# FINAL REPORT

*AAIU Report No. 2001-013*
*AAIU File No. 1998-006*
*Report Published: 20 Sept 2001*

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| **Aircraft Type and Registration:** | Boeing 767-300 (3Z9), OE-LAU | |
| **No and Make of Engines:** | 2 x Pratt & Whitney PW4056 turbofans | |
| **Aircraft Serial Number:** | 23765 | |
| **Year of Manufacture:** | 1987 | |
| **Date and Time (UTC):** | 8 November 1998, 13.04 hours | |
| **Location:** | Shannon Airport, Co. Clare, Ireland | |
| **Type of Flight:** | Public Transport | |
| **Persons on Board:** | Crew | 9 |
| | Passengers | 254 |
| **Injuries:** | Crew | Nil |
| | Passengers | Nil |
| **Nature of Damage:** | Nil | |
| **Commanders Licence:** | Airline Transport Pilots Licence | |
| **Commanders Age:** | 43 years | |
| **Commanders Flying Experience:** | Total Hours | 8373 hours |
| | Total on Type | 4202 hours |
| | Total on Type P1 | 376 hours |
| **Information Source:** | Watch Manager Shannon ATC<br>AAIU Field Investigation | |

## 0. Synopsis

The aircraft was scheduled to make a routine refuelling stop at Shannon. After a normal landing on Runway 24, ATC requested the aircraft to expedite its clearance off the runway. As the aircraft entered the turnaround area at the end of the runway, it failed to complete the 180° turn and skidded of the end of the runway. There were no injuries to passengers or crew and no significant damage to the aircraft.

## 1. Factual Information

### 1.1 History of the Flight

The aircraft was on a scheduled flight from Milan to Cuba and landed at Shannon Airport for a scheduled refuelling stop.

The aircraft landed normally on Runway 24 at Shannon Airport. It did not slow sufficiently to turn off at Taxiway Alpha (Appendix A) and it was therefore necessary to taxi to the end of Runway 24, where the turnaround is located in order to turn, prior to backtracking down the runway and clearing by Taxiway Alpha. As the aircraft taxied towards the turnaround, ATC requested that it expedite clearance of the runway, in order to clear the runway for following aircraft approaching this runway. Approaching the turning area, the pilot steered the aircraft slightly to the right of the centre-line, (Appendix B), in order to make more room for the 180º turn to the left. The pilot then attempted to turn the aircraft to the left, but the aircraft did not respond. The pilot subsequently stated that he could hear the nose wheel skidding at this time. Just before the aircraft reached the end of the runway, the nose suddenly swung to the left, but the aircraft continued to travel in the general direction of the runway centreline. The aircraft continued off the end of the runway and came to rest on a heading of 198° after the nose wheel had traversed 18 metres of the grass area. The right main wheels were 4 metres into the grass and the left main wheels remained on the strip of pavement where the threshold lights are located, which immediately adjoins the end of the runway.

The passengers were disembarked using a stairs at the rear of the aircraft. The aircraft was the de-fuelled and towed back onto the runway, without damage.

Inspection of the aircraft's undercarriage brakes and wheels revealed no defect that could have contributed to the incident. However, the right nose wheel tyre was well worn, with approximately 1 mm tread depth remaining.

### 1.2 Weather

Shannon Airport lay in a mild light SSE airstream at the time of the incident. The wind was 160º at 12 kts and visibility was greater than 10 km. The relative humidity was 78%. Their had been no rain earlier in the day, but the first traces of rain (less than 0.05 mm) were detected between 13.00 and 13.10 hours, i.e. about the time of the incident. On the previous day, 9.7 mm of rain had fallen up to 20.00 hours, and there was no further rain until 13.00 hours on the day of the incident, i.e. immediately before the aircraft landed. Evaporation of surface water during the night prior to the incident was considered negligible.

On the morning of the incident there was a 10 kt southerly wind, and one hour of sunshine. The relative humidity during this period fell from 90% to approximately 78% by 13.00 hours.

## 1.3 Runway and Turnaround

The turnaround area of Runway 24 is also the start of the reciprocal Runway 06. The runway section of the turnaround, i.e. the section of the turnaround formed by the extended runway, contains the threshold markings of Runway 06. These markings consist of twelve white strips, each 30 metres long and 1.80 metres wide, with a spacing of 1.80 metres between each strip, but with a spacing of 3.60 metres between the two strips on either side of the runway centreline. The space between the strips has a black appearance of unknown origin. The markings start 5 metres from the start of the concrete edge of Runway 06. The markings conform to the standards laid down in ICAO Annex 14, 'Aerodromes', and are commonly known as "piano keys". In conforming to the dimensions laid down for these markings in Annex 14, the markings cover a substantial portion of the runway section of the turnaround.

There are no turning circle centrelines, in the turnaround area, to assist the pilot while performing an 180º turn at the end of Runway 24.

The usable runway width of Runway 24 is 45 metres, which is too narrow to permit 180° turns of large aircraft, such as the B767. Local Traffic Regulations, as published in Aeronautical Information Publication (AIP) Ireland, states; - *"180° turns executed by wide-bodied aircraft on RWY 06/24 are permitted only at the runway ends."*. Therefore if such an aircraft, landing on Runway 24, does not slow down sufficiently to turn off safely at Taxiway Alpha, it has no choice but to continue to the turnaround area, and to turn there, in order to back track to Taxiway Alpha.

