Section/division Accident and Incident Investigation Division Form Number: CA 12-12a

AIRCRAFT ACCIDENT REPORT AND EXECUTIVE SUMMARY

Reference:	CA18/2/3/8719

Aircraft Registration	**ZS-SJW**	**Date of Accident**	7 December 2009	**Time of Accident**	0901Z
Type of Aircraft	Embraer 135-LR (Aeroplane)	**Type of Operation**	Domestic Schedule		
Pilot-in-command Licence Type	Airline Transport	**Age**	39	**Licence Valid**	Yes
Pilot-in-command Flying Experience	Total Flying Hours	11 973,5	Hours on Type	2 905,8	
Last point of departure	Cape Town International Airport (FACT), Western Cape province				
Next point of intended landing	George Airport (FAGG), Western Cape province				
Location of the accident site with reference to easily defined geographical points (GPS readings if possible)					
On the R404, a public road adjacent to the aerodrome (geographical co-ordinates: S34°00.306' E022°23.534')					
Meteorological Information	Surface wind: 090°/2-5 kt; Temperature: 20°C; Cloud base: 8 000 ft, with light rain				
Number of people on board	3 + 32	**No. of people injured**	3 + 7	**No. of people killed**	0

Synopsis

Flight SA8625 departed from Cape Town International Airport on a domestic scheduled flight to George Airport (FAGG) with three crew members and 32 passengers on board. The weather at FAGG was overcast with light rain, and the aircraft was cleared for an instrument landing system approach for runway 11. It touched down between the third and fourth landing marker. According to the air traffic controller, the landing itself appeared normal, but the aircraft did not vacate the runway to the left as it should have. Instead, it veered to the right, overran the runway and rolled on past the ILS localiser. Realising that something was wrong, he activated the crash alarm. The cockpit crew did not broadcast any messages to indicate that they were experiencing a problem. The aircraft collided with eleven approach lights before bursting through the aerodrome perimeter fence and coming to rest in a nose-down attitude on the R404 public road. Several motorists stopped and helped the passengers, who evacuated the aircraft through the service door (right front) and left mid-fuselage emergency exit. The aerodrome fire and rescue personnel arrived within minutes and assisted with the evacuation of the cockpit crew, who were trapped in the cockpit. Ten occupants were admitted to a local hospital for a check-up and released after a few hours. No serious injuries were reported.

Probable Cause

The crew were unable to decelerate the aircraft to a safe stop due to ineffective braking of the aircraft on a wet runway surface, resulting in an overrun.

IARC Date		Release Date	

AIRCRAFT ACCIDENT REPORT

Name of Owner	:	South African Airlink (Pty) Ltd
Name of Operator	:	South African Airlink (Pty) Ltd
Manufacturer	:	Embraer Aircraft Company
Model	:	135-LR (Long Range)
Nationality	:	South African
Registration Marks	:	ZS-SJW
Place	:	George Airport (FAGG)
Date	:	7 December 2009
Time	:	0901Z

All times given in this report are Co-ordinated Universal Time (UTC) and will be denoted by (Z). South African Standard Time is UTC plus two hours.

Purpose of the Investigation

*In terms of Regulation 12.03.1 of the Civil Aviation Regulations (1997,) this report was compiled in the interest of the promotion of aviation safety and the reduction of the risk of aviation accidents or incidents and **not to establish legal liability**.*

Disclaimer

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1. FACTUAL INFORMATION

1.1 History of flight

1.1.1 The crew signed on for duty at their head office at O.R. Tambo International Airport at 0320Z. Their roster for the day included four sectors with the aircraft ZS-SJW. The first sector, from O.R. Tambo to Upington Airport, was an uneventful flight; the first officer (FO) was the pilot flying (PF).

1.1.2 The second sector was from Upington to Cape Town International Airport (FACT), and the pilot-in-command (PIC) was the PF. The aircraft landed at 0736Z on a wet runway (1,6 mm of rain was measured at the time of landing). The aircraft was refuelled with 2 930 ℓ of Jet A1, the procedure being overseen by an aircraft maintenance engineer (AME) based at Cape Town.

1.1.3 At aircraft took off on the third sector at 0821Z. This was a domestic scheduled flight – SA8625 – to George Airport (FAGG) with three crew members and 32 passengers on board. The PIC was again the PF.

1.1.4 En route, the crew obtained the automatic terminal information system (ATIS) information for FAGG, which included the prevailing weather conditions. According to the crew, they anticipated an instrument landing system (ILS) approach for runway 29, and after communicating with air traffic control (ATC) at 0847Z, were cleared for the ILS/DME approach for runway 11 at FAGG. The weather at the time of landing was overcast with recent rain over the aerodrome, and the prevailing wind was from the east at five knots. At 08:59:05Z the crew radioed the ATC:

"*Regional Link 625 is clear, is established localiser runway 11 at 9 500 ft, field in sight*". At 08:59:15Z, the ATC cleared the aircraft to land on runway 11, advising the crew that the runway was wet. The PIC of a Boeing 737 that was at the holding point of runway 11 waiting to take off behind flight SA8625 afterwards stated: "*I recall there was a light drizzle with a cloud base of approximately 700 - 1 000 ft above ground level (AGL) at the time. I saw the aircraft on approach breaking cloud at more or less 1 000 ft AGL. The approach looked normal to me and speed looked okay. I did not see where the aircraft touched down. When we landed earlier that morning in light drizzle, touchdown and braking were normal.*"

1.1.5 The PF of SA8625 saw the runway as their aircraft broke through the cloud between 800 and 1 000 ft above aerodrome level (AAL) and about 7 nm from touchdown. The PNF then read out the V_{REF} (the reference landing approach speed, all engines operating) and V_{FS} (final segment speed) to the PF, which were communicated as 129 kt and 164 kt respectively (obtained from the cockpit voice recorder [CVR]). These were in accordance with the maximum allowable landing weight of 18,5 tons as specified in the speed chart of the aircraft's quick-reference handbook (QRH). The PF acknowledged that the speed was slightly high, raised the nose, selected full landing flap (45°) and regained the ILS glide path at 500 ft AAL. The speed bugs were set at 18,5 tons with + 5 kt for reference. The windscreen wipers were switched on and continuous ignition was selected during the approach due to the wet conditions.

1.1.6 Touchdown occurred at 09:01:09Z, two minutes and four seconds after the "field in sight" call was made. The PF could not recall anything abnormal about the flare or touchdown. As the aircraft was not equipped with auto-braking or thrust reversers, he applied light braking about four seconds after touchdown to get a feel for the braking action. As no reaction was felt, he progressively applied the brakes with greater intensity until maximum braking was applied. Despite this, no deceleration was felt. The PNF could recall the anti-skid cycling during the landing rollout, realised that they were not going to stop on the runway surface and tried to assist with the braking. He recalled seeing the "Park Brake On" light illuminated, although the PF could not recall activating the emergency park brake system at any time during the ground roll. The PNF described the landing as smooth and said that he had checked that the spoilers had deployed after touchdown, and announced them as open. According to the flight data recorder (FDR) data, the spoilers opened at 09:01:11Z, two seconds after touchdown, and remained open until 09:01:52Z, when the aircraft came to a halt at the bottom of an embankment.

1.1.7 As the end of the runway approached, the PF realised that the aircraft was not going to stop on the runway surface and steered it to the right to avoid colliding with the ILS localiser antenna structure. Once clear of this, he steered the aircraft back to the centreline, colliding with the approach lights for runway 29 while doing so. He then attempted to ground loop the aircraft to avoid colliding with the perimeter fence, but this was unsuccessful and the aeroplane continued straight ahead, crashing through the fence and coming to rest on the R404 road.

1.1.8 The PF said that he had given the "brace" command on Com 1 as he was unable to reach the passenger address system due to vibration from the uneven terrain, and was therefore uncertain if the passengers had heard the command. The CVR revealed that the PF had in fact given the "brace" command seven times. Most of the passengers said afterwards that they had heard the pilot broadcasting the "brace" command.

1.1.9 The landing was captured by three aerodrome surveillance cameras located respectively on the airport building, facing the apron, and pointing towards the runway. Each recorded a portion of the sequence. The aircraft was observed to touch down within the touchdown zone near the third landing marker, bounce up slightly for 1,5 seconds, and then settle on the runway. The spoilers deployed immediately and braking followed approximately four seconds later.

1.1.10 According to the ATC, nothing appeared untoward about the touchdown and there was no communication from the crew to indicate any problems. He expected the aircraft to turn left onto taxiway Delta at the end of the runway as per normal procedure, but it veered to the right off the runway, narrowly avoiding the ILS localiser antennas. Realising that something was wrong, he activated the crash alarm and the aerodrome rescue and fire-fighting (ARFF) personnel responded swiftly.

1.1.11 The aircraft then struck eleven approach lights for runway 29, crashed through the aerodrome perimeter fence, and skidded down an embankment, coming to rest in a nose-down attitude on the R404 road. Several motorists stopped and helped the passengers, who evacuated the aircraft through the service door on the right-hand side near the front and the left mid-fuselage emergency exit. The ARFF personnel arrived within minutes and assisted with the evacuation. They were compelled to break down the cockpit access door to free the crew as the door had become jammed due to the deformation of the nose structure and cockpit floor. The first officer's right lower leg was trapped and had to be freed by emergency personnel using the jaws of life. Both crew members remained conscious throughout the accident sequence. In an interview afterwards, they stated that they had been aware of the procedure to open the emergency exits, including the blow-out panel on the cockpit door, but had been unable to open either following the accident.

1.1.12 Ten people, including the three crew members, were admitted to a local hospital for an examination. All were discharged after several hours, with no serious injuries being reported.

1.1.13 The accident occurred during daylight conditions at the geographical co-ordinates South 34°00.306' East 022°23.534' and at an elevation of 610 ft above mean sea level (AMSL).

1.2 Injuries to persons

Injuries	Pilot	Crew	Pass.	Other
Fatal	-	-	-	-
Serious	-	-	-	-
Minor	2	1	7	-
None	-	-	25	-

1.3 Damage to aircraft

1.3.1 The aircraft rolled off the runway, and came to rest with its nose on the road and its aft fuselage on the embankment. It suffered substantial damage, especially to these two sections.

Figure 1(a): The aircraft after coming to rest on the roadway.

Figure 1(b): The size and angle of the embankment can be seen here.

Figure 1(c): The broken perimeter fence.

1.4 Other damage

1.4.1 No damage was caused to the runway surface. The PF managed to steer the aircraft to the right of the runway centreline, avoiding the ILS localiser antenna structure 163 m from the end of the runway stop-way. The aircraft then struck and damaged eleven runway approach lights before bursting through the aerodrome perimeter fence. About 100 m of wire-mesh and six wooden supports had to be replaced.

1.4.2 Minor damage was caused to the road surface and surrounding vegetation. The fuel tanks remained intact and no leakage occurred. All the fuel was drained from the aircraft prior to recovery.

1.5 Personnel information

1.5.1 Pilot-in-command (PIC)

Nationality	South African	Gender	Male	Age	39
Licence No.	0270236334	Licence Type	Airline Transport Pilot		
Licence valid	Yes	Type Endorsed	Yes		
Ratings	Instrument Rating, Test Flight Multi-Engine (Piston)				
Medical expiry date	31 July 2010 (Class 1)				
Restrictions	None				
Last line check	29 May 2009				
Last simulator check	3, 4 May 2009				
Last CRM* refresher	23 April 2009				
Previous accident(s)	None				

*Cockpit Resource Management

Flying experience

Total hours	11 973,5
Total past 90 days	148,6
Total on type past 90 days	148,6
Total on type	2 905,8

From 26 April 2006 until the day of the accident – 7 December 2009 – the PIC had made 175 landings at FAGG in an Embraer 135. Thirty-five of these had been ILS approaches.

The PIC was involved in a hydroplaning incident during a landing in heavy rain at Ndola International Airport (FVBU) in Zambia on 14 January 2008. All four main tyres required replacement due to flat spots caused by hard braking. No official investigation was conducted by the State of Occurrence (Zambia), as this was categorised as an incident.

1.5.1.1 Corrective action

On 1 February 2008, the operator issued an internal circular on hydroplaning – Red Tag 21. This provided guidance to flying crew on the condition and how to identify and deal with it. All flying crew were required to read the circular and sign off that they had done so and understood the content. A copy of Red Tag 21 is attached to this report as Annexure A.

Newly appointed flying crew were required to read all of the operator's red tags and sign them off accordingly.

1.5.2 First officer (FO)

Nationality	South African	Gender	Male	Age	23
Licence No.	0271023392	Licence Type	Airline Transport Pilot		
Licence valid	Yes	Type Endorsed	Yes		
Ratings	Instrument Rating				
Medical expiry date	31 October 2010 (Class 1)				
Restrictions	None				
Last line check	13 October 2009				
Last simulator check	23 and 24 September 2009				

Last CRM refresher	10 September 2009
Previous accident(s)	None

1.5.2.1 Flying experience

Total hours	2 336,3
Total past 90 days	188,8
Total on type past 90 days	188,8
Total on type	864,9

Prior to the accident flight, the first officer had made 66 landings at George aerodrome in an Embraer 135. Twenty-two of these had been ILS approaches.

1.5.3 Cabin attendant

Nationality	South African	Gender	Female	Age	23
Licence No.	*****************	Licence Type	Cabin Crew		
Licence valid	Yes	Type Endorsed	Yes		
Ratings	Held required ratings for aircraft type				
Medical expiry date	31 March 2010				
Restrictions	None				
Previous accidents	None				

There were thirty-two passengers and one cabin crew member on board the flight. This was in line with the requirements as stipulated in Part 121.02.5(1) of the Civil Aviation Regulation of 1997 and Document SA-CATS-OPS 121.

The cabin attendant began flying as a crew member with the operator in June 2008 and had accumulated a total of 1 504 flying hours at the time of the accident.

1.5.4 Crew rest

All three crew members had had a three-day rest period prior to signing on at 0320Z on 7 December 2009. The accident occurred during the third sector of a four-sector schedule.

1.5.5 Air traffic controller (ATC)

Nationality	South African	Gender	Male	Age	39
Licence No.	*****************	Licence Type	ATC		
Licence valid	Yes				
Ratings	Approach, Aerodrome and Approach Radar				
Unit rating	Position Grade Examiner / Instructor				
Medical expiry date	30 April 2011				
Restrictions	None				

1.6 Aircraft Information

1.6.1 General description

The Embraer 135-LR is a low-wing, T-tail, pressurised aircraft powered by two high-bypass ratio, rear-mounted Rolls-Royce AE 3007A1/3 turbofan engines. The tricycle landing gear is retractable, and has two tyres per strut. The flight deck accommodates two pilots, is fitted with an observer seat and has a glass cockpit panel equipped with highly integrated on-board avionics. The typical passenger configuration is three seats abreast, and ZS-SJW was configured for 37 passengers, all in economy class. Overhead stowage compartments ran the length of the cabin. The aircraft has one main door (left front) and one service door (right front) as well as two over-wing emergency exits.

