice in this case would have been for the captain to request the first officer to switch on the lights so that he could remain looking outside the aeroplane. The captain said that when he looked back outside to continue the turn onto the runway he presumed the 'line of very high intensity lights' were the centreline lights and aligned the aeroplane with them. The tight turn to align suggests that his mistake occurred after he had lost his previous lead-in cues.

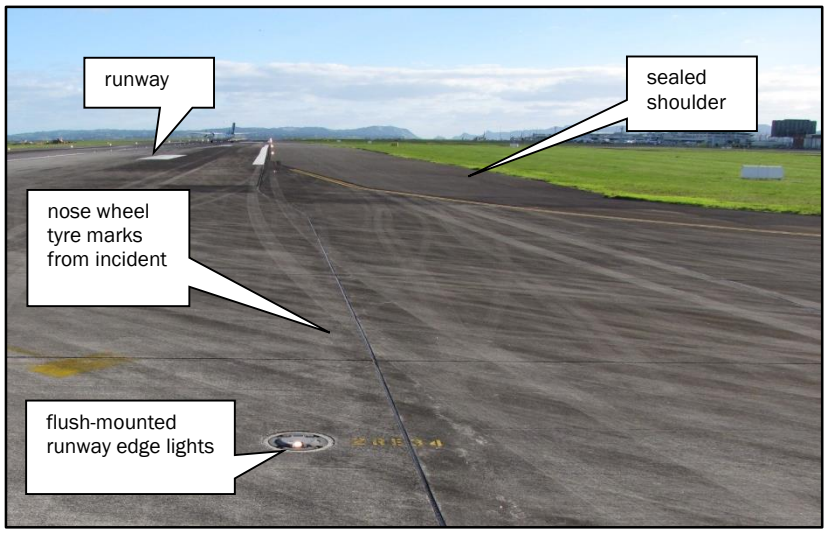

Figure 8
Runway 23 Left's entrance from taxiway A1
(at 1.5 m above the surface)

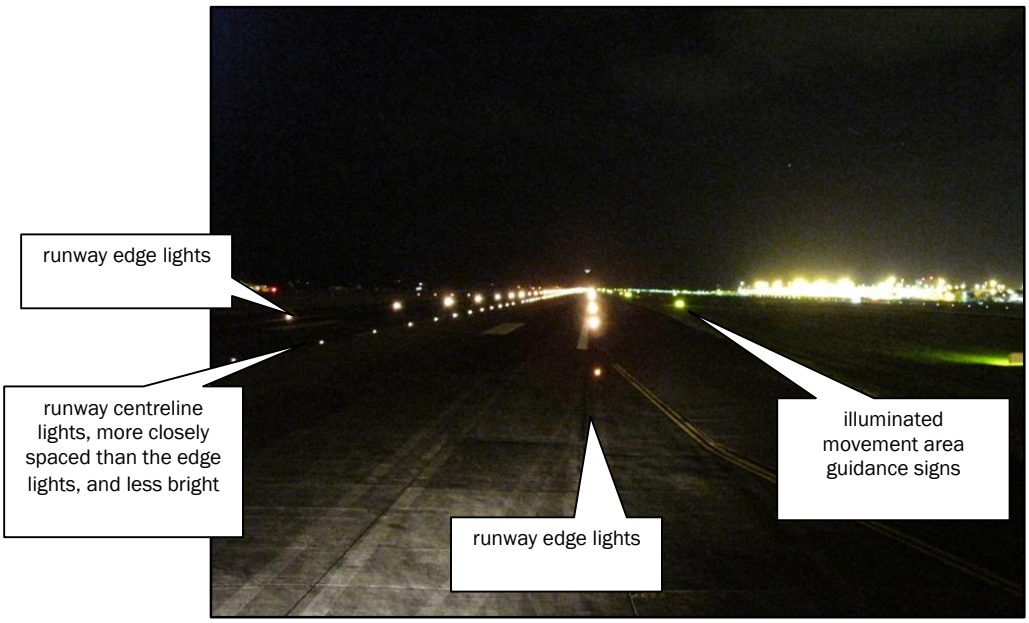

Figure 9
Runway 23 Left view while aligned with the edge lights
(at cockpit height, 5.0 m above the surface)

4.2.10. Once aligned, the runway lights should have appeared as three white lines converging at a single point in the distance. At a glance, it is possible to gain a visual impression that the runway edge lights are the centreline, but only if the line of illuminated movement area guidance signs are mistaken for the right-hand runway edge lights (see Figure 9). It was suggested that this type of illusion was present in the incident at Los Angeles International Airport (see paragraph 3.6.3 above).