## 1.4 Flight Recorder Data

The aircraft's Flight Data Recorder (FDR) was downloaded after the incident. It showed that the aircraft had a ground speed of approximately 18 kts when the turn to the left was initiated. The captain stated that he entered this area at 10 kts. It should be noted that accuracy of the ground speed as reported to the FDR can be compromised slightly when the aircraft is manoeuvring on the ground. Also there was a zero error in the Ground Speed System as it showed an indication of 2 kts after the aircraft had completely stopped.

## 1.5 Aircraft Information

The B767 is a wide-bodied jet transport aircraft powered by two large diameter turbofan engines.

The aircraft is equipped with an anti-skid device on the main-wheel braking system.  This senses the rapid slow-down in wheel rotation speed that precedes wheel skidding during braking, and then releases the brakes momentarily to prevent skidding. At very low speeds, the anti-skid transducer does not have sufficient amplitude to permit reliable measurement of the wheel speed. A sudden loss of the wheel speed signal could be interpreted by the anti-skid device as a wheel skid, resulting in a brake release signal while the aircraft is manoeuvring at low speed or when the pilot is attempting to bring the aircraft to a standstill. To prevent this, the system is automatically disconnected when the ground speed reduces to a speed of 8 to 9 kts. Pilots are therefore aware that when taxiing below this speed that the antiskid protection is not available and that this is of particular concern when the aircraft is making tight turns at low speed, especially when using differential wheel braking to aid the turn.

The aircraft is equipped with nose wheel steering, which is controlled by a tiller mounted beside the pilot. The nose wheel steering is also coupled to the rudder pedals such that up to 7° of nose wheel steering is commanded by full rudder displacement. The steering forces generated by the nose wheel must overcome the tendency of the main landing gear bogies to keep the aircraft travelling straight ahead and must also balance the centrifugal forces developed during a turn. Nose wheel effectiveness is increased at lower speeds because the centrifugal forces are lower. When manoeuvring in restricted turning areas, and using large steering angles, it is possible for the nose wheels to skid if the surface friction is too low or if the aircraft speed is too high. Skidding of the nose wheel can also occur if maximum steering angles are applied rapidly at very low forward speed on a low friction surface, where the nose tyres tend to skid rather than roll in the direction of the turn. The possibility of skidding is also increased when the aircraft is operating with an aft centre of gravity, which results in more weight being carried by the main undercarriage and less by the nose wheels. The pilot also has the option of using differential power to turn more tightly in confined areas but the delayed power reaction of the large diameter fan engines make this difficult to control. Furthermore there is the complication that the increased power on one side also tends to accelerate the aircraft forward, thereby compounding the control problems.

Boeing sets a minimum depth of tread for B767 nose wheel tyres of 0.8 mm.

The track of the main undercarriage of a B767-300 is 9.3m, measured to the centrelines of the main undercarriage.

## 1.6 Aircraft Manufacturer's Recommendations

Boeing Document D6-58328 page 67, dated January1986, gives the turning requirements for the B767-300. The minimum calculated turning circle diameter for a 180° turn is 146 ft (44.6 meters) for a slow continuous turn, conducted at idle thrust and the nose wheel turned to 65° prior to starting the manoeuvre and allowing for a 4° tyre slip angle for the nose wheel. This figure makes no allowance for variations in pilot technique or surface conditions, nor any allowance for a safety margin. Boeing recommends that approximately 10 ft or 3 metres be added to this figure to take account for operational variations. This document also shows that standard aircraft turning manoeuvres, such as making a 90° turn off a runway onto a taxiway, are based on a 30 metre turning radius, which is achieved using a steering angle of 42°, without allowing for wheel slip angle. The path of the nose wheel is the critical factor when executing both minimum and 30 metre radius turns, in that the nose wheel determines the outer limits of the turn radius. The outboard main wheel tracks inside the path followed by the nose wheel. The only exception to this situation is when straightening up out of the tight turn, when the outer main wheel starts to determine the outer limits of the turn.

Boeing further recommends that the turn should not be started until there is sufficient forward speed to carry the aircraft through the turn and that stopping, (either intentionally or inadvertently due to lack of speed) during the turn should be avoided, as excessive thrust, (which would be difficult to control), will be required to get the aircraft moving again. The use of differential thrust can produce a slight decrease of the required turning circle. Boeing also states that differential thrust may be required to get the aircraft to turn when it is heavy.

Appendix B shows the minimum and 30 metre radius turning requirements of the B767-300 superimposed on the turnaround area.

In response to a query arising from this incident, Boeing stated that the data used for the B767-300 simulator document predicted that nose–wheel skidding would not occur at speeds below 15 kts on a dry runway using full nose steering input (65°), and should not occur below 25 kts using 40° nose steering input.

## 1.7 Runway Friction Standards

International Standards, as laid down in International Civil Aviation Organisation (ICAO) Annex 14 and ICAO manuals, define runway friction requirements. These standards are primarily to ensure adequate braking performance during a landing, and in particular, to prevent aquaplaning during the braking sequence of a landing. Aquaplaning can easily be encountered at the high speeds normally encountered during landing when a film of water is present on the runway.