Figure 2: A file photograph of ZS-SJW in the landing configuration.

1.6.2 Airframe

Type	Embraer 135-LR	
Serial No.	145-423	
Manufacturer	Embraer Aircraft Company	
Year of manufacture	2001	
Total airframe hours (at time of accident)	21 291,25 / 17 003	
Last inspection (hours, cycles & date)* *(see note below)*	21 125,38 / 16 825	11 November 2009
Hours since last inspection	165,87	
C of A (issue date)	11 May 2001	
C of A currency fee (expiry date)	10 May 2010	
C of R (issue date) (present owner)	30 April 2001	
Operating categories	Standard	
Maximum allowable takeoff weight	20 000 kg	
Maximum allowable landing weight	18 500 kg	
Recommended fuel type	Jet A1	
Fuel type used	Jet A1	

* This was the last inspection signed off in the aircraft's airframe logbook. The inspection type was indicated as A05-cycles, and was a cycle-driven check in accordance with the approved maintenance schedule. The inspection was part of workpack No. 45685.

On 5 December 2009, a routine 14-day inspection, part of workpack No. 46101, was carried out on the aircraft. This was not signed off in the airframe logbook, but was captured on the aircraft maintenance organisation's (AMO's) internal maintenance monitoring procedure – the IAS Live System.

The technical log and report (the flight folio) indicates that an after-flight inspection was signed off prior to the flight departing from its home base on the morning of 7 December 2009. The inspection report indicates that tyre pressures were checked prior to the flight. All four main tyres remained inflated after the incident at FAGG, despite being substantially damaged during the overrun.

Engine No. 1

Type	Rolls-Royce AE 3007A1/3
Serial number	CAE 311925
Hours since new	17 831,47
Cycles since new	15 169

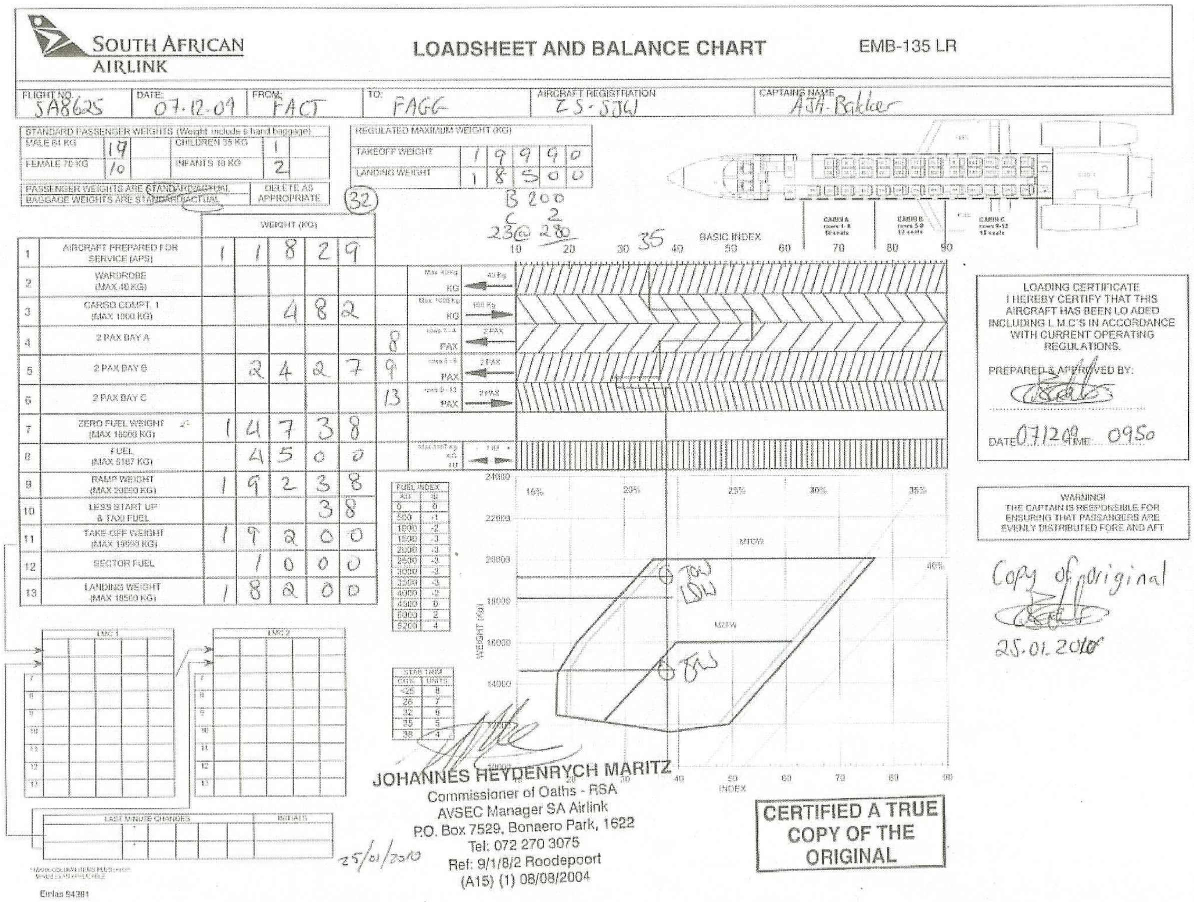
Engine No. 2

Type	Rolls-Royce AE 3007A1/3
Serial number	CAE 311754
Hours since new	16 428,38
Cycles since new	13 320

1.6.3 Weight and balance

The original loadsheet and balance chart (green copy) was recovered from the accident site. Although in poor condition, it was still legible. The landing weight was indicated as 18 200 kg (40 124 lb). For the sake of clarity, the investigating team requested that the operator submit a copy of the loadsheet (see Figure 3).

The aircraft was found to be in accordance with the prescribed limitation approved for landing, which was a maximum of 18 500 kg (40 785 lb), as stipulated in the aircraft flight manual (AFM), chapter 2, Limitations, pp2-6.



SOUTH AFRICAN AIRLINK

LOADSHEET AND BALANCE CHART EMB-135 LR

FLIGHT NO.	DATE:	FROM:	TO:	AIRCRAFT REGISTRATION	CAPTAINS NAME
SA8625	07.12.09	FACT	FAGG	ZS-SJW	AJH Bakker

STANDARD PASSENGER WEIGHTS (Weight include s hand baggage)			
MALE 84 KG	19	CHILDREN 35 KG	1
FEMALE 70 KG	10	INFANTS 10 KG	2

PASSENGER WEIGHTS ARE STANDARD/ACTUAL. BAGGAGE WEIGHTS ARE STANDARD/ACTUAL. DELETE AS APPROPRIATE (32)

REGULATED MAXIMUM WEIGHT (KG)	
TAKEOFF WEIGHT	19990
LANDING WEIGHT	18500

B 200 C 2 23@ 280

		WEIGHT (KG)	
1	AIRCRAFT PREPARED FOR SERVICE (APS)	11829	
2	WARDROBE (MAX 40 KG)		
3	CARGO COMPT. 1 (MAX 1000 KG)	482	
4	2 PAX BAY A		8
5	2 PAX BAY B	2427	9
6	2 PAX BAY C		13
7	ZERO FUEL WEIGHT (MAX 16000 KG)	14738	
8	FUEL (MAX 5187 KG)	4500	
9	RAMP WEIGHT (MAX 20050 KG)	19238	
10	LESS START UP & TAXI FUEL	38	
11	TAKE-OFF WEIGHT (MAX 19990 KG)	19200	
12	SECTOR FUEL	1000	
13	LANDING WEIGHT (MAX 18500 KG)	18200	

FUEL INDEX KG	IU
0	0
500	-1
1000	-2
1500	-3
2000	-3
2500	-3
3000	-3
3500	-3
4000	-2
4500	0
5000	2
5200	4

STAB TRIM CG%	UNITS
<25	8
26	7
32	6
35	5
38	4

BASIC INDEX 35

LOADING CERTIFICATE
I HEREBY CERTIFY THAT THIS AIRCRAFT HAS BEEN LOADED INCLUDING L.M.C'S IN ACCORDANCE WITH CURRENT OPERATING REGULATIONS.
PREPARED & APPROVED BY:
DATE 07.12.09 TIME 0950

WARNING!
THE CAPTAIN IS RESPONSIBLE FOR ENSURING THAT PASSANGERS ARE EVENLY DISTRIBUTED FORE AND AFT

Copy of original 25.01.2010

JOHANNES HEYDENRYCH MARITZ
Commissioner of Oaths - RSA
AVSEC Manager SA Airlink
P.O. Box 7529, Bonaero Park, 1622
Tel: 072 270 3075
Ref: 9/1/8/2 Roodepoort
(A15) (1) 08/08/2004

25/01/2010

CERTIFIED A TRUE COPY OF THE ORIGINAL

Figure 3: Copy of the loadsheet and balance chart for the accident flight.

1.6.4 Approach and landing speeds applicable

The optimal approach and landing speeds are determined by the manufacturer during the certification programme of the aircraft. Using the appropriate table from the Embraer quick reference handbook (see Figure 4), the following speeds were obtained for these conditions: landing weight 18 500 kg, approach flap 9°, landing flap 45° and no ice encountered.

Reference speed: V_{REF} = 129 KIAS
Final segment speed: V_{FS} = 164 KIAS

PERFORMANCE DATA

AE3007A1/3 ENGINES

APPROACH CLIMB SPEED (V_{APPCLB}) & REFERENCE SPEED (V_{REF}) and FINAL SEGMENT SPEED (V_{FS})					
Weight (kg)	Approach Flaps 9° Landing Flaps 22°		Approach Flaps 9° Landing Flaps 45°		V_{FS} (KIAS)
	V_{APPCLB} & V_{REF} (KIAS)		V_{APPCLB} & V_{REF} (KIAS)		
	No ice encounter	After ice encounter	No ice encounter	After ice encounter	
12000	105	111	104	109	133
12500	107	113	106	111	135
13000	109	115	108	114	138
13500	111	117	110	116	140
14000	114	120	112	118	143
14500	116	122	114	120	145
15000	118	124	116	122	148
15500	120	126	118	124	150
16000	121	128	120	126	153
16500	123	130	122	128	155
17000	125	132	124	130	157
17500	127	134	126	132	159
18000	129	136	127	134	161
18500	131	138	129	135	164
19000	133	139	131	137	166
19500	134	141	132	139	168
20000	136	143	134	141	170
20500	138	145	136	142	172
21000	139	147	137	144	174

NOTE: For Cat II operations use the after ice encounter speeds.

APPROACH SPEED (V_{APP})
$V_{APP} = V_{REF}$ + ½headwind + full gust

QRH-145/1169 CODE 08

PD-6 **ORIGINAL**

Figure 4: Speed table from Embraer quick reference handbook.

The FDR analysis determined that the speed of the aircraft at 50 ft above the threshold was 143 KIAS.

1.6.5 Landing/Stop distance calculations

1.6.5.1 Landing distance defined by FAA certification requirement:

Source: FAA Advisory Circular (AC) 25-7A (chapter 2, section 2, Landing 25.125)

"The landing distance is the horizontal distance from the point at which the main gear of the airplane is 50 feet above the landing surface (treated as a horizontal plane through the touchdown point) to the point at which the airplane is brought to a

stop. (For water landings, a speed of approximately 3 knots is considered 'stopped')"

1.6.5.2 Background to landing distance requirements

The required landing distances for the various operating configurations are determined by the manufacturer during the certification programme of the aircraft. Embraer document GP-1971, dated 26 April, 2004 and revised 5 July 2008, provides the following:

"Understanding V_{REF} and Approach Speeds
Before establishing any definition about approach speeds, we must first understand how a landing is defined under the civil aviation regulation, especially factors that must be accounted for.

NOTE: The regulations quoted below are from the Federal Aviation Administration Regulations (FAR) as well as the Joint Aviation Administration Regulations (JAR) as these were the applicable regulations under which the aircraft was subjected for certification purposes.

FAR/JAR 25.125 – Landings

(a) The horizontal distance necessary to land and come to a complete stop from a point 50 feet above the landing surface must be determined (for standard temperatures, at each weight, altitude, and wind within the operational limits established by the applicant for the airplane) as follows:

(1) The airplane must be in the landing configuration.

(2) A stabilised approach, with a calibrated airspeed of V_{REF}, must be maintained down to the 50 feet height.
V_{REF} may not be less than:

(1) 1.23 V_{S1g}.

(2) V_{MCL} (minimum control speed in air on landing configuration)

(3) A speed that provides maneuvering capability on approach and landing.

*As per the text above, the first statement that validates all the certified landing data is **CROSSING THE THRESHOLD WITH V_{REF} at a height of 50 feet.***

During certification the actual landing distance is demonstrated as follows:

- *Standard temperature.*
- *Landing configuration: landing gear and flaps set for landing.*
- *Stabilised approach at V_{REF}.*
- *Changes in configuration, power or thrust, and speed, must be made in accordance with the established procedures for service operation.*
- *Determination on a level, smooth, DRY and hard-surfaced runway.*
- *The landing must be made without excessive vertical acceleration, tendency to bounce, nose over, ground loop, porpoise, or water loop.*
- *If any device is used that depends on the operation of any engine (such as thrust reversers), and if the landing distance would be noticeably increased*

when a landing is made with that engine inoperative, the landing distance must be determined with that engine inoperative unless the use of compensating means will result in a landing distance not more than that with each engine operating. The reverse thrust effect is not accounted for during Embraer airplane landing certification.

- *The landing may not require exceptional piloting skill or alertness.*
- *The pressure on the wheel braking systems may not exceed those specified by the brake manufacturer (maximum braking capability) and may not be used so as to cause excessive wear of brakes or tyres.*
- *Means other than wheel brakes may be used if that means:*
  - *Operation is reliable and safe.*
  - *Operation is such that consistent results can be expected in service; and is such that exceptional skill is not required to control the airplane.*

In regard to Embraer airplanes, other braking resources mean the use of spoilers on the ground."

1.6.5.3 Landing distance calculations

The values below were obtained in conjunction with the aircraft manufacturer by making use of Embraer performance software. The manufacturer performed landing distance calculations for two speeds.

V_{REF} = 128 KIAS (determined by Embraer software for a landing weight of 18 200kg). The speed at 50 ft above the threshold was 143 KIAS, according to FDR data, which was V_{REF} + 15 kt, using the environmental conditions for runway 11 at the time of landing and the actual aircraft configuration (see values below).