4.2.11. However, if either pilot had taken the time to make a closer inspection, they would have seen that the relative intensity and spacing of the three lines of lights was not normal when lined up on the edge lights. The rolling take-off reduced the opportunity for either pilot to recognise this mistake.

4.2.12. The aeroplane had some navigation system features that could have shown the aeroplane's position relative to the runway centreline; for example, the localiser beam of the runway instrument landing system could be switched to indicate alignment on the primary flight display. The operator's flight crew operating manual did refer to the benefits of these cross-checks for take-off in low visibility. However, it was not usual for pilots to use these features when visibility was good, as it was on this night, and neither pilot had them selected for this take-off. The operator subsequently amended its manual to encourage the routine use of on-board systems that show pilots they are lined up in the centre of the correct runway.

4.3. Debris on the runway

4.3.1. The captain realised that he had aligned the aeroplane on the edge lights as shown by his correction partway through the take-off and his subsequent conversation with the first officer after take-off. However, he did not report the incident to the tower controller. That decision put following flights at risk.

4.3.2. Debris from broken edge lights lay scattered on the runway edge for nearly three hours until it was discovered during the next daylight runway inspection.

4.3.3. Debris left on runways has contributed to accidents and incidents, so it is essential that any event that may have caused debris to be left on the runway is reported as soon as practicable to air traffic control.

4.4. Taxiway and runway lighting systems

4.4.1. Auckland International Airport Limited (the airport operator) has an aerodrome operator's certificate issued under Civil Aviation Rules Part 139. The assets used for guiding aircraft movements, such as the control tower, airport lighting and navigation systems, are separately owned and operated by Airways. The airport operator is responsible for the operation and maintenance of these systems in accordance with its operating certificate, but contracts those functions to Airways.

4.4.2. The international standards and recommended practices for aerodrome lighting systems are published in Annex 14 to the ICAO Convention (Aerodrome Design and Operations, Volume 1), (ICAO, 2009). The lighting installations at Auckland were found to comply with Annex 14, Volume 1. However, an anomaly was identified with the intensity settings for various lights.

4.4.3. Annex 14, Volume 1 defines the types of aerodrome light fitting, their colour and location, and the spacing between fittings. It also requires that the lighting intensity be adjustable to suit the ambient lighting conditions or pilot requests. Guidance for setting the appropriate lighting intensity to the ambient lighting conditions is provided by tables and charts in the Aerodrome Design Manual (ICAO, 2004)[20] and ICAO recommends that similar guidance be provided to air traffic controllers (ICAO, 2007 A, pp. 7-21).

4.4.4. Tower controllers can select five light intensity steps for the runway lights and three for the taxiway lights, but these steps are not associated with the intensities that ICAO recommends for various ambient lighting conditions. The runway centreline and edge light intensities can be set to OFF, 1%, 3%, 10%, 30% and 100% and the taxiway centreline lights to OFF, 10%,

[20] See citations: Aerodrome Design Manual, Part 4, Visual aids, Doc 9157.

30% and 100%. Airways calibrates the aerodrome lighting circuits to match the percentage steps that can be selected in the control tower. However, it does not measure the light intensities emitted by various lights at each adjustment step and relate those intensities to the tower settings. Airways advised that the most recent calibration of this nature had been carried out in 1992 on the taxiway centreline lights.

4.4.5. The type of lamp, its wattage, the optical performance and any deterioration from age or external contamination on the lens are all factors that can affect the output light intensity of a fitting. The expected light output can be calculated based on the input current and the characteristics of new lamps, but only measurement can confirm the actual light output. In-situ measurement is particularly relevant with fittings that are expected to have specific optical characteristics and variable intensity settings for aerodrome safety, such as taxiway and runway lights.

4.4.6. The Airways Manual of Air Traffic Services requires controllers to select 'appropriate intensities' whenever the runway lighting is in use. The manual does not list what those appropriate settings might be, although guidance is provided to controllers through on-the-job training.

4.4.7. Tower controllers at Auckland had a general practice of setting the runway edge lights one intensity step above that for the runway centreline lights, with the intention that the edge lights would be brighter. They had no way of knowing whether the actual lighting intensity or the relative intensities of the centreline and edge lights matched the ICAO recommendations.

4.4.8. At the time of this incident the tower controller had, in accordance with the general practice, set the taxiway centreline intensity to 10%, the runway centreline to 3% and the runway edge lights to 10%.

4.4.9. Airways calculated the light intensities (measured in candela)[21] for the incident settings, using information about the light fittings and the relationship between electrical circuit current and light output intensity. These values are compared in Table 1 with the ICAO Aerodrome Design Manual's guidance and recommended (shaded) intensities for low ambient light conditions at night.