The main features of the ICAO Standards to prevent aquaplaning are the use of good drainage and a textured runway surface, which prevents the build up of a water layer between the aircraft tyre and the runway surface. The Standards further stipulate that the dynamic friction of the runway be measured routinely. These tests are performed at Shannon with a special device, a “GripTester”, towed at speed along the runway, and the friction characteristics are measured over a length of 100 metres, or more. It is also specified that the tests should be conducted up to 5 metres off the centreline, i.e. in the area of the runway traversed by the main wheel of an aircraft. This is to ensure that the runway friction is measured on the area of the runway traversed by the main wheels during braking. Tests are therefore not conducted on the painted areas, such as the centrelines. Furthermore, because of the speeds at which these tests are performed, it is impossible to conduct them on the threshold markings when the threshold is at the extremity of the runway. After this incident, Aer Rianta Shannon confirmed that, to meet the ICAO standards, they conduct runway friction tests at speeds in excess of 50 kts (57.5 mph) and that they do not conduct the tests on painted areas of the runway.

There is no standard laid down in Annex 14 in relation to the surface friction requirement of airport manoeuvring areas such as taxiways, apron areas or turning areas.

Because the Standards and tests laid down in Annex 14 relate to high speed braking performance, it is doubtful if the current provisions of Annex 14 would be a suitable basis for the friction standards of low speed manoeuvring areas. Furthermore there is the practical difficulty, even impossibility, of performing the high-speed tests in confined areas, such as runway end turning areas.

In strict terms, the turning area at the end of Runway 24 in Shannon is part of both Runway 24 and the reciprocal Runway 06, and should therefore conform to the surface friction requirements for the runway area. However there is a real practical difficulty in performing the specified tests in this confined area. Furthermore the standard runway surface friction tests are of debatable relevance to slow speed manoeuvring areas.

## 1.8 Examination of the Threshold Markings Area

The threshold markings of Runway 06 were examined. The white strips had been previously painted using a thick hard paint, which had been repainted many times over the years, and this paint had completely filled the runway's textured surface. This resulted in a smooth hard surface on the strips. However, in places, large pieces of this painted surface, with a thickness of several layers of paint, had broken away, leaving depressions in the surface. These depressions varied in size and depth, being 1 to 3 mm deep with horizontal dimensions exceeding 300 mm.

When the markings were subsequently repainted, the fresh paint sealed this void in the surface, but did not fill them. The result was widespread depressed areas in the painted stripe. These depressions were capable of retaining considerable amounts of rainwater.

A new type of patented thin film coating (see Para 1.9 below) had been recently applied to the piano key markings at Shannon Airport. This coating had been applied over the old paint, which had already filled in the surface texture of the runway.

The aircraft left tyre skid marks on the unmarked 5 meters at the extreme end of the runway, i.e. in the bare concrete area between the end of the markings and the end of the runway. These were angled to the left of the runway heading by approximately 40°. No skid or other markings associated with this incident were found on the runway markings.

## 1.9 Patented Thin Film Coating

Runway markings suffer from blackening, due to rubber deposits produced by aircraft tyres, and consequently require frequent renewal to ensure their visibility. When conventional paint markings are renewed, they are frequently simply over-painted. This produces a substantial build up of layers of paint, which, in time, will completely fill the grooved surface of the runway. This results in a flat, smooth, hard, low friction surface. The effect of rainwater on such a surface is to further reduce the friction characteristics and to render the surface slippery.

The patented thin film coating[1] used on the piano key markings at Shannon was specifically developed, by an Irish company, to produce a very thin marking layer on the runway surface. Typical coating thickness achieved is 30 to 40 microns. This avoids filling the runway grooves and ensures minimal adverse effects on the friction characteristics of the runway. The thin film also permits frequent renewal of the markings without filling the groves. The coating has a number of other desirable features, such as quick drying time, and contains special additives to ensure high opacity and to enhance its friction characteristics. For optimum performance the coating should be applied to a bare runway surface, or onto a surface where the surface grooving has not been compromised. Where there are existing conventional paint markings, particularly when there is a build-up of paint layers, the old paint should be removed. If the coating is simply applied over the hard smooth surface of the existing markings, the desired high friction characteristics are not achieved.

[1] Several patents cover this product including European Patent EP 0447235 and USA Patent Number 5,167,705.

The same company has also developed an applied-friction-surface coating for use in conjunction with the thin film coating, where the underlying surface has poor friction characteristics. This was not used in this case.

Aer Rianta, in particular at Dublin Airport, has been involved in the development of this product with the patent holder.

## 1.10 Rainwater on the Markings

The pilot stated that there was light rain as he was landing. An analysis conducted by Met Eireann, the Irish Meteorological Service, deduced that the depression in the runway markings would not be full, to the brim, of water, but would have contained substantially more than a thin film of water. On arrival on the scene four hours after the incident, during a period heavy rain, an AAIU inspector noted that the wet markings were extremely slippery.

## 1.11 Tests of the Markings

Subsequent to this incident the AAIU conducted tests to determine the friction of the threshold markings. Because of the dynamic nature of the standard tests as per Annex 14, the normal standard procedure for measuring runway friction could not be used to determine the friction on the white threshold markings. Therefore the static friction was measured, using a portable skid tester, pendulum type. This device is commonly used for testing the friction of road markings. The friction was measured in two different conditions: -

**Damp surface**
and
**Wet surface**

The friction was measured in three areas, namely: -

- **The white markings**
- **The black coloured area between the white markings**
- **Standard concrete area, which would be representative of the normal (unpainted) area of the runway.**

The values obtained were as detailed in the following table. The higher values indicate a higher surface friction.

| | **SKID RESISTANCE** | |
|---|---|---|
| | **Damp** | **Wet** |
| **White markings** | **37** | **35** |
| **Black area** | **43** | **35** |
| **Concrete** | **105** | **102** |

It is not possible to make a direct co-relation between these results and those obtained with a normal dynamic tester, such as that used for testing the main part of the runway. Therefore the above tests are purely for comparative purposes, and are included in this report due to the absence of an agreed international standard for testing the friction of low speed manoeuvring areas at airports. However, it can be stated that the friction of the damp white markings were only 35% of that of the damp standard runway, while the wet white markings were 34% of the wet standard runway. The black coloured area had superior friction compared to the white area while dry but was only 41% of the standard runway. However it was the same as the white markings when wet. The black coloured area had the same textured surface as the unpainted concrete of the runway and was therefore probably less conducive to viscous aquaplaning (see Para 1.15 below).