Item	**Value**
Landing weight	18 200 kg
Centre of gravity	39%
Flaps	45°
Runway slope	+ 0,4%
Aerodrome elevation	648 ft amsl

The following calculations were made to establish the runway length required for the aircraft to stop. The runway at FAGG was 2 000 m long, with an additional 60 m asphalt overrun area – adequate for a safe landing.

Speed	Unfactored landing distance	Dry-factored landing distance	Wet-factored landing distance
V_{REF}	816 m	1 361 m	1 565 m
V_{REF}+15	978 m	1 630 m	1 874 m

The landing distances were calculated using the FDR data. The calculated V_{REF} was 128 kt; however, the actual indicated aircraft speed at 50 ft above the runway threshold was 143 kt. The actual touchdown speed was 132 KIAS, with a 5 kt headwind. The calculated factored landing distance in this case was 1 874 m (6 147 ft), the required distance to stop the aircraft on a wet runway surface with a V_{REF} of 143 kt. This value makes provision for all operational variables following a stabilised approach not exceeding an angle of 3° down to a 50-ft height at a calibrated airspeed not less than 1,4 V_{SO} (stalling speed in landing configuration with flaps down and no power applied).

Reference: ATSB Transport Safety Report (Aviation Research and Analysis Report AR-2008-018(1), Runway Excursions, p68.

"A range of operational variables/factors, which include runway surface conditions, piloting techniques, tyre and brake deterioration, atmospheric instability such as a gust or wind-shear, crosswinds, wet runway surface, approach to touchdown and flight path deviations increase the risk of runway excursion accidents occurring as they generally increase the rollout length required after touchdown to stop the aircraft. For this reason, regulators set minimum requirements for landing lengths. These are often factored into published landing distances for different conditions, and are included in the AFM or operator standard operating procedures (SOPs) for that aircraft type. The primary regulatory requirements for landing distance calculations are listed below.

- *<u>United States and Europe</u> – FAA Part 121.195 and JAA JAR-OPS-1 require that the total available runway length be 1,67 times greater than the actual landing rollout length (as measured in dry conditions). If the runway is water-affected, this increases to 1,92. This is also known as the "15% rule" (FAA, 1965).*

- *<u>Australia</u> – the Civil Aviation Safety Authority (CASA) has indicated that under Civil Aviation Safety Regulation (CASR) Part 121, it will require the actual landing rollout length to be 60 to 70% of the total available runway length (CASA, 2002a). This is the same as the 1,67/1,92 factored by the FAA and JAA.*

- *<u>United Kingdom</u> – The Civil Aviation Authority requires that the total available runway length be 1,92 times greater than the actual landing rollout length (dry). This applies irrespective of the runway conditions at the destination airport (CAA, 2006).*

At a minimum, the FAA also recommends use of the '70% rule' when pilots are calculating the required runway length before landing. This rule states that the actual rollout length should never be more than 70% of the total available runway length available at the destination airport, irrespective of the prevailing conditions (FAA, 2007)."

The unfactored landing distance chart from the AFM can be found on p16 of this report. It should be noted that the values table above was obtained in conjunction with the aircraft manufacturer by making use of Embraer Performance Software.

<u>Definitions:</u>

<u>Unfactored landing distance</u> (landing distance without any safety margin additives)
The unfactored landing distance is the actual distance to land the aircraft from a point 50 ft above the runway threshold at V_{REF}, using only the brakes and spoilers as deceleration devices (i.e., no engine thrust reversers fitted).

The required landing distance for dispatch is the unfactored landing distance, which increases by 66,7% for a dry runway or 91,7% for a wet runway.

<u>Factored landing distances</u>

To obtain the "dry" runway factored landing distance, the unfactored landing distance should be multiplied by 1,67.

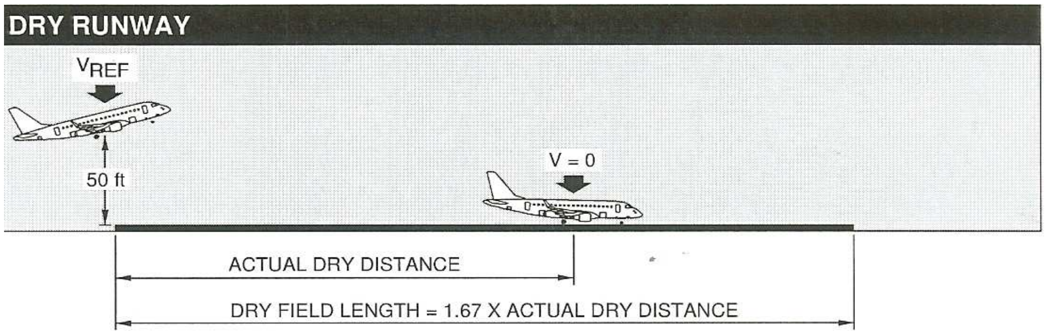


Figure 5(a): Dry runway diagram from Embraer quick reference handbook.

To obtain the "wet" runway factored landing distance, the unfactored landing distance should be multiplied by 1,92. The wet runway landing condition demonstration is not required during certification flight tests.

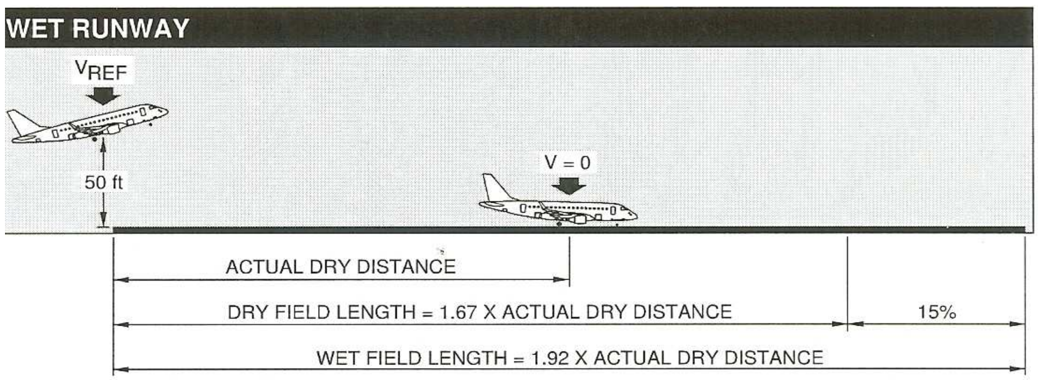


Figure 5(b): Wet runway diagram from Embraer quick reference handbook.

PERFORMANCE DATA

AE3007A1/3 ENGINES

UNFACTORED LANDING DISTANCE

UNFACTORED LANDING DISTANCE (METERS)
EMB-135 - FLAPS 45°
NO ICE ENCOUNTER
ISA CONDITIONS - SLOPE 0%

WEIGHT (kg)	ALTITUDE							
	0 ft				1000 ft			
	WIND				WIND			
	-10 kt	0 kt	10 kt	20 kt	-10 kt	0 kt	10 kt	20 kt
20000	1015	887	840	791	1038	908	860	811
19000	975	850	805	757	997	870	824	776
18000	936	815	771	724	957	834	788	741
17000	898	780	736	691	917	797	753	707
16000	860	745	703	659	878	762	719	674
15000	822	711	670	626	839	726	684	641
14000	784	677	636	594	800	691	650	607
13000	747	642	603	562	762	656	616	574
12000	709	608	570	529	723	621	582	541

WEIGHT (kg)	ALTITUDE							
	2000 ft				3000 ft			
	WIND				WIND			
	-10 kt	0 kt	10 kt	20 kt	-10 kt	0 kt	10 kt	20 kt
20000	1062	929	881	831	1086	952	903	853
19000	1019	891	844	795	1043	912	864	815
18000	978	853	807	759	1000	873	827	778
17000	936	815	770	724	957	834	789	742
16000	896	779	735	690	915	796	752	706
15000	856	742	700	655	874	759	716	671
14000	816	706	665	621	834	721	680	636
13000	777	670	630	587	793	684	644	601
12000	737	634	595	554	752	647	608	566

WEIGHT (kg)	ALTITUDE							
	4000 ft				5000 ft			
	WIND				WIND			
	-10 kt	0 kt	10 kt	20 kt	-10 kt	0 kt	10 kt	20 kt
20000	1113	976	926	875	1140	1001	950	898
19000	1067	934	886	836	1093	958	909	858
18000	1023	894	847	798	1047	916	868	819
17000	978	853	808	760	1001	874	828	779
16000	936	815	770	723	957	834	789	742
15000	893	776	732	687	913	794	750	704
14000	851	738	696	651	870	755	712	667
13000	810	700	659	616	827	716	674	631
12000	768	662	622	580	784	677	636	594

NOTE: UNFACTORED LANDING DISTANCES CORRECTIONS FOR FLAPS 45°:

Temperature: Add 3.0 m per each 1 °C above ISA.
Decrease 1.5 m per each 1 °C below ISA.

Slope: Add 50 m per each 1% slope down.
Decrease 20 m per each 1% slope up.

Wet runway: Multiply the factor indicated in the abnormal and emergency procedures by 1.50.

QRH-145/1169
CODE 08

PD-10 **ORIGINAL**

Figure 6: Unfactored landing distance table from Embraer quick reference handbook.

1.6.6 Embraer 135 performance

The operator of ZS-SJW published performance information in the operations manual, and also ran a computerised performance calculation system at its head office that was available to flight crews. The manual offered advice for operation on slippery runways, but did not specify how flight crews should make performance decisions on wet runways that "*may be slippery when wet*". The table in the manual required knowledge of braking action before slippery runway calculations could be made.

1.6.7 Weather radar

The Embraer 135 is equipped with a single weather radar system. The control panel for the radar is located on the pedestal between the two pilots and allows specific settings to be made – gain, tilt, mode, ground suppression “on” or “off”, and predictive wind-shear “on” or “off”. The returns are displayed on the multi flight display (MFD). The range for each pilot can be adjusted independently with a control knob on the glare shield.

1.6.8 Aircraft seats and restraint systems

The cockpit seats are fixed to slide rails for fore and aft adjustment, and can also be laterally adjusted. They are certified to JAR 25.561 standards. A review of the cockpit seat design documents indicated that these seats do not exceed the minimum requirements.

The pilot’s and co-pilot’s seatbelts each consists of five straps. The pilot’s left lap belt straps and co-pilot’s right lap belt straps are permanently fixed to a rotary buckle with quick-release latch locks operated by turning a device on the buckle face. The two upper straps are connected to an inertia reel attached to the backrest that allows the pilot to bend forward slowly. Abrupt movements or high acceleration locks the upper straps, preventing the pilot from being flung forward against the instrument panel. The inertia reel can be mechanically locked through a lever on the seat. The observer’s seat is equipped with a complete set of seat belts.

The passenger and cabin crew seats of ZS-SJW were certified to JAR 25.561 (described as 9 g horizontally) and JAR 25.562 (described as 16 g horizontally) standards. Passenger seats were equipped with a lap belt while supplemental loop belts were provided for passengers travelling with infants.

The flight attendant’s seat was positioned to the left of the cockpit bulkhead, next to the cockpit access door and close to the main service door. The seat was of the fold-away type to allow ease of access and was equipped with a lap and shoulder harness.

1.6.9 Emergency exits

The Embraer 135 operations manual, section 1-11-40, states:

“There are two forward doors (main and service), two over-wing emergency exits, two cockpit windows, one each side, as well as a blow-out panel on the cockpit door that can be used for emergency evacuation. Both forward doors are designed to be opened either from the interior or the exterior. The doors have a very slight, inward initial-opening movement.”

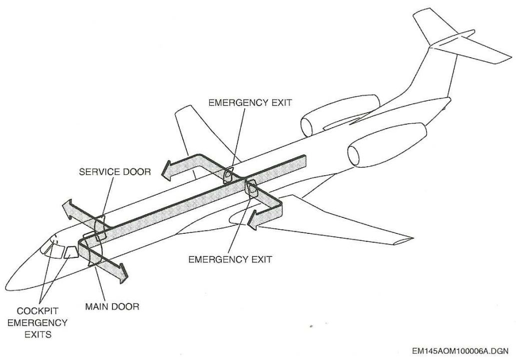
The instructions state that to open the doors from the interior, one must "lift the door control lever and pull it to its stop". This disengages two latches on the top of the door, thereby unlocking it.

There are two emergency exit hatches for passenger evacuation. These are located on each side of the aircraft, centered over the wings in row 9 A and 9 B, C respectively. These devices can be opened either from the interior or exterior by removing the upper access cover, pulling the handle, holding the hatch and removing it from the passage. During the accident in question, only the left over-wing emergency exit was removed at seat 9 A. The cabin attendant said that seats

9 B, C had been unoccupied during the flight.

The cockpit windows of the Embraer 135 are designed to be partially opened or even totally removed from the inside when the aircraft is on the ground. A rope is positioned above each window to assist in evacuation. After the aircraft came to a halt on the R404 road the crew members tried to open the cockpit windows from the inside but were unsuccessful in doing so.

The cockpit door between the passenger's cabin and cockpit is provided with an emergency exit which is accessible when the blow-out panel is removed. However, due to the deformation of the cockpit and nose structure, the door had to be removed by rescue personnel to free the cockpit crew.



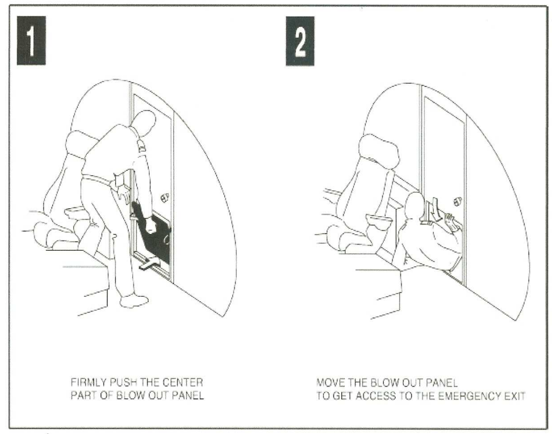


Figure 7: Emergency exits on the Embraer 135 and blow-out panel on cockpit door.

1.6.10 Evacuation escape devices

The aircraft was not equipped with any evacuation escape devices to facilitate rapid escape in an emergency.

1.6.11 Emergency lighting

The Embraer 135 operations manual, section 2-06-20, states:

"The aircraft is equipped with an emergency lighting system that is controlled through the emergency lighting switch located on the overhead panel in the flight deck or through the attendant emergency lighting button located at the attendant's panel.