Table 1: Lighting intensity in candela

	Taxiway centreline	Runway centreline	Runway edge	Ratio of centreline intensity to edge intensity
Light colour	Green	White		
ICAO-recommended intensities (shaded)	20-50	10-20	20-40	1:2
Actual settings	6	177	1,333	1:7.5

4.4.10. The ICAO guidance on the minimum setting for taxiway centreline lights[22] at night is 20 candela. If the background is 'high brightness' or if fog conditions exist, ICAO suggests that the intensity be increased to 50 candela. Neither high brightness nor fog conditions existed at

[21] Candela is the internationally recognised unit of luminous intensity in a given direction. One candela is approximately the light given out by a common candle.
[22] ICAO Aerodrome Design Manual Doc 9157 AN/901, section 4.6.6.

the time of this incident. The actual intensity of the taxiway centreline lights for this incident was set at six candela, 14 candela less than the ICAO minimum.

4.4.11. The intensity of the runway centreline lights was set well above the recommended range[23]. With very low ambient light conditions and good visibility, ICAO recommended that the runway centreline lights be set to between 10 and 20 candela. However, they were set brighter at 177 candela. The recommended setting for the runway edge lights[24] was 20-40 candela, but the actual setting on the night was 1,333 candela.

4.4.12. Although the intensities of the taxiway lead-in lights and the runway centreline and edge lights were not as recommended by ICAO, the runway edge lights were brighter than the runway centreline lights, as required. Adherence to the ICAO standards provides pilots anywhere in the world with consistent cues for ground manoeuvring, so any variance from the standards can contribute to a pilot making an error. The variances in lighting seen at Auckland Airport are a safety issue that the Commission is recommending that the chief executive of Auckland Airport address.

4.4.13. Auckland Airport is one of many certificated aerodromes in New Zealand that have different owners of the aerodrome itself and of the visual aids to navigation (including aerodrome lighting). It is possible that variances in runway lighting, like those found at Auckland International Airport, may also exist at other aerodromes. Therefore the Commission is recommending that the Director of Civil Aviation, in conjunction with the chief executive of Airways, check that all certificated aerodromes comply in all respects with the ICAO standards for aerodrome lighting.

4.5. The regulatory framework

4.5.1. The international requirements for aerodrome design and operation are set out in Annex 14, Volume 1. New Zealand has given effect to Annex 14, Volume 1 through Civil Aviation Rule 139.51, Aerodrome design requirements, and its associated advisory circular, AC139-6, but the means of this intent is ambiguous.

4.5.2. Rule 139.51 stated at the time that aerodromes must have physical characteristics, visual aids and equipment, including lighting, commensurate with the needs of aircraft that will use the aerodrome. The advisory circular to the rule, AC139-6, says that compliance with the physical characteristics, the types of equipment, installations and the standards detailed in the circular is an acceptable means of complying with Rule 139.51.

4.5.3. New Zealand is required by Article 38 of the Convention to advise ICAO of any differences between New Zealand's civil aviation requirements and the standards of ICAO. The current list of differences[25] states that the standards of Annex 14, Volume 1 are met by compliance with AC139-6.

4.5.4. A review of the electronic filing of differences between Annex 14, Volume 1 and AC139-6 revealed numerous administrative errors in both the advisory circular and the filing of differences between the two documents. Examples included: stating that the Annex 14, Volume 1 requirements for taxiway centreline lights were met by the section in the advisory circular that dealt with taxiway edge lights; and incorrect referencing in the advisory circular to relevant Annex 14, Volume 1 appendices that define technical specifications for equipment.

4.5.5. Since this incident the CAA has made major changes to Part 139. The revised rule published on 1 August 2015 addressed the potential ambiguity with aerodrome design requirements. However, the CAA advised that the published versions of AC139-6 and the electronic filing of differences with Annex 14, Volume 1 will remain until the revision of all 16 of its associated advisory circulars has been completed.

[23] ICAO Doc 9157 AN/901, table 5-3.
[24] ICAO Doc 9157 AN/901, table 5-3.
[25] As at 3 December 2015 this was: Sixth edition volume 1 – July 2013: Annex 14, Volume 1, Amendment 11.

4.5.6. AC139-6 restates many of the relevant sections of Annex 14, Volume 1, with the exception that the advisory circular uses the word 'should' wherever Annex 14, Volume 1 uses the word 'shall'. The status of ICAO Annex components and the organisation's editorial practices are described in the Foreword to Annex 14, Volume 1. It states that the use of the word 'shall' signifies a standard that must be complied with, and the word 'should' signifies a recommended practice. This change in phraseology by the CAA, away from the ICAO convention, enables the possibility of acceptable means of compliance specified in the advisory circular being applied in different ways.