## 1.12 Centreline Markings

ICAO Annex 14 Section 5.2.8, lays down the standards for the markings of the centre lines on taxiways and sections of runways that lead on to taxiways. This requires that centreline guidelines be provided. Section 5.2.8.1 states "*Taxiway centre line marking shall be provided on a paved taxiway, de/anti-icing facility and apron where the code number is 3 or 4 in such a way as to provide continuous guidance between the runway centre line and aircraft stands*".

## 1.13 Runway Layout at Shannon

Due to the prevailing wind direction, Runway 24 is the most commonly used runway at Shannon Airport. Air Traffic Controllers at Shannon are faced with the difficulty of accessing if a given aircraft, landing on this runway, will have slowed sufficiently to turn off at Taxiway Alpha, or if it will have to continue to the end of the runway, to the turnaround area, in order to execute a 180º turn, and then to backtrack to Taxiway Alpha. This applies only to larger aircraft, which are incapable of turning within the 45 meter width of the runway. If an aircraft has to taxi to the turnaround and then return to Taxiway Alpha, the period of which the manoeuvring aircraft is on the runway, blocking other aircraft approaching the runway, is increased by several minutes.

If the controllers allow time for every aircraft to taxi to the turnaround and backtrack, the result is a long spacing between aircraft approaching the airport, and consequent delays and increased flight time. If the controller judges that the lead aircraft can slow sufficiently, to turn off directly at Taxiway Alpha, he can reduce the spacing of following aircraft. This results in a considerable time and cost saving to operators, and increases airport capacity. However, the judgement is complex, being influenced by aircraft type, landing weight, wind speed and direction, runway surface conditions, pilots' skill and other factors.

If the controller judges that the lead aircraft can turn off at Taxiway Alpha, and spaces the following traffic accordingly, and in the event, the aircraft fails to turn off at Taxiway Alpha, then the controller is forced to direct the following traffic to overshoot and go round again. This causes delays and increased costs, and is an unpopular occurrence with operators and passengers. Passenger anxiety can be increased considerably when a low level go-around is initiated.

The net result is extra pressure on the air traffic controller to make a judgement on the ability of an aircraft to slow down before Taxiway Alpha. In cases where the air traffic controller judges that an aircraft should be able to stop before Taxiway Alpha, but in the event the aircraft fails to stop by Taxiway Alpha (and has to taxi to the turnaround to turn, and then backtrack to Taxiway Alpha), the air traffic controller will frequently request the aircraft to expedite, in order to clear the runway as quickly as possible for the following aircraft, thereby possibly avoiding the necessity for the following aircraft to overshoot.

It is also noted that Taxiway Alpha requires an aircraft landing on Runway 24 to turn by 100° to clear the runway. This means that the aircraft must be slowed to a virtual stop before attempting to turn of Runway 24 onto Taxiway Alpha. In order to permit aircraft to turn off at higher speeds, a large radius turn-off, with a maximum angle of 45°, but preferably 30°, is recommended in ICAO Annex 14.

## 1.14 Interim Safety Recommendation

Because of the factors identified early in this investigation, the AAIU issued the following interim safety recommendation on 8 December 1998: ***"That the Irish Aviation Authority should issue a notam, advising operators of the possibility of low friction on the turning area at the end of Runway 24 at Shannon Airport, particularly in wet conditions". (SR 36 of 1998)***

The IAA responded by issuing the following NOTAM, reference 1819/98, on 11 December 1998, which stated:
**"Caution advised when turning on turning area at end RWY 24 due possibility of low friction particularly in wet conditions."**

Aer Rianta, the airport operator, responded by removing all the existing paint on the turning area at the end of Runway 24 and replaced it with new markings consisting of the thin film high friction coating, which were applied in accordance with the recommendations of the manufacturer of the coating. On 9 September 1999 Aer Rianta requested that the NOTAM be withdrawn.

## 1.15 Aquaplaning

The presence of a layer of water can reduce the coefficient of friction of a runway surface in three different ways: viscous aquaplaning, dynamic aquaplaning, and reverted rubber aquaplaning. All three can degrade both the braking and cornering ability of the airplane, but while viscous and reverted rubber aquaplaning can occur only during braking or cornering, dynamic aquaplaning can occur any time sufficient speed and water depth exist. On the other hand, viscous and reverted rubber aquaplaning don not require much water to be present, and can occur when a runaway is simply damp and aircraft speeds are relatively low. Aquaplaning adversely affects both the stopping distance and directional control of an aircraft.

Loss of tyre braking and cornering ability during operations on damp (defined as a water layer thickness less than 0.01 inches or 0.25 mm) or wet (defined as a water layer thickness of 0.01 to 0.1 inches or 0.25 to 2.5 mm) runways is predominantly attributable to viscous aquaplaning. Conditions are conducive for viscous aquaplaning to occur when a relatively thin film of water reduces the coefficient of friction between the tyre and the runway. In simple terms, it makes the runway slippery. This thin layer of water can reduce the braking and cornering ability of a tyre by reducing the coefficient of friction between the tyre and the runway surface. The texture of the runway, the skid resistance of the exposed aggregate in the runway, and the tyre's tread depth determine how much friction will be lost. On smooth surfaces, a layer of water only 0.01 inches or 0.25 mm thick can significantly reduce the runway's coefficient of friction. This reduction of friction can occur at any speed. Viscous aquaplaning usually leaves no indications on the runway or the tyre.