The emergency lighting consists of internal and external lights that provide proper illumination for emergency cabin evacuation. These lights are powered by four dedicated batteries charged through the essential bus. Battery power is sufficient to supply all internal and external emergency lights for approximately 15 minutes.
Internal emergency lights consist of the cockpit light, aisle lights, main door lights, galley service door lights, over-wing emergency exit lights, floor proximity lights and EXIT signs as follows:

- *Cockpit light: This light is located along the cockpit ceiling to provide general cockpit emergency illumination.*

- *Aisle lights: Four dome lights are located along the aisle for general* *emergency cabin illumination.*

- *Main door, galley service door and over-wing emergency exits lights: Four lights are installed for the purpose of illuminating the passageway leading from the main aisle to each of the exit openings.*

- *Floor proximity emergency lights: Either electroluminescent or photoluminescent strips are installed along the passenger cabin floor to provide a means of identifying the emergency escape path even in conditions of dense smoke.*

The exterior emergency lights installed are as follows:

- *Two lights installed on each side of the wing-to-fuselage fairing in order to illuminate the wing escape route and the ground area.*

- *One emergency light installed in the main door and in the service door provides illumination of the external main door and service door areas when the door is open."*

1.6.12 Emergency equipment

The cabin of ZS-SJW was equipped with portable emergency equipment in accordance with regulations.

1.7 Meteorological information

1.7.1 An official weather report was obtained from the South African Weather Services (SAWS). The weather office in George (based at the aerodrome) reported that the following conditions prevailed at 0900Z on 7 December 2009:

Wind direction	070°TN	Wind speed	2 kt	Visibility	> 10 km
Temperature	19,6℃	Clouds	Overcast	Cloud base	8 000 ft
Dew point	17,8℃				

Note: The magnetic variation for the George area is 25°.

Light rain was falling in the area at the time that ZS-SJW landed at George aerodrome. Approximately 3 mm of rain was recorded there during the two hours preceding the landing. (Refer to chart below. Source: SAWS)

Figure 8. Rainfall recorded at George aerodrome during the period in question.

1.7.2 Weather forecast for George aerodrome

The pre-departure weather information (TAF – terminal aerodrome forecast) that the crew obtained when they signed on for duty supplied the following weather forecast for George aerodrome:

"*FAGG 070000Z 0703/07/12 08010KT 9999 SCT008 BKN080 PROB30 TEMPO 0703/0705 BKN005 TEMPO 0706/0712 4000-SHRA PROB40 TEMPO 0706/0712 –TS FEW080CB TX26/0712ZTN15/0704Z=*"

This predicted showers and rain between 0600Z and 1200Z with possible fluctuations in some of the elements lasting between 30 minutes and an hour, and visibility reduced during the rain to 4 000 m. This forecast fell within the period of the accident.

METAR information for George aerodrome at the time of the accident:

"FAGG 071000Z 13003KT 070V160 5000 -RA OVC050 20/19 Q1011
FAGG 070900Z 08007KT 040V130 9999 -RA BKN080 19/18 Q1011
FAGG 070800Z 23010KT 9000 -RA OVC080 18/18 Q1012"

METAR decoded for 0900Z:

Location: FAGG
Day of month: 07
Time: 0900 UTC
Wind: True direction = 080°, speed: 7 kt

Wind direction variable between 040° and 130°
Visibility: 10 km or more
Weather: Light rain
Clouds: broken sky at 8 000 ft
Temperature: 19℃
Dew point: 18℃
QNH (sea-level pressure): 1011 hPa

1.7.3 Rainfall data for George over a three-month period (source: SAWS).

	November 2009	December 2009	January 2010
Date	George Weather Office	George Weather Office	George Weather Office
1		0,8	0,2
2	0,2		0,2
3			0,2
4			4,9
5	0,2		
6			
7		**31,8**	1,8
8			1,4
9	7,6		
10	3,8		
11			0,4
12			
13		1,4	
14	0,2	1,3	
15	0,2		4,5
16	8,0		0,4
17			
18		1,8	
19	0,6		
20			0,8
21			
22	0,1		
23			0,4
24		1,6	
25			
26			0,8
27			0,2
28			3,3
29			
30	8,6		
31			0,9
Total	**29,5**	**38,9**	**20,4**

Note: A significant amount of rain fell later in the day after the accident occurred. At the time of the accident, the total rainfall measured was 3 mm.

1.7.4 ATC wind update to crew

At 08:59:15Z, while on its approach, SA8625 was advised by the ATC that the surface wind was 130° at 5 kt. At 09:01:00Z, the ATC radioed that the wind was 090° at 5 kt. The PF replied: *"Okay, it stays pretty much on the nose."*

1.8 Aids to navigation

1.8.1 The aircraft was equipped with the following navigational aids:

- Magnetic compass
- Automatic direction finder (ADF)
- Very high frequency omni-directional radio range (VOR)
- Distance measuring equipment (DME)
- Instrument landing system (ILS)
- Global positioning system (GPS)
- Transponder
- Weather radar

1.8.2 Runway 11 ILS (instrument landing system) approach

The crew was cleared by ATC for an ILS/DME approach for runway 11 at George. The published decision height was 922 ft AMSL. The landing aids were serviceable and no anomalies or malfunctions were reported by the flight crew or ATC that had any effect on the approach.

1.8.3 Calibration of ground navigational aids

A calibration flight check of the ILS runway 11 was carried out by the SACAA flight inspection calibration division on 7 October 2009. The glideslope was found to be within limits, with a measured approach angle of 3,0º. The localiser was flight-checked on the same day and no adjustments were necessary. The VOR/DME was flight-checked on 29 June 2009 and found to be operational.

1.9 Communications

1.9.1 External communication

The aircraft was in constant radio contact with the FAGG control tower on the VHF frequency 118.9 MHz during the approach and landing. No aircraft communication system malfunction was reported by the flight crew before or during the landing. The aircraft was cleared for the ILS approach for runway 11, and the ATC advised the crew that the runway was wet, as called for in ICAO document 4444, chapter 12, Phraseologies, paragraph 12.3.1.10, p12-9.

According to the ATC, the landing itself appeared normal. However, the aircraft then failed to turn into taxiway Delta at the end of the runway, and veered to the right, passing the ILS localiser antenna. Realising there was a problem, the ATC activated the crash alarm to activate the ARFF services.

1.9.2 Aerodrome rescue fire-fighting (ARFF) communication

After activating the alarm, the ATC was contacted immediately by the ARFF station on the active aerodrome frequency for more details. He responded: *"The Embraer has overrun the runway. The Embraer has overrun the runway past the threshold of runway 29 on the grass at the localiser antennas."*

The ARFF immediately dispatched personnel to the scene in line with air traffic management requirements as stipulated in ICAO document 4444, chapter 7, paragraph 7.1.2.1, p7-2. They arrived within the three-minute timeframe as called for in ICAO Annex 14, volume I, chapter 9, paragraph 9.2.23. There was no fire to attend to and their primary task was to rescue the occupants and secure the accident site.

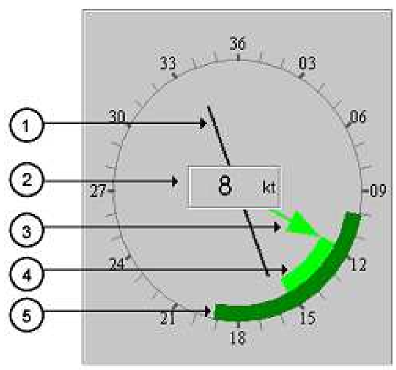
A transcript of the ATC and aircraft communication is attached as Annexure B.

1.9.3 Air traffic control wind data

The ATC obtained the basic wind data from the automated weather observing system (AWOS) similar to the display in Figure 9.

Wind direction and speed is indicated digitally, providing an instantaneous two-minute and ten-minute average to the controller.

Windsocks, of which there were three at the aerodrome, indicate wind speed and direction. At FAGG, they serve to identify a mountain (berg) wind or a strong crosswind. This is correlated with what the ATC sees on the AWOS. Wind speed and direction can be obtained from six points on the airfield. ATC cleared ZS-SJW for landing on runway 11 and told the crew: *"130° at 5 kt".*



1 = Runway direction

2 = Wind speed at the threshold, in preconfigured units. This is normally an instant value.

3 = Wind direction at the threshold, in tens of degrees. This is normally an average of the wind direction values during the last 2 minutes. Depending on the system configuration, it can also be an instant or 10-minute average value. See Figure 9 on page 51. In this example, the wind direction is 120 degrees.

4 = The range of wind variation during the last 2 minutes, in tens of degrees (the inner bar).

5 = The range of wind variation during the last 10 minutes, in tens of degrees (the outer bar).

Figure 9: A digital wind rose.

1.10 Aerodrome information

1.10.1 Aerodrome details

Location	Six km south-west of the town of George	
Co-ordinates	South 34°00'24.13" East 022°22'27.41"	
Elevation	648 ft	
Runway designations	11/29	02/20 (runway now closed)
Runway dimensions	2 000 m x 45 m	1 160 m x 30 m
Runway used	11	
Threshold elevation	622 ft	
Runway slope	Upslope of + 0,4%	
Runway grooved	Partial (to the right of centreline runway 11 – 120 m)	
Runway surface	Asphalt *Note: rehabilitation work was performed from 16 July to 6 November 2009*	
Approach facilities	ILS, DME, VOR, NDB, runway lights, PAPIs	
Aerodrome status	Licensed, valid until 31 January 2010	
Aerodrome official opening	28 May 1977	

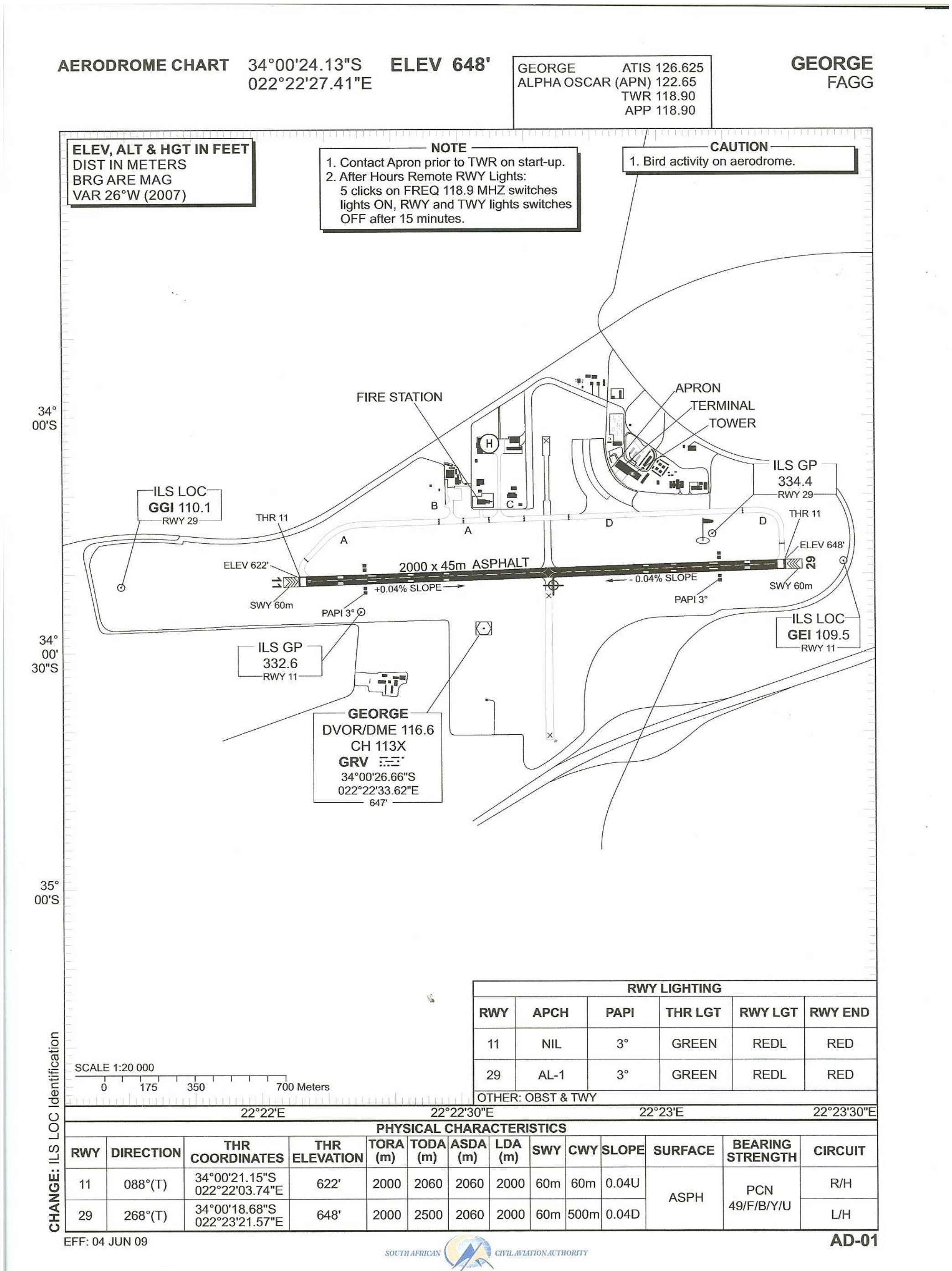
The aerodrome was built in 1977 as an exact replica of the Keetmanshoop aerodrome in Namibia.

In 1994, ownership of the airport was transferred from the Department of Transport to the Airports Company of South Africa (ACSA).

George Airport is relatively small and handles approximately 250 000 passengers annually.

The ICAO reference code number and letter for the airport is 4C and relates to the aircraft which it can accommodate: Boeing 737-2/3/4/800, MD82 and similar-sized aeroplanes. The aerodrome reference code table referred to may be found in ICAO Annex 14, volume 1, paragraph 1.7, Reference code.

Figure 10 highlights the navigational aids and ground stations at George aerodrome



RWY LIGHTING

RWY	APCH	PAPI	THR LGT	RWY LGT	RWY END
11	NIL	3°	GREEN	REDL	RED
29	AL-1	3°	GREEN	REDL	RED
OTHER: OBST & TWY					

PHYSICAL CHARACTERISTICS

RWY	DIRECTION	THR COORDINATES	THR ELEVATION	TORA (m)	TODA (m)	ASDA (m)	LDA (m)	SWY	CWY	SLOPE	SURFACE	BEARING STRENGTH	CIRCUIT
11	088°(T)	34°00'21.15"S 022°22'03.74"E	622'	2000	2060	2060	2000	60m	60m	0.04U	ASPH	PCN 49/F/B/Y/U	R/H
29	268°(T)	34°00'18.68"S 022°23'21.57"E	648'	2000	2500	2060	2000	60m	500m	0.04D			L/H

Figure 10: George aerodrome chart as published at the time of the accident.
Source: SACAA website (www.caa.co.za).