4.5.7. The CAA says the use of the word 'shall' in an advisory circular is not appropriate because the circular describes only one means of compliance and other means may be acceptable. The CAA's rationale is that unless the Director accepts another means of compliance, the requirements in the advisory circular must be met. Once selected, the acceptable means of compliance must be adhered to fully. However, the CAA's use of 'should' in advisory circulars could be misleading, because one could infer that full adherence to the chosen means of compliance is optional.

4.5.8. In the interests of improved regulation in the transport sector, the Commission is recommending that when revising AC139-6, or any other advisory circular, the Director of Civil Aviation address any ambiguity caused by advisory circulars using verbs that allow an ICAO standard requirement to be regarded as a recommended and not a mandatory practice.

5. Findings

5.1. While the pilots were conducting last-minute checks and tasks before the take-off, the captain lost awareness of precisely where his aeroplane was in relation to the runway centreline.

5.2. Three factors contributed to the aeroplane taking off while it was misaligned:

- the potential illusion created by the illuminated manoeuvre area guidance signs parallel to and along the length of the runway, which, in the absence of a thorough check of aeroplane position, could be mistaken for the runway edge lights
- no other means were used to confirm positively the aeroplane's position, such as the first officer's cross-check or the use of on-board navigation systems
- the rolling take-off which reduced the time available for either pilot to realise the error.

5.3. The intensities of the taxiway centreline lights and the runway lights at the time of the incident did not meet those recommended by the International Civil Aviation Organization. The Commission was not able to determine whether this safety issue contributed to this particular incident. Nevertheless it is an issue that should be addressed to enhance aviation safety.

5.4. The Civil Aviation Authority of New Zealand advisory circular AC139-6, which describes aerodrome design and operating requirements, is based on Annex 14 to the Convention on International Civil Aviation, Aerodromes, Volume 1, Aerodrome design and operations, but contained a number of administrative errors and a different phraseology that may have led to the inconsistent application of this acceptable means of compliance with Civil Aviation Rule 139.51, Aerodrome design requirements. Whilst these errors and differences did not contribute to this incident, the Commission is concerned that they could contribute to accidents in the future.

5.5. The captain's decision to not report the incident to the tower controller as soon as practicable after take-off put the following flights at risk from debris contaminating the runway.

6. Safety actions

General

6.1. The Commission classifies safety actions by two types:

(a) safety actions taken by the regulator or an operator to address safety issues identified by the Commission during an inquiry that would otherwise result in the Commission issuing a recommendation

(b) safety actions taken by the regulator or an operator to address other safety issues that would not normally result in the Commission issuing a recommendation.

Safety actions addressing safety issues identified during an inquiry

6.2. The operator revised the before-take-off checks in its Flight Crew Operating Manual to ensure that the aeroplane instrumentation that could show runway alignment was used routinely and not only during low-visibility conditions.

6.3. The CAA had been in the process of reviewing Part 139 for several years and this resulted in amendment 10 being issued on 1 August 2015. This amendment made a substantive change to Part 139 that included expanding Rule 139.51 and adding several appendices, including one dedicated to visual aids. The CAA stated that it will co-ordinate and update the electronic filing of differences from ICAO Annex 14, Volume 1 when the major revision of Part 139 and its associated advisory circulars is completed in 2016.

Safety actions addressing other safety issues

6.4. The intersection of taxiway A1 and the runway is greater than 90 degrees. To reduce the risk of an aeroplane 'cutting the corner' when entering the runway, there is additional pavement on the inside (right hand) of the turn (see Figure 5). At the time of this incident, the taxiway edge marking was near the edge of this pavement. A wide entrance to a runway has been recognised as a contributing factor in some runway misalignments.

6.5. Airways, in conjunction with Auckland International Airport Limited, has realigned the taxiway edge marking at the intersection of taxiway A1 and runway 23 Left, and added transverse stripes on the inside corner. These measures have reduced the apparent width of the taxiway at the intersection.

7. Recommendations

General

7.1. The Commission may issue, or give notice of, recommendations to any person or organisation that it considers the most appropriate to address the identified safety issues, depending on whether these safety issues are applicable to a single operator only or to the wider transport sector. In this case, recommendations have been issued to the CAA, Airways, and Auckland International Airport Limited.

7.2. In the interests of transport safety it is important that these recommendations are implemented without delay to help prevent similar accidents or incidents occurring in the future.