Reverted rubber aquaplaning can also occur during braking when the heat of friction developed at the contact patch causes the reversion of the rubber to its un-cured state and turns the moisture on a damp runway into steam. The pressure of the steam is sufficient to raise the centre of the tyre off the runway while the edges remain in contact. This greatly reduces the coefficient of friction available during braking and cornering. Proof of reverted rubber shows up in the skid marks laid down by the tyres. Two black tracks where the reverted rubber on the edges of the contact patch is laid down on the runway and between the black stripes a clean section of the runway where it has literally been steam cleaned. On a concrete runway this steam-cleaned stripe will look almost white.

## 1.16 Additional Information

This incident is not the only incident arising from the problems associated with Taxiway Alpha at Shannon and it’s effects on the ATC situation. A B747 taxied off the edge of Runway 24 while attempting a late turn near Taxiway Alpha on 24 October 1998. This incident was the subject of an AAIU investigation. AAIU Report 1999/015 refers.

Subsequent to the current incident the operator flew a technical team in from Italy with spare wheels and other components to ferry the aircraft back to Italy. They did not bring a replacement Cockpit Voice Recorder (CVR) nor Flight Data Recorder (FDR) with them. Following discussion with the AAIU it was agreed that the aircraft would be ferried back to Italy with both recorders installed but with the CVR circuit breaker pulled in order to avoid over-taping of the incident voice recording. This was not necessary with the FDR, as its longer recording duration would ensure that the incident information was retained. The contents of both recorders were then to be returned to the AAIU for analysis. However on the ferry flight the FDR circuit breaker was pulled and the CVR left in, with the result that the incident information on the CVR was over-taped and lost.

After the incident, the ATC recording was impounded and it confirmed that the aircraft was asked to expedite its clearance off the runway.

The manufacturer's recommendations for the application of the high friction thin-film runway marking coating stated that the coating was to be applied to a surface with has good friction characteristics. It was not designed to be applied over existing coatings of different paint type.

Shortly after this incident another pilot reported to ATC that he found the turning of the turnaround to be very slippery.

Tyre marks made by other aircraft in the turning area clearly showed that, generally, aircraft kept well to the right before turning on the turnaround, as did the aircraft in question.

A company registered in Hong Kong owned the aircraft and the registered operator was LaudaAir (Austria) and the aircraft carried an Austrian registration. However it was being operated by a LaudaAir company in Italy, LaudaAir S.P., that holds an Italian Air Operators Certificate. By agreement between the Austrian and Italian authorities, regulation of the aircraft was conducted by the Italian authorities.

## 2. Analysis

2.1 The threshold markings covered a substantial portion of the turnaround area, and most of the area in which aircraft actually turn.

2.2 The markings had been recoated several times over the years, using a hard thick paint. This paint had completely filled the textured surface of the runway. This textured surface is designed to produce grip on the surface but also to produce ridges that would protrude above any thin layer of rainwater on the runway. The result of the repainting was to produce a hard, flat slippery surface.

2.3 Between repainting of the markings on previous occasions, sizeable areas of the paint had broken away. When the marking was subsequently repainted the resultant holes were not refilled but just coated in paint. This produced rainwater-retaining depressions on the markings. Because of the repainting, the bottom of the depressions was smooth, hard and slippery.

2.4 Analysis of the dimensions of the painted strips and the wheel track of a B767-300 shows when the aircraft is travelling parallel to the strip markings at Shannon, it is possible for the majority of the nose and main wheel contact areas to be on the white strip markings simultaneously.

2.5 The patented thin film coating was not correctly applied. It was designed to form a very thin film on bare or cleaned concrete, thereby preserving the profiled surface of the runway. Because it was applied over layers of existing paint, this coating was ineffective in restoring the friction of the runway.

2.6 It should be noted that while the black coloured area between the white strips had superior friction characteristics, compared to the white strips, when dry, the static friction value was still well below that of the bare concrete. Furthermore when wet, the static friction of the black coloured areas was the same as the white stripes.

2.7 The meteorological analysis and the pilot's observations indicate that the markings were wet at the time of the landing and that the depressions would have had a significant film of water in them.

2.8 The foregoing produced situation whereby the much of the actual turning area of the turnaround was covered by a low friction surface, which became more slippery when wet, and because of the retained water in the depressions, was conducive to viscous aquaplaning.

2.9 It should be noted that the friction tests used in this report did not conform to any internationally recognised standard for testing the friction of runway end areas, for the simple reason that there is currently no effective standard test for such areas. Therefore the above tests are for comparative purposes only.

2.10 The aircraft's right nose wheel tyre exceeded the minimum recommended tread depth by only 0.2 mm, which would reduce its resistance to viscous aquaplaning. In the turn to the left, friction loss by the right nose wheel tyre would be more critical than that of the left tyre.

2.11 While the turnaround area is effectively part of the runway, the standard runway friction tests, conducted at speed, could not be conducted in this area because of the adjacent end of the runway.

2.12 There are no standards or recommended practices laid down by ICAO or by the IAA for minimum surface friction in airport manoeuvring areas, nor are any standards laid down for the measurement of surface friction in these areas.