The chart contained two errors. The upslope and downslope of the runway – indicated as + 0,04% and – 0,04% – should read + 0,4% and – 0,4%. And the latitude reading shown as 35°00'S on the lower left vertical axis should be 34°01'00"S.

Figure 11 shows the instrument approach chart for FAGG as published at the time of the accident. (Source: SACAA website – www.caa.co.za). The aerodrome permits ILS CAT I and VOR approaches for both runways, as well as an NDB approach for runway 29.

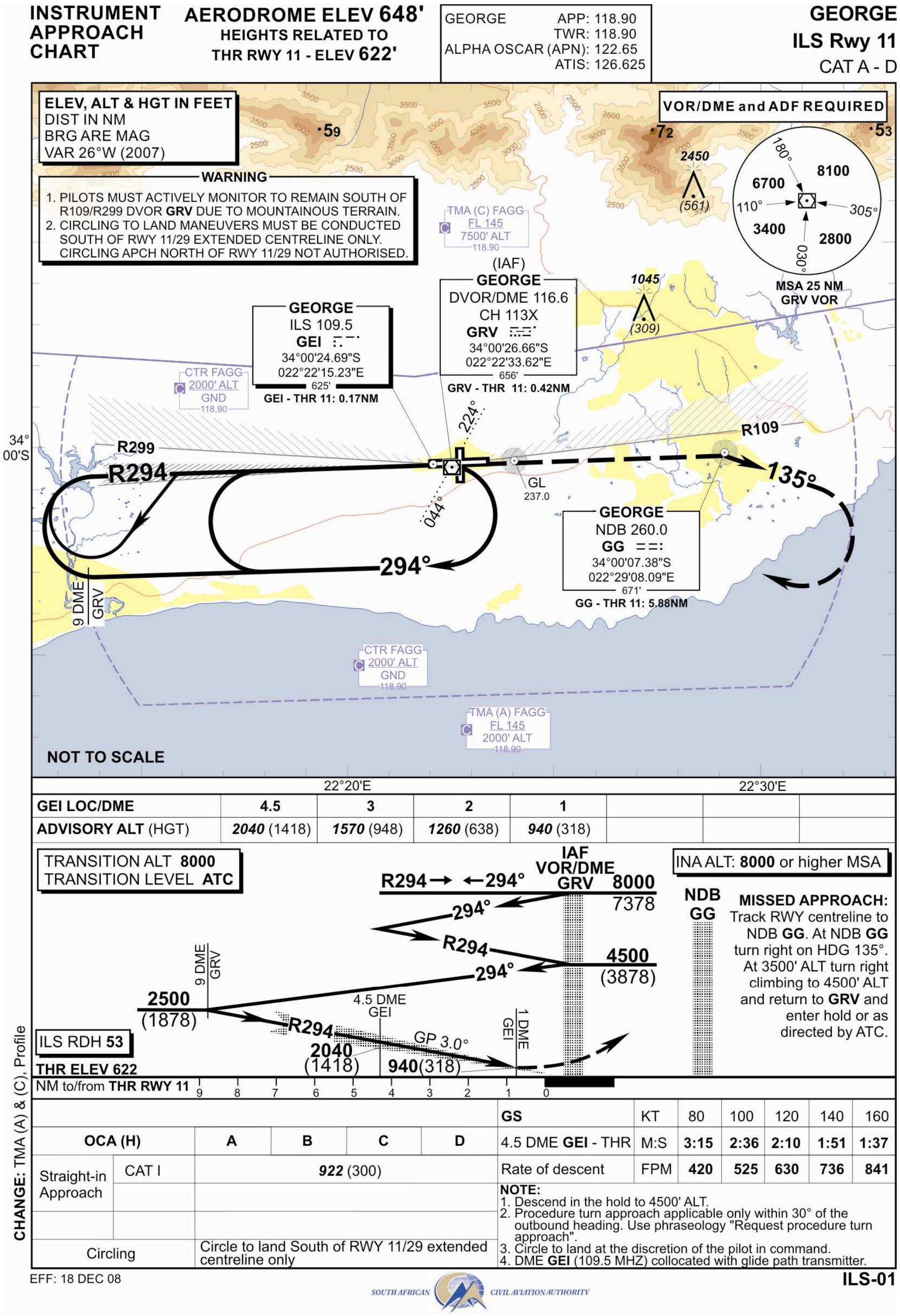


Figure 11: The instrument approach chart for ILS for runway 11.

1.10.2 Aerodrome certification requirements

i. Regulations for the certification of aerodromes are defined in the Civil Aviation Regulations 1997 (CARs), Part 139, Aerodromes and Heliports: Licensing and Operation, as amended.

ii. These restrict the use by an aeroplane flown in commercial air transport operations and with a maximum certificated mass exceeding 5 700 kg, to an aerodrome licensed in terms of Part 139.

iii. The issue and renewal of an aerodrome licence is subject to the aerodrome complying with these regulations, as complemented by the standards contained in the relevant ICAO annexes and documents listed in Document SA-CATS-AH and any recommended practice contained in these documents which the Commissioner may have incorporated as a standard. An aerodrome licence is valid for a period determined by the Commissioner calculated from the date on which the licence is issued or renewed (it may not exceed five years, however). Compliance with the regulations and standards for the purposes of issuing or renewing a licence is determined by means of audit procedures and inspections by the SACAA during the preceding licence period or before the issuing of a new licence.

iv. The holder of a licence is obligated to inform the Director (referred to as the Commissioner at the time of the accident) of any alterations to, or obstructions or work on, the aerodrome and to ensure that the aerodrome is maintained in a serviceable condition.

v. The aerodrome design and operating standards contained in Document SA-CATS-AH, Aerodromes and Heliports, are based on those of ICAO Annex 14, volume 1, Aerodrome Design and Operations, and are incorporated by reference to Annex 14 in the Technical Standard 139.02.2:

"139.02.2 Aerodrome Design Requirements

1. Aerodrome design standard
The aerodrome design and operating standards which apply in respect of the physical characteristics, obstacle limitation surfaces, visual aids, operations and equipment and installations provided at an aerodrome, are:

(a) the appropriate aerodrome design standards contained in the latest editions of the following annexes to the Convention of International Civil Aviation:

- *Annex 14 Aerodromes, Volume I Aerodrome Design and Operations;*
- *Annex 10 Aeronautical Telecommunications, Volume 1 (Radio Navigation Aids); and*
- *Annex 17 Security – Safeguarding International Civil Aviation Against Acts of Unlawful Interference."*

vi. ICAO Annex 14, volume I, requires that the surface of a runway shall be constructed without irregularities that would result in loss in friction characteristics or otherwise adversely affect the takeoff or landing of an aeroplane and for the surface of a paved runway to be so constructed as to provide good friction characteristics when the runway is wet.

1.10.3 Runway rehabilitation

From 16 July to 6 November 2009, the runway and taxiways at George Airport were subjected to a rehabilitation process to maintain the integrity of the pavement for the following five to six years – a short-term holding action. The work was performed mostly at night after normal aerodrome operational hours. During this period the following NOTAMs (Notices to Airmen) were issued:
The NOTAM was applicable from 25 July 2009 until 19 November 2009. (See copy of NOTAMs on next page).

```
25 JUL 2009 09:38  FROM FAJSYNYX
PREPARED BY NTAMBUM
 (B0000/09 NOTAMN
Q)FACA/QMRLC/IV/NBO/A/000/999/3400S02222E005
A)FAGG B)0907251300 C)0911080400 EST
D)MON-FRI 1800-0400, SAT 1300-0400, SUN 1800-0400
E)RWY 11/29 CLSD.)

25 JUL 2009 09:38  IMI=N  PIB=Y  EXIMP=N  DIST=Y
(B0624/09 NOTAMN
A)FAGG B)0907251300 C)0911080400 EST
D)MON-FRI 1800-0400, SAT 1300-0400, SUN 1800-0400
E)RWY 11/29 CLSD.)

06 NOV 2009 16:23
PREPARED BY FAGGTWR
 (FAGG0000/ NOTAMN
A)FAGG B)0911081800 C)0911190400
D)MON-FRI 1800-0400, SAT 1300-0400, SUN 1800-0400
E) RWY 11/29 CLSD DUE REHABILITATION WORK BEING DONE   )

06 NOV 2009 16:47  IMI=N  PIB=Y  EXIMP=N  DIST=Y
(B0949/09 NOTAMN
A)FAGG B)0911081800 C)0911190400
D)MON-FRI BTN 1800-0400, SAT 1300-0400 AND SUN 1800-0400
E)RWY 11/29 CLSD DUE REHABILITATION WIP.)
```

Scope of work performed by aerodrome contractors (Source: consulting engineers):

Maintenance of runway 11/29 and taxiways	***Comments***
The work included the following asphalt repairs and maintenance:	Site establishment started 16 July 2009.
i) Milling and paving of localised failed areas (patching) on runway 11/29 as indicated on drawings and by the engineer on site. The area of patching represents approximately 3,7% of the total surfaced runway area and 7,7% if only the inner 21 m are taken into account.	Sandblasting of taxiways started on 27 July 2009.
ii) Milling and paving of localised failed areas (patching) on taxiway A, taxiway B, the apron taxiway and a section of runway 02/20 as indicated on drawings and by the engineer on site.	Crack sealing started on 4 August and continued for most of the contract period.
iii) Surface treatment of runway shoulders using 30% diluted emulsion. This was applied at an average rate of 0,55 ℓ/m² (calculated on the received records).	SP 2000 started on the apron on 8 August and completed by 3 September.
iv) Surface treatment of taxiway shoulders using MSP3 emulsion.	Trial sections of asphalt started on 14 September on the apron.
v) Surface treatment of runway and taxiway centre sections using polymerised rejuvenator bitumen seal (SP 2000). SP 2000 was tested only in this small trial section, and ultimately was not used for construction purposes.	Runway asphalt was started on 15 October.
vi) Crack sealing as indicated by the engineer.	*Fog-spray application was started on 10 October and completed on 31 October.
vii) Removal and replacing of runway and taxiway paint markings as indicated by the engineer.	Completion date given as 6 November 2009.

Additional maintenance to the runway

1. Determining the number of centreline lights to be removed (sub-contractor).
2. Reinstating the centreline lights.

SS 60 fog-spray was applied to the runway over 22 days. The task was performed in four phases, mostly at night after normal aerodrome operating hours (Source: consulting engineers).

Phase	Date	Location	Vol	Average application rate	Location	Vol	Total
			Litres	**ℓ/m²**		**Litres**	**Litres**
1	10 Oct	Runway edges	20 350	0,57	Taxiway	-	20 350
2	22 Oct	Runway surface	9 500	0,62	Taxiway	1 250	10 750
3	23 Oct	Runway surface	550	0,78	Taxiway	9 550	10 100
4	31 Oct	Runway surface	19 800	0,50	Taxiway	10 800	30 600
			50 200			**21 600**	**71 800**

Total surface area of the runway and both stop-ways (Source: George aerodrome chart).

Paved area	Length (m)	Width (m)	Total surface m^2
Runway 11/29	2 000	45	90 000
Stop-way 11	60	45	2 700
Stop-way 29	60	45	2 700
			95 400

The total quantity of fog-spray applied to the runway and taxiway surfaces during rehabilitation was 71 800ℓ, according to the consulting engineers. The average application rate for the runway surface was 0,58ℓ/m² with a slight run-off observed from the runway edges. The fog-spray application rate was 0,78ℓ/m² for the stop-way of runway 11 (approach runway 29) and 0,75ℓ/m² for the stop-way of runway 29 (approach runway 11) as tabled below (Source: consulting engineers).

Date October 2009	Location	Application rate ℓ/m²	Total m^2	Volume in litres
23	Stop-way 11	0,78	2 700	2 106
30	Stop-way 29	0,75	2 700	2 050
				4 156

The fog-spray application chart for the runway and both stop-ways is attached as Annexure D.

The runway surface was not subjected to any form of cleaning, such as high pressure water or mechanical water brush, once the fog-spray application was completed.

For additional information on fog-spray, refer to Annexure E.

1.10.4 Incident with fog-spray pick-up on aircraft tyres.

According to the project report of April 2010 (ACSA Contract GG/09/18/AB), an aircraft landing at FAGG on 23 October 2009 picked up fog-spray on its tyres. After this incident, fog-spray was applied to the runway only during sunlight.

1.10.5 Runway surface grooving

In 1989, slots were cut into runway 11 west of the intersection of runway 11/29 and the old runway 02/20 (now closed). Their purpose was to allow for water drainage, but they were not cut according to internationally accepted standards for runway grooving, as shown in Figures 14(a) and (b).

The slots were cut at 45° to the centreline, and ran from the centreline to the runway edge for a distance of 120 m westward from a point 36 m west of the western edge of runway 02/20. They were on average 10 mm wide and 55 mm deep, spaced at 1,4 m intervals (measured perpendicularly), and cut only on the right-hand side of the runway. As a result of the pressure of numerous landings, the asphalt had crept and several slots had partially closed up. Cracks had also formed. According to aerodrome officials, the slotted area had been a cause of concern because of inadequate drainage during rainy conditions.

Figure 12: The slots cut into the runway surface at George aerodrome.

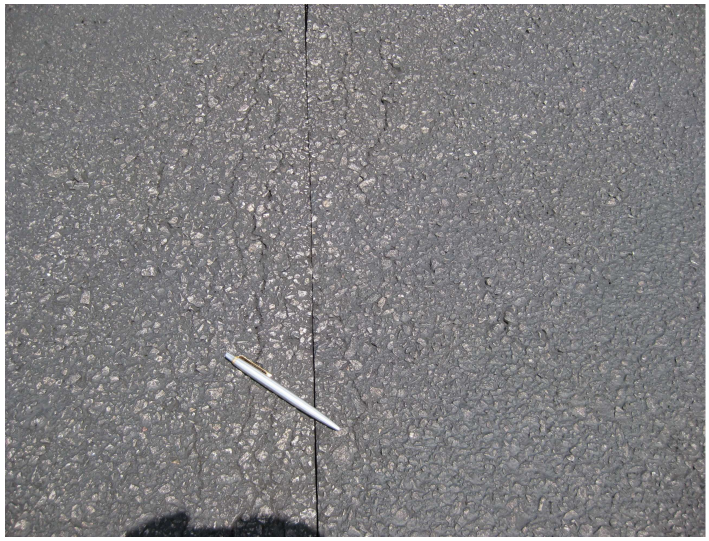


Figure 13: One of the closed-up slots.

Figure 14(a): Example of a properly grooved runway.
The grooves are 3 mm wide, 4 mm deep and 25 mm apart.