Recommendations

7.3. New Zealand has advised ICAO that the standards of Annex 14, Volume 1 are met in this country by compliance with AC139-6. A review of the AC139-6 revealed numerous administrative errors in transposing the requirements of Annex 14, Volume 1 into the advisory circular.

7.4. The advisory circular uses the word 'should' where Annex 14, Volume 1 uses the word 'shall'. ICAO consistently uses 'shall' to signify a standard (which must be complied with) and 'should' to signify a recommended practice. The CAA maintains that 'shall' is inappropriate in an advisory circular because, as the title suggests, a circular is not a rule. The CAA says that because AC139-6 is an 'acceptable means of compliance' with Rule 139.51, the advisory circular is, in effect, a standard equivalent to Annex 14, Volume 1. Therefore the CAA's use of 'should' rather than 'shall' in its advisory circulars conflicts with ICAO's and potentially leads to an unintended ambiguity in the interpretation of the compliance requirements.

7.4.1. On 1 February 2016 the Commission recommended that the Director of Civil Aviation review the use of 'should' in advisory circulars so that any ambiguity regarding compliance requirements is removed (017/15).

On 18 February 2016, the Civil Aviation Authority replied:

> In our letter of, 29 November 2015, we advised that Advisory Circulars contain information pertaining to an acceptable means of compliance. The key point we sought to make is that an Advisory Circular does not describe the *only* means of compliance with the requirements of a Rule (although there are some exceptions, such as particular performance standards for specified equipment).
>
> While the Director appreciates the point the Commission is making in its recommendation – that is avoid un-intentional ambiguity – it is not appropriate for him to accept the recommendation as worded. Advisory Circulars have a specific role within the civil aviation system. The Director wishes to maintain the flexibility that Advisory Circulars currently provide (in particular with respect to Rules that are more performance based as opposed to those that are prescriptive in their design). That said, the Director does accept the point that care should be taken to ensure that Advisory Circulars are clearly worded, and do not create confusion.

7.5. Airways maintains the runway lighting systems, including calibration of the electrical currents for the different aerodrome lighting circuits to match the percentage intensity steps selected in the control tower. ICAO recommends that the actual light intensities emitted from the different runway fittings in the field be measured as part of a regular preventive maintenance programme[26]. However, Airways does not routinely do this.

7.5.1. On 1 February 2016 the Commission recommended that the chief executive of Auckland International Airport Limited, in conjunction with the chief executive of Airways, measure and recalibrate luminous intensity settings for the taxiway centreline lights, runway centreline and

[26] Annex 14, Volume 1, section 10.5.3.

runway edge lights and reconfigure the associated control tower setting selections so that controllers may select the respective light intensities recommended by ICAO for various levels of ambient lighting (019/15).

On 22 February 2016, Auckland International Airport replied:

> Auckland Airport supports the recommendation from the TAIC report, which is to measure and recalibrate luminous intensity settings for the taxiway centreline lights, runway centreline and runway edge lights and reconfigure the associated control tower setting selections. Auckland Airport will undertake full consultation with Airways Corporation NZ on the requirements and timing of these actions and anticipate a proposed timeline for implementation will be able to be advised to the CAA on completion of this consultation. The consultation outcome is expected to be available by the end of April 2016.

7.6. At many of New Zealand's certificated aerodromes, the aerodrome operator is different from the owner and operator of the visual aids to navigation (which include aerodrome lighting). Their respective operational responsibilities are guided by Part 139 and AC 139-6. It is possible that variances in runway lighting, like those found at Auckland International Airport, may exist at other aerodromes for the following reasons:

a. The administrative errors as described in this report that existed between the New Zealand interpretation of the ICAO standards and recommended practices in Rule 139.51 and advisory circular AC139-6,

b. Part 139 was significantly revised in August 2015 to address potential ambiguities in aerodrome design requirements but the aerodromes have yet to be audited against this revision.

7.6.1. On 25 February 2016 the Commission recommended that the Director of Civil Aviation, in conjunction with the chief executive of Airways, check that aerodrome runway lighting systems at all certificated aerodromes comply with Part 139 (020/15).

On 9 March 2016, Civil Aviation Authority replied:

> The recommendation to check aerodrome lighting systems at certified aerodromes for compliance against Rule Part 139 will be implemented. However, the audit schedule to satisfy the work specified in the recommendation will take some time. Therefore an implementation date cannot be provided at this stage.

8. Key lessons

8.1. Entering an active runway is a critical phase of flight. Pilots must give the manoeuvre their full attention and use all available means to confirm that they are lining up in the centre of the correct runway.

8.2. It is essential that pilots report as soon as practicable any suspicion that a runway is contaminated with debris.

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