2.13 When the pilot made a slight initial turn to the right, in order to give more room for the sharp 180° turn to the left, the aircraft was on the unmarked section of the runway and because of the adequate friction in this area, no control problem was experienced.

2.14 The intention of the pilot was to execute a 30 metre radius turn rather than to use the minimum radius of 22.3 metres. This would allow a slightly faster turn and would also reduce the possibility of loss of the momentum required to complete the turn. In order to execute the 30 metre radius turn he would have initiated the left turn of the nose wheel just as it entered the area containing the piano key markings, Point A in Appendix B. At this point the nose wheel started to hydroplane and the nose wheel skidded and the aircraft failed to turn. The aircraft continued in a straight line and the main wheels entered the low fraction markings and probably aquaplaned, thereby destroying braking action. The nose wheels, orientated for the left turn, then entered the unmarked final 5 metres of the runway (Point B) and regained a grip on the runway and turned the aircraft by 42° to the left. As the right main wheels entered the unmarked area they also regained a grip on the surface and caused the aircraft to travel along the 198° heading. However it was impossible to avoid exiting off the runway in this limited distance.

2.15 The absence of rubber or marks on the piano key area indicated that both the nose and main wheels experienced viscous aquaplaning in the while in the piano key area.

2.16 The nose of the aircraft entered the turning area of the turnaround probably at about 15 kts, slightly above the maximum recommended ground speed to execute a 180° turn. However there were still 30 metres of runway to be traversed before reaching the apex of the turn, allowing 5 metres clearance. The pilot could have reasonable expected to achieve sufficient braking action brake within this distance which would cause the aircraft to decelerated to a speed below the maximum recommended turning speed.

2.17 The fact that the aircraft both changed heading and started to turn to the left in the last 5 metres unmarked section of the runway clearly indicate that if normal runway friction was available throughout the turning area, the aircraft would have successfully executed the turn, and that reduced surface friction rather than aircraft speed was the cause of the loss of directional control.

2.18 The fact that the outer main wheel starts to follow a track outside the nose-wheel track, while the aircraft is straightening out of a tight turn, results in pilots keeping to the extreme right of the turning area before making the turn on this turnaround. This is to avoid the possibility of outer (right) main wheel running off the runway edge near Point C (Appendix B) while exiting the 180° turn. The absence of guidance lines in the turning area would further increase pilots' concern in this regard.

2.19 The provisions of Annex 14 Section 5.2.8 are unclear as to whether centreline guidelines are required in turnaround areas. However the portion of Section 5.2.8.1 (see above) would indicate that continuous guidelines are required once the aircraft has to move off the runway centre line in order to reach its stand.

2.20 The non-provision of replacement flight recorders by the operator for the ferry flight and the error in the circuit breaker selection of the CVR may have lost information valuable to this investigation.

2.21 Because the aircraft, on landing, did not slow sufficiently to enable it to turn off by Taxiway Alpha, the pilot was requested by ATC to expedite clearing the runway. This involved taxing to the end of Runway 24, turnings 180° on the turnaround and then backtracking back down Runway 24 to clear the runway by Taxiway Alpha.

2.22 The pilot acceded to ATC's request to expedite. This may have lead to the use of a somewhat higher speed than normal when approaching the turnaround.

2.23 The operational difficulties arising from the location of Taxiway Alpha and the lack of turn-off or holding facilities at the end of Runway 24 were a factor in this and other incidents at Shannon. This incident and others resulted in the airport being closed for several hours and considerable interruption to services. The incident also resulted in the longest runway in the country, and a critical resource for any potential aircraft in difficulty in the Eastern Atlantic area, being unavailable, suddenly and without notice.

2.24 The dimensions of the turnaround manoeuvring area of Runway 24 allow little safety margin when turning large aircraft such as the B767. Pilots could enter such turns at very slow speed, with minimum engine thrust, to achieve a low turning radius. At low speed there is the attendant possibility of a critical loss of momentum causing the aircraft to inadvertently stop in the turn. This leads to the consequent difficulty of getting the aircraft moving again, by increasing engine thrust, while preventing the aircraft from straightening up and thereby running off the edge of the paved area. This problem is greater with large wide-bodied twin-engined aircraft than with larger four engined aircraft.

This is because the available differential power is less in the twin-engined aircraft as the available thrust is closer to the aircraft centre-line. Inadvertently stopping during the turn may even require a tow truck to turn the aircraft. Where pilots have been requested by ATC to expedite their clearance, they would be particularly anxious to avoid inadvertent stopping.

Alternatively pilots may enter such 180° turns with sufficient speed to ensure that they do not stop inadvertently. The resultant use of extra speed increases the possibility of skidding and/or aquaplaning, particularly in conditions of reduced surface friction.

## 3. <u>Conclusions</u>

### 3.1 Findings

3.1.1 The aircraft probably entered the turning area of the turnaround at a slightly higher speed than the recommended maximum turning speed.

3.1.2 There was a major reduction of friction in the turnaround area of the runway, due to the hard surface of the markings, the conditions of the markings and the retention of rainwater in the depressions in the markings. The surface in this area was conducive to viscous aquaplaning.

3.1.3 Steering and braking control was lost due to viscous aquaplaning while the aircraft was in the area of the runway covered by the piano key markings.

3.1.4 If the turning area had the same surface friction as the unmarked area of the runway, the turn would have been successfully executed.