Figure 14(b): A fully grooved runway surface in a thunderstorm.

The purpose of grooving is to enhance the natural drainage from the surface as well as the forced drainage from the tyre-to-runway contact area. The grooves:

- provide escape channels for the water in the critical contact area;
- add to the texture of the runway surface;
- can prevent hydroplaning or help to bring hydroplaning to an end;
- do not add to the friction;
- do not change the friction characteristics of the runway surface between the grooves;
- reduce the aggregate surface at the tyre-runway interface.

1.10.6 Runway friction level test

Guidance material supplement to ICAO Annex 14, volume I, section 7, Determination of friction characteristics of wet paved runways, reads as follows:

"7.2 Runways should be evaluated when first constructed or after resurfacing to determine the wet runway surface friction characteristics.

7.3 Friction tests of existing surface conditions should be taken periodically in order to identify runways with low friction when wet. A State should define what minimum friction level it considers acceptable before a runway is classified as slippery when wet and publish this value in the State's aeronautical information publication (AIP). When the friction of a runway is found to be below this reported value, then such information should be promulgated by NOTAM. The State should also establish a maintenance planning level, below which, appropriate corrective maintenance action should be initiated to improve the friction. However, when the friction characteristics for either the entire runway or a portion thereof are below the minimum friction level, corrective maintenance action must be taken without delay. Friction measurements should be taken at intervals that will ensure identification of runways in need of maintenance or special surface treatment before the condition becomes serious. The time interval between measurements will depend on factors such as: aircraft type and frequency of usage, climatic conditions, pavement type, and pavement service and maintenance requirements."

In relation to the above, no evidence could be found that the SACAA (the "State") had defined the minimum friction level for a runway surface when wet, nor was this level published in an AIP as called for above.

1.10.7 Runway friction tests at George aerodrome

On 1 September 2009, a friction test was conducted on the runway and taxiways at FAGG by an independent service provider using a GripTester MK-2, Serial No. GT467. The apparatus had an automated 1,0 mm water filming self-wetting device, meaning that it would deposit a prescribed flow of water 1 mm deep immediately in front of the test tyre. The water was supplied from a 600ℓ reservoir carried at the back of a light utility vehicle that towed the GripTester. This was a new apparatus purchased by the service provider and calibrated by the manufacturer in June 2009 prior to shipment to South Africa.

The GripTester was used to establish values in the ICAO Annex 14, volume I, attachment A, section 7, table A-1 (Friction levels for new and existing runway surfaces), after extensive trials at NASA Wallops Flight Facility in May 1993. This does not imply that the ICAO has approved the friction-measuring device or the associated friction values. It has simply published the information as a guide.

According to the ICAO, it is up to States to decide when a runway is deemed to be slippery when wet.

The relevant ICAO extract reads:

"2.9.6 A runway or portion thereof shall be determined as being slippery when wet when the measurements specified in 10.2.3 show that the runway surface friction characteristics as measured by a continuous friction measuring device are below the minimum friction level specified by the State.
Note – Guidance on determining and expressing the minimum friction level is provided in Attachment A, section 7."

In this context, it should be noted that the UK, as the country where the GripTester is manufactured. UK, CAP 683 provide guidance material on the subject under the heading The Assessment of Runway Surface Friction Characteristics (34). They have developed their own friction-level values based on a test water depth of 0,25 mm.

The South African service provider kept a calibration history of the unit after taking delivery. The measuring tyre is the sensor of the friction-measuring device.

The GripTester is a fixed slippage device with the measuring wheel fitted with a smooth standard tyre geared to rotate at a proportionally different rate to the drive wheels, thereby producing a 14,5% slip relative to these wheels. The drag force induced on the slipping wheel and the vertical force is monitored, and the calculated friction coefficient (called the Grip Number – GN) is logged on a computer file. The GripTester is one of several continuous friction-measuring equipment (CFME) devices recognized in the guidance material supplementary to the Standards and Recommended Practices in ICAO Annex 14, volume I, attachment A, section 7, table A-1.

It should be noted that fundamental reasons for measuring friction are to predict the safe braking profile of the runway surface, the safe travelling speed of the aircraft, and an understanding of the variation in effective friction in longitudinal braking. Friction is not constant and varies as a function of slip speed. For this reason, the use of one friction number can be misleading.

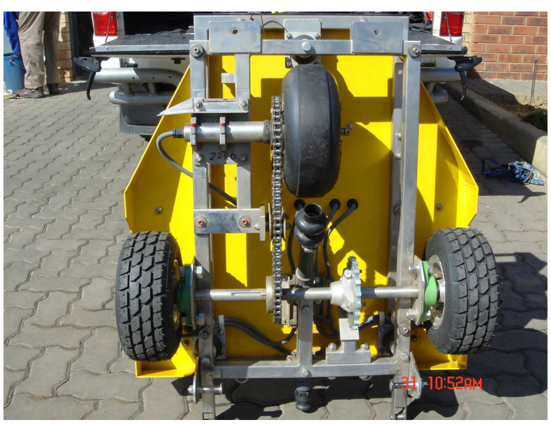


Figure 15(a): Lower section of GripTester MK-2.

Figure 15(b): Machine attached to LUV.

Figure 15(c): Water flow during the testing.

Figure 15(d): Friction test at FAGG.

A runway friction test was conducted at 65 km/h on a dry runway surface on 1 September 2009. Assessment of the data reflects that the average friction level was **0,69**, a value between the design objective level of 0,74 and the maintenance level of 0,53. The tables below reflect the average skid resistance for each friction test run as well as the average of the combined test values for the runway at 65 km/h. The associated graphs for each test run tabled below may be found in Annexure E attached to this report.

Runway 11 intervals	1 m left of centreline	3 m left of centreline	5 m left of centreline	8 m left of centreline	**Average**
Average friction level	0,68	0,69	0,68	0,69	**0,69**

Runway 29 intervals	1 m left of centreline	3 m left of centreline	5 m left of centreline	8 m left of centreline	**Average**
Average friction level	0,67	0,66	0,70	0,68	**0,68**

Average friction level for the runway at 65 km/h	**0,69**

The friction test referred to above was conducted at the request of the sub-contractor earmarked to treat the runway surface with a polymerised rejuvenator bitumen seal, known as SP 2000. The request followed an assessment of the runway surface by an international consulting engineering company.

It was decided to treat a small patch of approximately 30 m² on the western side of runway 29 about 300 m from the start of the runway with SP 2000. The GripTester was then passed over the treated patch during its test runs. Analysis of the data indicated that the friction value had fallen to below the minimum friction level over that patch. Figures 16(a) and (b) display the GripTester data for the entire runway length measured at 1 m and 3 m intervals to the left of the centreline of runway 29 respectively. The downward spike about 300 m from the start of runway 29 showed a significant decrease in friction over the SP2000 treated area. The measurement recorded was below the minimum friction level (MFL) of 0,43 (grip number), and reflected the negative effect of the SP2000 on the skid resistance of the runway.

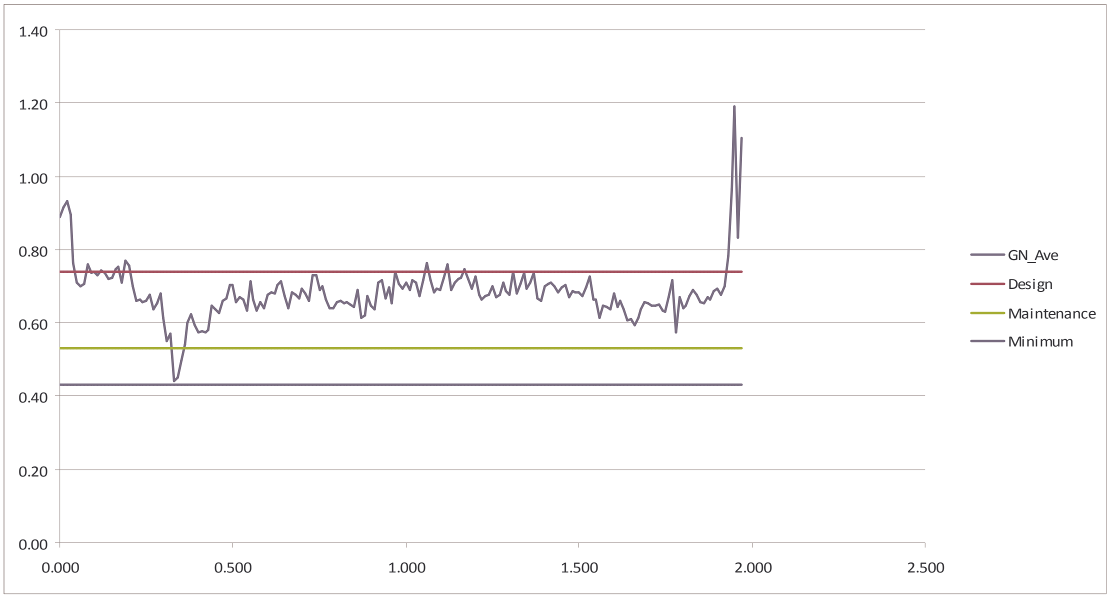


Figure 16(a): Friction test result for runway 29 – taken one metre to the left of the centreline.

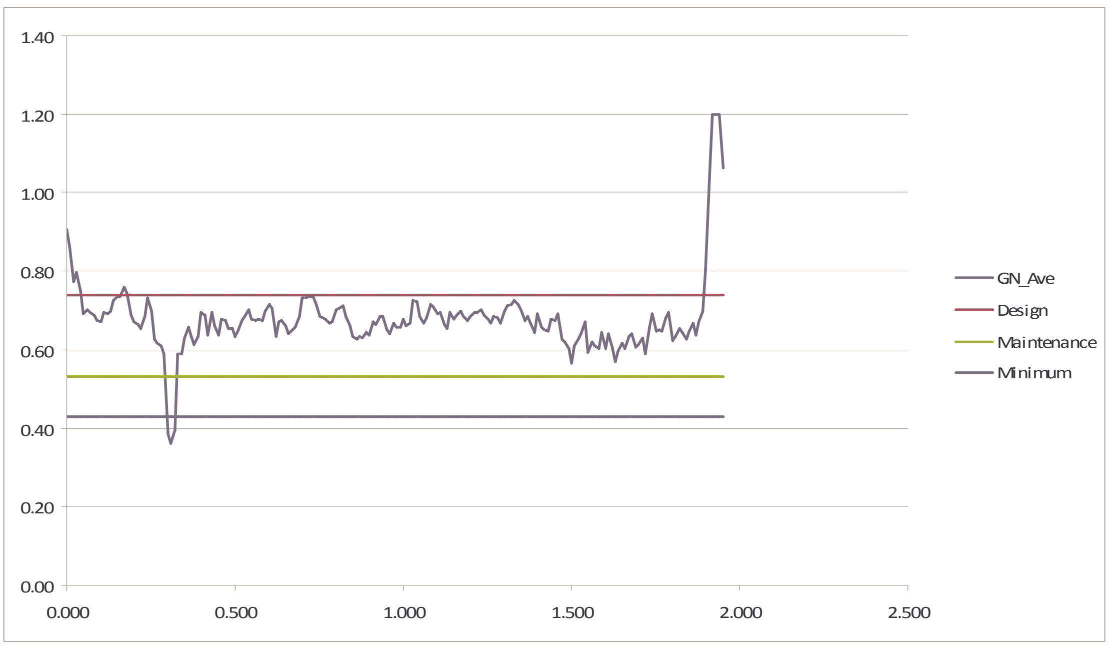


Figure 16(b): Friction test result for runway 29 – taken three metres to the left of the centreline.

Following the evaluation of the data, the sub-contractor forwarded a letter to the contractor stating that he considered their product unsuitable for the rejuvenation of the runway surface. He wrote: *"It is our opinion that the possibility of aquaplaning cannot be ruled out regardless of the fact that no geometric upgrades are made to the existing layout."* The sub-contractor officially withdrew from the project on 4 September 2009.

A replacement product now had to be found and the contractor designated for the task sourced SS 60 stable mix bitumen emulsion fog-spray. This was applied to the runway surface from 10 to 31 October 2009. However, the product was not tested prior to being applied as the SP 2000 had been. A friction test of the runway was conducted only after the entire runway surface had been treated.

The aerodrome licence holder was requested to explain the process of how SS 60 had been sourced. They replied: *"The decision to change the product was taken by SSI who are experienced consulting engineers and not ACSA. ACSA understands from SSI that the main reason for the change was the 'curing time' of SP 2000 which was much longer than that of SS 60."*

The SS 60 emulsion was diluted with water and applied to the runway surface as an enrichment spray. The product is a low-viscosity, anionic, slow-set bitumen emulsion without any dissolving additives, which means that the solid content (the bitumen) will sit on top of most of the aggregate as well as fill the voids of the continuously graded asphalt. As a result, it will reduce the micro- and macro-texture of the runway, both of which are essential for good friction.

In a post-accident report, Arcus Gibb, the engineering consultancy to the aerodrome licence holder, stated: *"The change to a fog-spray was most probably the correct action, as the SP 2000 (thicker surface application with the fine aggregate) would have adversely affected the macro-texture (filling the typical 0,4 to 0,6 mm texture of the continuous grade surfacing layer possible to a 0,2 to 0,4 mm remaining texture); this the too low friction levels as allegedly obtained on the trial of SP2000."*

Following completion of the runway rehabilitation programme and the application of fog-spray, the services of the same GripTester service provider were obtained to conduct a series of skid resistance tests on 6 November 2009, six days after completion of treatment. These were conducted at 1 m, 3 m, 5 m and 8 m intervals left of the centreline on runway 11/29. The skid resistance friction readings for the total runway length reflected an average value of **0,40**, which fell below the minimum friction level (MFL) range of 0,43, according to ICAO Annex 14, volume I, attachment A, section 7, table A-1 for the 65 km/h test.

ICAO Annex 14, volume I states:

"10.2.4 Corrective maintenance action shall be taken when the friction characteristics for either the entire runway or a portion thereof are below a minimum friction level specified by the State.

Note – A portion of runway in the order of 100 m long may be considered significant for maintenance or reporting action.

10.2.5 Recommendation – Corrective maintenance action should be considered when the friction characteristics for or a portion thereof are below a maintenance planning level specified by the State."

The tables below reflect the average value for each friction test run as well as the average of the combined value for the runway at 65 km/h on a dry runway surface. The associated graphs for each test run tabled below may be found in Annexure E of this report.

Runway 11 intervals	1 m left of centreline	3 m left of centreline	5 m left of centreline	8 m left of centreline	**Average**
Average friction level	0,45	0,46	0,43	0,39	**0,43**

Runway 29 intervals	1 m left of centreline	3 m left of centreline	5 m left of centreline	8 m left of centreline	**Average**

Average friction level	0,42	0,41	0,35	0,32	**0,37**

Average friction level for the runway at 65 km/h	**0,40**

On 9 December, two days after the accident, the GripTester was used to perform another series of skid resistance tests on the runway. These were conducted at 65 km/h and at the same runway intervals as the previous two tests. The skid resistance test results reflected an average value of **0,77**, which exceeded the design objective level of 0,74 and were a significant improvement on the readings of 6 November. The associated graphs for each test run tabled below may be found in Annexure E.

Runway 11 intervals	1 m left of centreline	3 m left of centreline	5 m left of centreline	8 m left of centreline	**Average**
Average friction level	0,72	0,72	0,80	0,84	**0,77**

Runway 29 intervals	1 m left of centreline	3 m left of centreline	5 m left of centreline	8 m left of centreline	**Average**
Average friction level	0,72	0,69	0,81	0,84	**0,77**
Average friction level for the runway at 65 km/h					**0,77**

Although the investigating team was still in George at the time of the above-mentioned test, the test was conducted under the auspices of the aerodrome licence holder. No member of the investigating team nor any members of the regulating authority concerned with aerodrome safety were informed by the aerodrome licence holder of the test. These results were made available to the investigating team by the aerodrome licence holder some time after the test was conducted.

On 15 February 2010, another skid resistance test was performed on the runway. This time the tests were conducted at 95 km/h as well as 65 km/h. This was the first 95 km/h test conducted on the runway and therefore no comparisons could be made with previous data. The test data for the 65 km/h test reflects a slight impairment compared with the results of the test of 9 December 2009. The average friction test results reflected a value of **0,70**, which was below the design objective level of 0,74 but above the maintenance planning level of 0,53.

NOTE: The average friction result for this test was 0,01 above the average test result obtained with the 1 September 2009 test (0,69), which was the friction test prior to the application of the fog-spray. The tables below are only applicable to the skid resistance tests conducted at 65 km/h on a dry runway surface. The associated graphs for each test run tabled below may be found in Annexure F.

Runway 11 intervals	1 m left of centreline	3 m left of centreline	5 m left of centreline	8 m left of centreline	**Average**
Average friction level	0,71	0,70	0,71	0,74	**0,72**

Runway 29 intervals	1 m left of centreline	3 m left of centreline	5 m left of centreline	8 m left of centreline	**Average**
Average friction level	0,67	0,65	0,72	0,71	**0,69**

Average friction level for the runway at 65 km/h	**0,70**

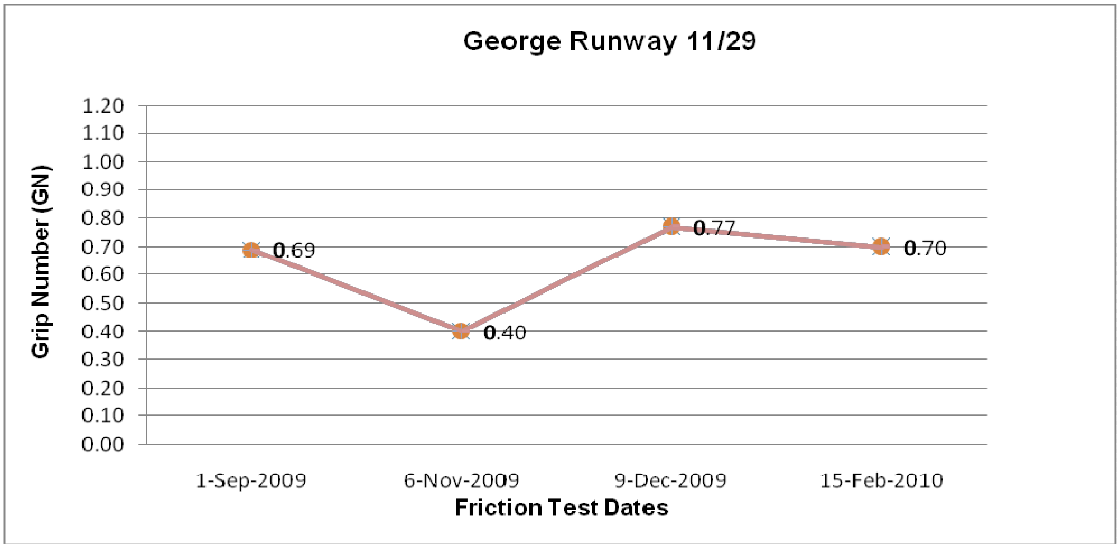


Figure 17: The average friction values for the four tests at a test speed of 65 km/h.

Assessments of the data indicate that the average friction value for the 95 km/h test was **0,66**, which was above the design objective level of 0,64. The table below shows results from the skid resistance tests conducted at 95 km/h.

Runway 11 intervals	1 m left of centreline	3 m left of centreline	5 m left of centreline	8 m left of centreline	**Average**
Average friction level	0,65	0,67	0,65	0,68	**0,66**

Runway 29 intervals	1 m left of centreline	3 m left of centreline	5 m left of centreline	8 m left of centreline	**Average**
Average friction level	0,63	0,64	0,68	0,69	**0,66**

Average friction level for the runway at 95 km/h	**0,66**

NOTE 1: No evidence could be found showing that the CARs Part 139, read with the SA-CATS-AH, had defined the minimum friction levels at 65 km/h and 95 km/h. ICAO Annex 14, volume I requires that friction levels and the type of friction device should be published in the AIP of the State.

NOTE 2: All four 65 km/h friction tests referred to above were conducted by the same service provider, making use of the same GripTester device. The variable results could be attributed to several factors: environmental conditions, the runway surface before and after rehabilitation, the effect of traffic (both aircraft and vehicles) on the runway surface between test dates, and the ageing of the surface following the application of the fog-spray.

The same systems operator performed all the tests with the exception of the first that was conducted on 1 September 2009.

NOTE 3: The average values of all four tests tabled above were calculated using a speed range of between 62 km/h and 68 km/h for the 65 km/h test and 92 km/h and 98 km/h for the 95 km/h test. Therefore the value of the initial phase of the test (acceleration from 0 to 62 km/h) and the deceleration stop at the end of the runway did not form part of the data considered, as it did not meet the standard speed limit restrictions according to ICAO Annex 14, volume I, section 7, attachment A, table A-1.

NOTE 4: The investigator-in-charge had the opportunity to witness the test conducted on 15 February 2010.

1.10.8 Runway macro-texture

The primary function of macro-texture is to provide drainage paths for surface water to disperse beneath the aircraft's tyres. This property becomes more important as:

i. Aircraft speed increases

ii. Tyre tread depth decreases

iii. Water depth increases

All three factors contribute to hydroplaning.

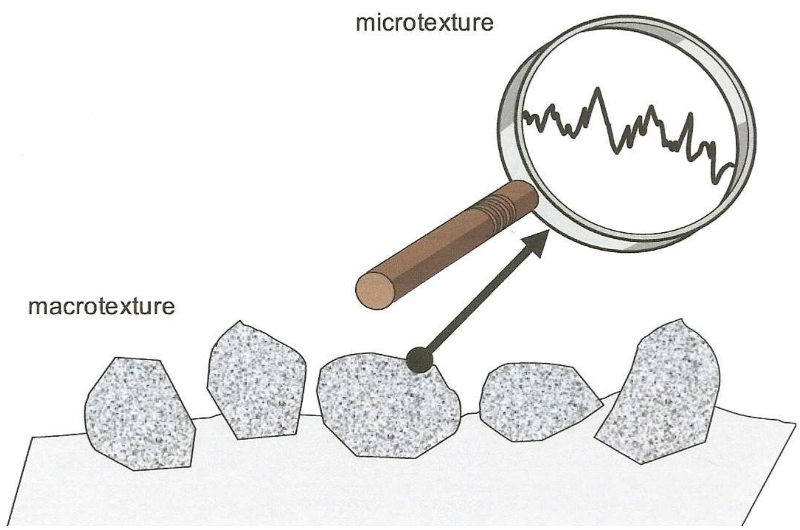


Figure 18: The difference between micro-texture and macro-texture.

Pavement texture depths can only be determined by direct measurements. During a runway inspection conducted on 15 February 2010 by a team of engineers and technicians participating in the investigation, ten sand-patch tests (known as a volumetric patch method) were conducted on the runway surface to obtain data on its macro-texture. The results are tabled below:

No.	Latitude	Longitude	Volume (ml)	Width (mm)	Length (mm)	Texture depth
1	34°0058267	22°3684333	500	500	1465	0,68 mm
2	34°0058150	22°3705983	500	500	2080	0,48 mm
3	34°0057500	22°3725783	500	500	2930	0,34 mm
4	34°0056250	22°3743700	500	500	1760	0,57 mm
5	34°0056983	22°3745283	500	500	2520	0,40 mm
6	34°0054950	22°3781383	500	500	1450	0,69 mm
7	34°0055700	22°3784667	500	500	1770	0,56 mm
8	34°0054733	22°3789333	500	500	4200	0,24 mm
9	34°0055433	22°3790367	500	500	1500	0,67 mm

10	34°0054333	22°3801317	500	500	3020	0,33 mm
Average result of the 10 tests						**0,47 mm**

*NOTE: No similar test was conducted before the application of the fog-spray in October 2009. It was therefore impossible to compare the runway surface macro-texture before and after rehabilitation.

Measuring mean profile depth (MPD)

On 15 February 2009, the MPD of the runway was measured with a Dynatest road surface profiler 5051 Mark II using a laser beam. These tests were conducted along the entire length of the runway at the same intervals from the centreline as before.

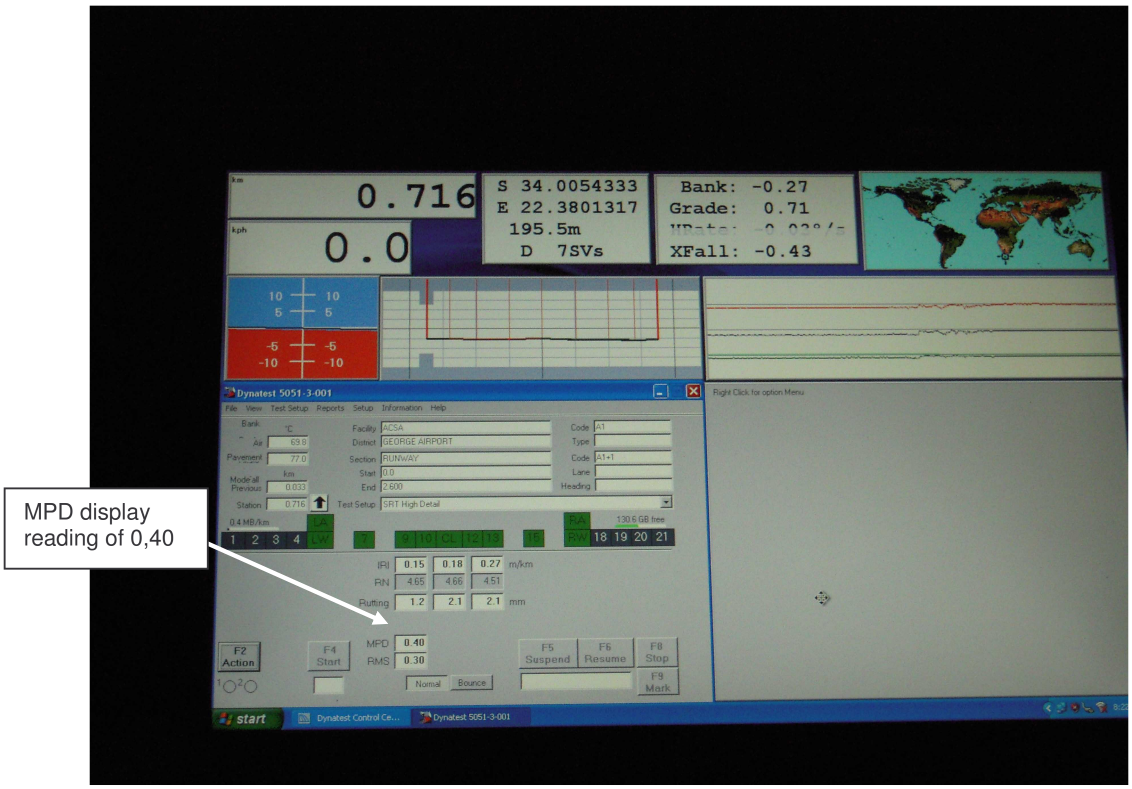


Figure 19: The onboard computer display of the MPD reading of 0,40 and other readings.

Figure 20: The specialised vehicle used for the Dynatest.

The results were obtained from the independent consulting engineering project report dated April 2010. The average texture depth was found to be in the order of 0,63 mm, as shown below. Certain areas on the runway displayed better values than others.

Left				Right			
Distance from centreline				Distance from centreline			
8 m	5 m	3 m	1 m	1 m	3 m	5 m	8 m
0,62	0,73	0,69	0,65	0,65	0,60	0,62	0,55
0,63	0,68	0,71	0,66	0,53	0,67	0,59	0,61
0,58	0,71	0,65	0,84	0,74	0,65	0,69	0,59
0,46	0,70	0,62	0,50	0,56	0,59	0,63	0,45
0,46	0,67	0,63	0,67	0,62	0,64	0,61	0,56
0,56	0,70	0,66	0,67	0,61	0,64	0,64	0,55
0,65 mm (average per half runway width)				0,61 mm (average per half runway width)			

(Source: Independent Consulting Engineering Project Report, dated April 2010)

ICAO Annex 14, volume I, chapter 3, Physical Characteristics, sub-heading 3.1.25, states that the surface texture depth of a new surface should be not less than 1,0 mm. It does not indicate appropriate values that would be suitable for maintenance surveys. Therefore guidance was taken from FAA Advisory Circular 150/5320-12C (shown below). It should be noted that the runway surface in question was not a new surface, therefore the standards in the FAA Advisory Circular were referred to.

ICAO Annex 14, volume I, chapter 3, contains the following standards and recommendations pertinent to the design of the surface of a runway.

*"**Surface of runways***

*3.1.22 The surface of a runway **shall** [investigators' emphasis] be constructed without irregularities that would result in loss in friction characteristics or otherwise adversely affect the takeoff or landing of an aeroplane.*

3.1.23 The surface of a paved runway ***shall*** *[investigators' emphasis] be so constructed as to provide good friction characteristics when the runway is wet.*

3.1.24 Recommendation – Measurements of the friction characteristics of a new or resurfaced runway should be made with a continuous friction measuring device using self-wetting features in order to assure that the design objectives with respect to its friction characteristics have been achieved.
Note – Guidance on friction characteristics of new runway surfaces is given in Attachment A, Section 7. Additional guidance is included in the Airport Services Manual (Doc 9137), Part 2.