3.1.5 The patented thin film coating was applied to the runway surface in an inappropriate manner.

3.1.6 The aircraft's right nose wheel tyre was only 0.2mm above the minimum recommended tread depth. This reduced the tyre's resistance to aquaplaning.

3.1.7 The pilot was under pressure to comply with ATC's request to expedite the manoeuvre of taxing to the turnaround, turning thereon and backtracking to Taxiway Alpha.

3.1.8 The judgement-call by an Air Traffic Controller as to whether such a large aircraft landing on Runway 24 would be able to slow sufficiently to turn off at Taxiway Alpha, or have to taxy to the turnaround and backtrack, was, and continues to be, problematical.

3.1.9 The result of an inadvertent miscall of such a problematical judgement produced pressure for ATC staff, and consequently on the pilot of the aircraft, to expedite clearance of the runway.

3.1.10 There are no international, or national, standards or recommended practices for the quality of surface friction on manoeuvring areas at airports, or any standard method of monitoring the friction quality of such surfaces.

3.1.11 Because the turnaround area is largely covered by the runway threshold piano key markings, there are no steering centre line guidance marks in the turnaround area of Runway 24.

3.1.12 The dimensions of the turnaround area at the end of Runway 24 provide a limited safety margin when turning large aircraft. This situation is exacerbated by the absence of guidelines.

3.1.13 The operator's failure to provide replacement flight recorders for the ferry flight and the subsequent error in setting the recorders' circuit breakers resulted in the loss of CVR information in relation to this incident.

### 3.2 Causes

3.2.1 The speed at which the aircraft entered the turning area exceeded the speed at which a 180° turn could be executed, giving the friction conditions prevailing in that area at the time.

3.2.2 The cause of the aircraft skidding off the end of the runway was the low friction of the surface of the threshold markings, which covered the turning area of the turnaround at the end of the runway.

3.2.3 The low friction of the turnaround surface was due to inappropriate painting and maintenance of the threshold markings, exacerbated by rainwater being retained in depressions in the markings.

3.2.4 The limited size of the turning area gave inadequate safety margin in the event of skidding.

3.2.5 The constraints of the design of Runway 24 in Shannon resulted in ATC placing some pressure on the pilot to expedite his clearance of the runway.

## 4. Safety Recommendations

4.1 Aer Rianta should review the runway marking in its airports to ensure that there are no other runway areas in a similar condition to that of the turning area of Runway 24 at Shannon prior to the remedial action been taken. **(SR 27 of 2001)**

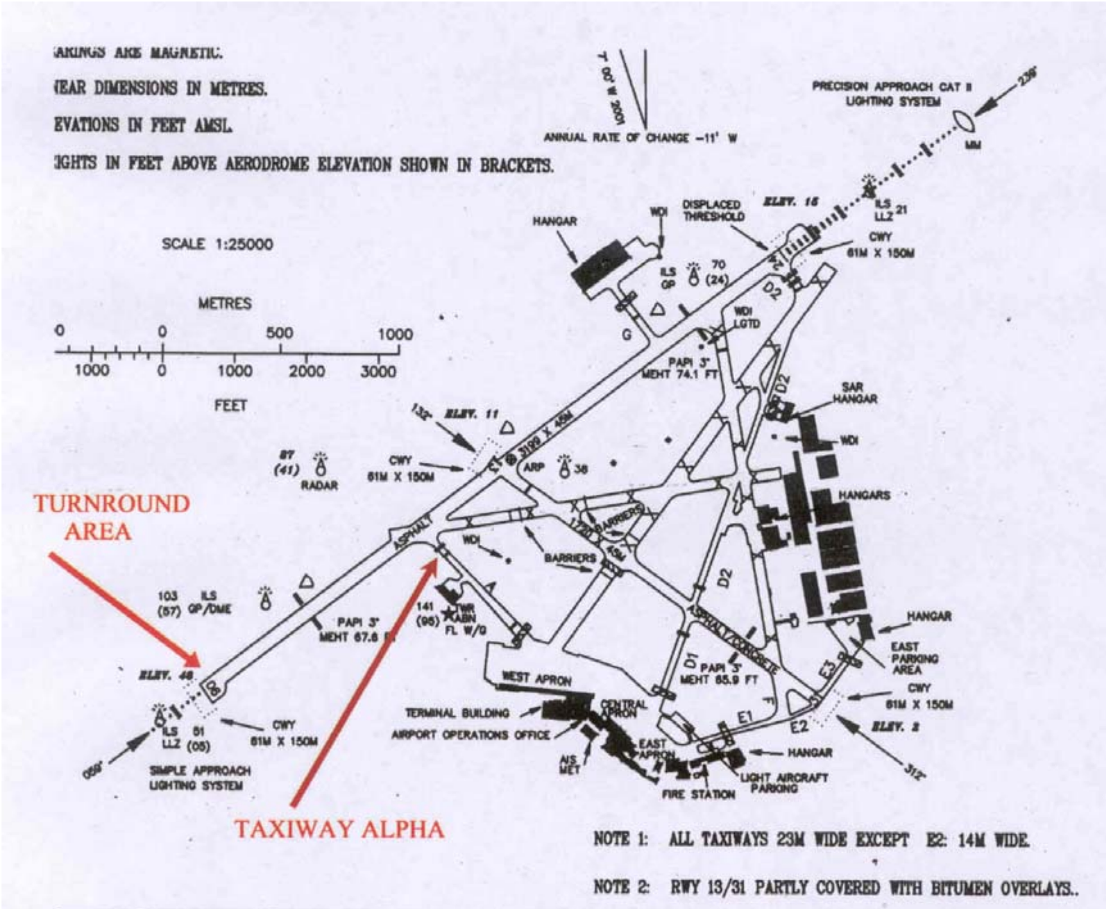
4.2 ICAO should develop international requirements for surface friction measurement and monitoring of surface friction in aircraft manoeuvring areas. **(SR 28 of 2001)**

4.3 ICAO should clarify the international requirements in Annex 14 regarding the marking of centrelines, used for taxying guidance, in relation to co-located threshold markings and turnarounds. **(SR 29 of 2001)**

4.4 The IAA and Aer Rianta should jointly review the operational difficulties arising from the layout of Runway 24 and Taxiway Alpha at Shannon, with particular consideration to options such as the construction of a taxiway to the end of Runway 24, a holding area off the turnaround and/or a high-speed run-off along the runway. **(SR 30 of 2001)**

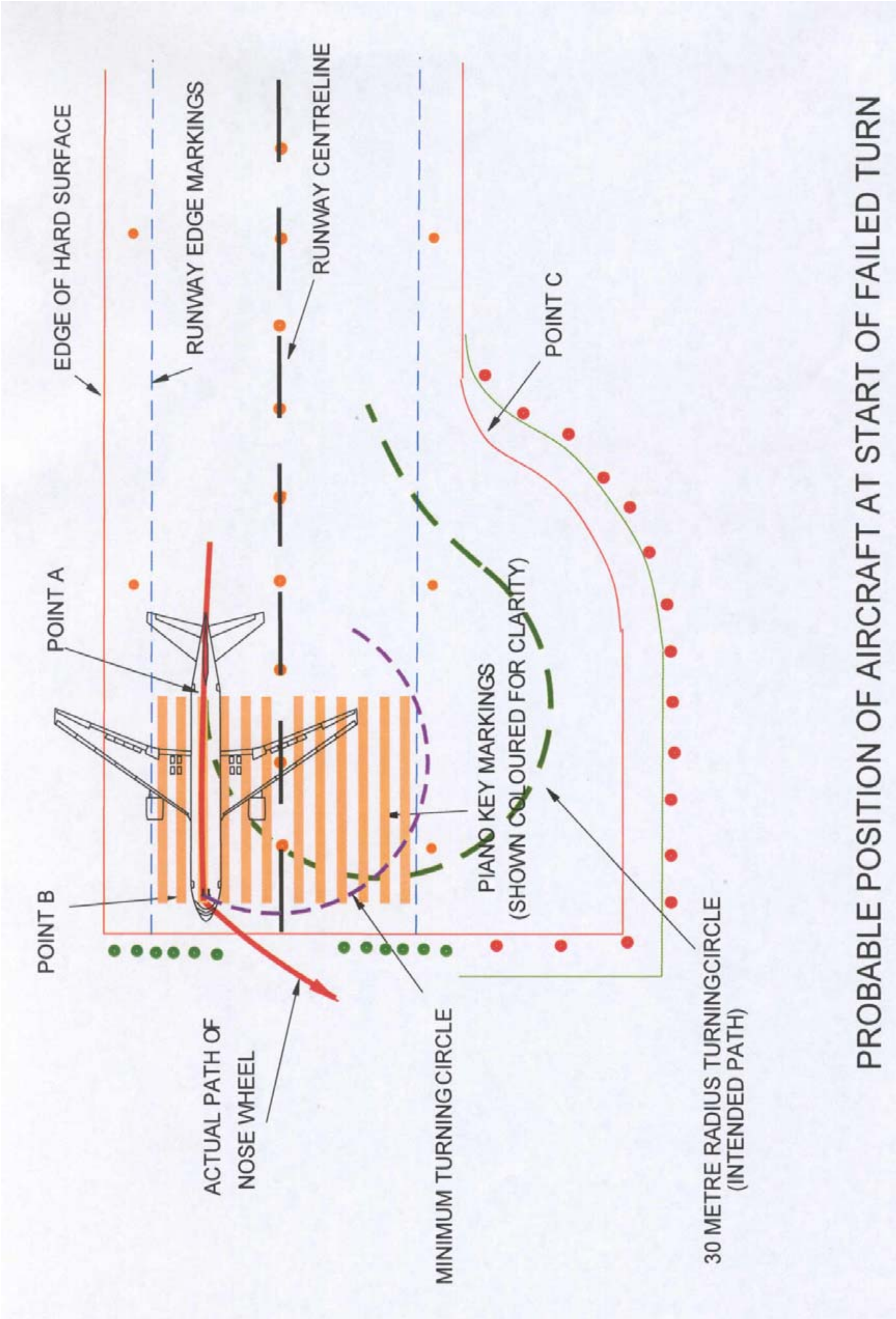
4.5 The IAA and Aer Rianta should review the use of the turnaround area as the location for the threshold markings for Runway 06. **(SR 31 of 2001)**

**APPENDIX A**




LAYOUT OF SHANNON AIRPORT
SHOWING THE TURNROUND AREA
AND TAXIWAY APLHA

## APPENDIX B


EDGE OF HARD SURFACE
RUNWAY EDGE MARKINGS
RUNWAY CENTRELINE
POINT A
POINT B
POINT C
PIANO KEY MARKINGS
(SHOWN COLOURED FOR CLARITY)
ACTUAL PATH OF
NOSE WHEEL
MINIMUM TURNINGCIRCLE
30 METRE RADIUS TURNINGCIRCLE
(INTENDED PATH)
PROBABLE POSITION OF AIRCRAFT AT START OF FAILED TURN