3.1.25 Recommendation – The average surface texture depth of a new surface should be not less than 1,0 mm.

Note 1 – This normally requires some form of special surface treatment."

Advisory Circular No. 150/5320-12C issued by the FAA provides the following guidance:

"Paragraph 3-23 Recommended Texture Depths

a. Newly constructed pavements

The recommended texture depths to provide good skid-resistance for newly constructed concrete or asphalts pavement is 0,045 inch (1,14 mm) in the United States of America. A lower value indicates a deficiency in macro-texture that will require correction as the surface deteriorates.

b. Existing pavements

(1) When the average texture depth measurement in a runway zone (i.e., touchdown, midpoint and rollout) falls below 0,045 inch (1,14 mm), the airport operator should conduct texture depth measurements each time a runway friction survey is conducted.

(2) When the average texture depth measurement in a runway zone is below 0,030 inches (0,76 mm) but above 0,016 inch (0,40 mm), the airport operator should initiate plans to correct the pavement texture deficiency within a year.

(3) When the average texture depth measurement in a runway zone (i.e., touchdown, midpoint and rollout) falls below 0,010 inch (0,25 mm), the airport operator should initiate plans to correct the pavement texture deficiency within two months.

c. Retexturing

Retexturing of the pavement surface should improve the average texture depth to a minimum of 0,030 inch (0,76 mm)."

Level (measured by NASA grease smear method	**Average texture**

	depth (mm)
Newly constructed pavements	1,14
Existing pavement – correction within a year when within	0,76 - 0,40
Existing pavement – correction within two months when below	0,25

(Summary of data from FAA Advisory Circular No. 150/5320-12C)

At FAGG, the average macro-texture depth was 0,47 mm according to the sand patch method and 0,63 mm according to the Dynatest profiler. Both these figures fall within the lower end of the FAA's measurements for correcting the pavement texture (0,76 mm to 0,40 mm). According to FAA recommendations, the aerodrome licence holder should start preparing for texture treatment within a year, and minimum texture depths (0,25 mm) should not be exceeded.

It should be also noted that the average macro-texture of 0,47 mm (sand patch) and 0,63 mm (Dynatest profiler) was an average for the entire runway, while the recommendation in the FAA Advisory Circular refers to runway zones (i.e., touchdown, midpoint, and rollout).

1.10.9 Features and functions of micro-texture:

- It is the fine texture of a pavement aggregate and is determined by the nature of the aggregate itself. It is defined as being less than 0,5mm deep.
- Micro-texture is lost over time by the effects of polishing by aircraft and vehicle tyres.
- It is the dominant factor in skid resistance at low speeds.
- Micro-texture provides sliding contact resistance.
- Aggregates that have very fine surface micro-texture and are prone to polishing are generally not used as sealing aggregates.

The micro-texture of the FAGG runway could not be measured during the investigation. It was, however, noted that a large amount of aggregate was coated with bitumen fog-spray. The milled areas contained mostly large, rounded aggregate substantially different in size and shape from the primary runway surface texture.

The following was obtained from the consulting engineering project report No. P02.JNB.000168/02 (GG/09/18/AB dated April 2010):

"7.1 Following a request by the aerodrome management at the airport and in line with normal practice after construction, friction tests were conducted on the runway surface on Friday 6 November 2009, six days after the final fog-spray was applied. The tests were conducted by a service provider using a GripTester Mark 2 at 65 km/h. As expected, the results were disappointingly low due to that fact that the bitumen residue was still very fresh and tender. Even though only 0,5 ℓ/m² bituminous fog-spray was applied (resulting in a film thickness of 0,15 mm), the micro-texture was sufficiently affected to prevent the necessary friction development in a short period of time.

7.3 Caution: It has however also been found that fog-spray negatively affects the friction conditions of the surface immediately after construction and such construction activities should be NOTAMed well in advance for proper safe operational reasons. Longer breaking distance would need to be considered by pilots for at least three weeks after construction, it seems."

1.10.10 Runway transverse slope

The runway transverse slope, also known as the camber, was measured by an independent service provider, who found an average crossfall of 333 mm left and 264 mm right of the centreline of runway 11. These values equate to 1,52% left and 1,20% right of the centreline (they were obtained from the runway map shown below, which was made available by the aerodrome licence holder).

To the right of the centreline of runway 11, in the area of the intersection, the crossfall was only 21 mm to 22 mm. The camber in the slotted area 36 m to the west of the intersection (see 1.10.5 above) was only 0,1%, which to all intents and purposes means that the runway was flat in this area. However, it did have a longitudinal slope of +0,4%.

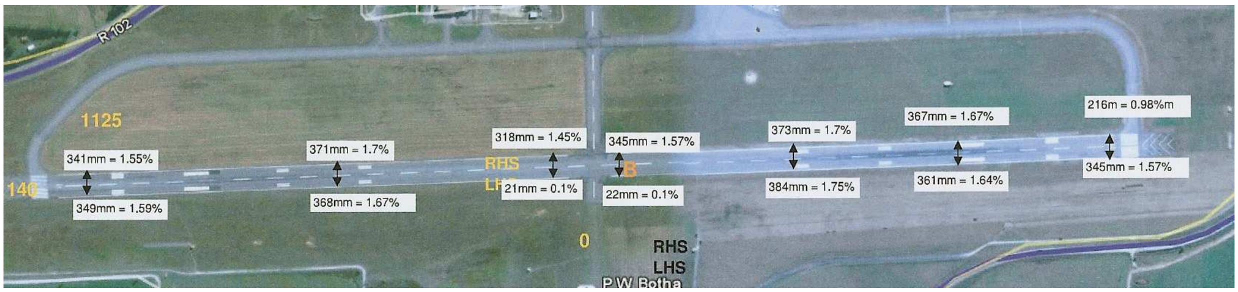


Figure 21: Transverse slope data with values and positions.

In addition to conducting a friction test on 15 February 2010, a laser profile vehicle was used to measure the runway camber and the international roughness index (IRI), the texture logged as the mean profile depth (MPD) as well as surface rutting. The laser profile software clip in Figure 22 includes a photograph from a video clip taken by the onboard camera of the laser profile vehicle. This displayed a runway camber value of 0,1% taken 8 m to the left of the centreline of runway 11 in the area of the intersection.

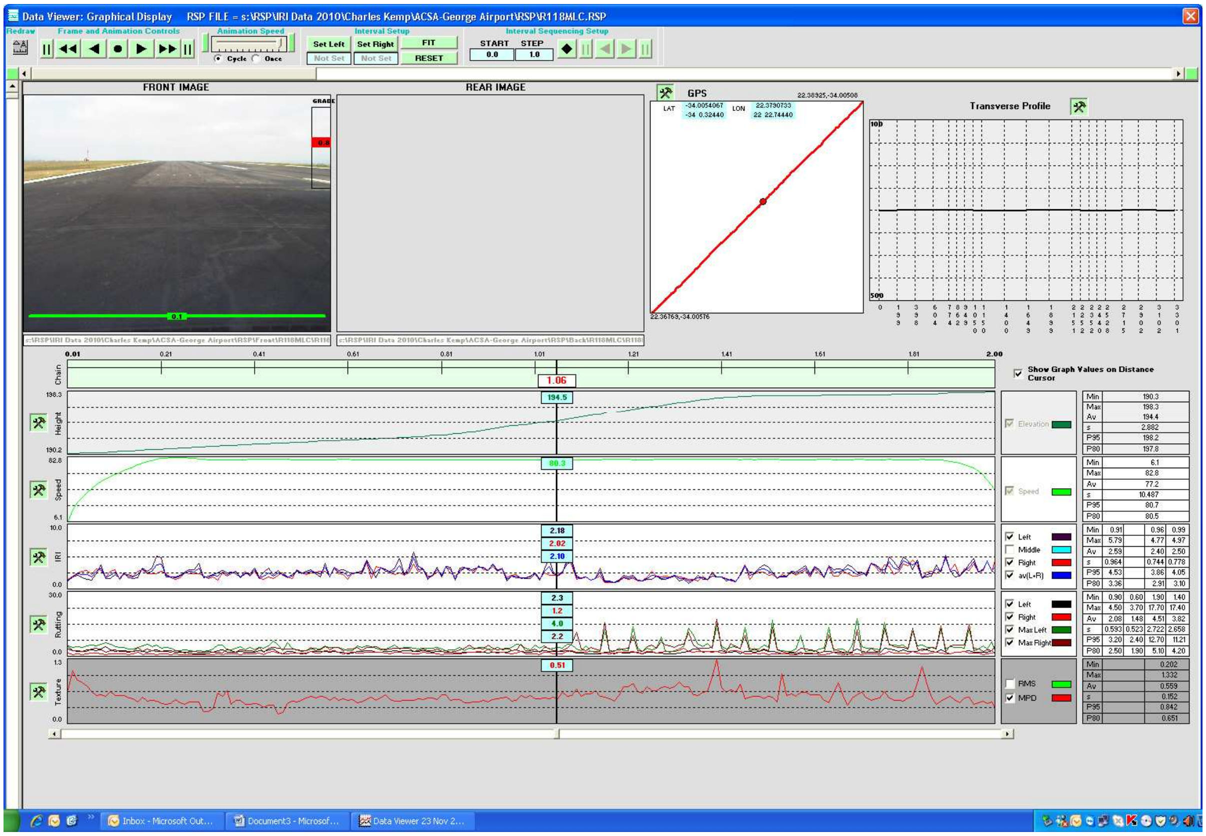


Figure 22: Map page from laser profile software, taken 8 m to the left of the centreline of runway 11.

Explanation of Figure 22

The red line and dot to the right of the photograph shows the location on the runway where the data was captured, supported by a GPS position. To the right of this is the transverse slope profile graph, which here displays a straight line, indicating that the runway surface was basically flat at this location. There are five graphs in the lower section. From the top, they indicate: the distance from the start of the runway (here 1,06 km), the runway elevation, the IRI, the surface rutting, and the MPD (here 0,51). The average MPD for this specific run measured over the entire length of the runway was 0,556 mm. The runway was surveyed by the laser profile vehicle at specific distances from the centreline in both runway directions.

Runway 11/29 at FAGG was a code number 4 and code letter C facility. The international requirements applicable to transverse slopes for such a runway are defined in ICAO Annex 14, chapter 3, recommendation 3.1.19 and 3.1.20:

"3.1.19 Transverse slopes

Recommendation – To promote the most rapid drainage of water, the runway surface should, if practicable, be cambered except where a single crossfall from high to low in the direction of the wind most frequently associated with rain would ensure rapid drainage. The transverse slope should ideally be:

— 1,5% where the code letter is C, D, E or F; and
— 2% where the code letter is A or B;
but in any event should not exceed 1,5% or 2%, as applicable, nor be less than 1% except at runway or taxiway intersections where flatter slopes may be

necessary. For a cambered surface the transverse slope on each side of the centreline should be symmetrical.

Note – On wet runways with crosswind conditions the problem of aquaplaning from poor drainage is apt to be accentuated. In Attachment A, Section 7, information is given concerning this problem and other relevant factors.

3.1.20 Recommendation – The transverse slope should be substantially the same throughout the length of a runway except at an intersection with another runway or a taxiway where an even transition should be provided taking account of the need for adequate drainage.

1.10.11 Runway repairs (milling and paving of failed areas)

Several areas on the runway had been repaired (the patches were backfilled). These areas were clearly visible as the aggregate used (continuously graded NMAS 19.0) was substantially larger than that of the primary runway surface texture. The predominant aggregate in the repaired sections had a pebbled appearance in contrast to the well-compacted primary runway surface texture.

Figure 23(a): A milled area on the runway.

Figure 23(b): Close-up of the milled aggregate, which was 15-20 mm in diameter.

1.10.12 Runway surface evenness

On 16 March 2010, an area of runway 11 about 402 m from the end of the runway and approximately two metres to the right of the centreline (geographical co-ordinates S34°00'19.31" E022°23'05.95") was selected at random. Two containers, each containing 20 litres of water, were emptied here to observe the water runoff. Most of the water formed a puddle on the runway surface 3 m to 4 m in diameter. The ARFF personnel were requested to measure its depth, and employed two methods to do so:

- A special ruler used as a "dipstick";
- Three security access cards placed on top of each other and laid flat on the runway surface. As each card was 1 mm thick, the depth of the puddle could be ascertained to be between 2,5 mm and 3 mm.

After a substantial period, the water slowly ran off towards the left of runway 29. The runway camber in this area of the runway was measured to be above 1,5%, which should have indicated good drainage.

This test was conducted following an observation made during a runway inspection on 12 March 2010, during which it was raining. Puddles were found over the entire length and width of the runway surface, but mostly at the runway intersection, where the active runway 11/29 and old runway 01/19 (now a closed runway) cross. This was attributed to a relatively flat runway surface with very little camber in this area. The presence of puddles was confirmed by a Boeing 737-400 pilot performing landing and rejected takeoff tests on the same day. His observations are documented in 1.16.5.

Unfortunately, as the area had been declared a disaster area because of drought, the investigators were unable conduct a thorough evaluation of the surface by using water tankers to wet the entire runway.

ICAO Annex 14, volume I, Aerodromes, attachment A, section 5 states the following on runway surface evenness:

"5.5 Deformation of the runway with time may also increase the possibility of the formation of water pools. Pools as shallow as approximately 3 mm in depth, particularly if they are located where they are likely to be encountered at high speed by landing aeroplanes, can induce aquaplaning, which can then be sustained on a wet runway by a much shallower depth of water. Improved guidance regarding the significant length and depth of pools relative to aquaplaning is the subject of further research. It is, of course, especially necessary to prevent pools from forming whenever there is a possibility that they might become frozen."

Figure 24: The puddle of water on the runway and the subsequent runoff to the left of the runway.

Measuring standing water on runways

The aerodrome licence holder's standard procedure for measuring standing water on runways is as follows:

- *"An ATC member initiates the procedure by means of a request for standing water reading to be carried out, by contacting the aerodrome licence holder Aerodrome Rescue Fire Fighting Services (ARFFS) Watch Tower/Room.*
- *The ARFFS member on duty in the Watch Tower/Room dispatches a vehicle to carry out the water reading duties in the areas requested by ATC.*
- *The designated ARFFS member/s collect/s the water depth meter/ruler and proceed/s to the areas where water easily collects. This includes the follow areas:*
    - *the threshold;*
    - *touchdown area;*
    - *exits of runways;*
    - *RWY rapid exit taxiways;*
    - *pooling areas/standing water etc.*
- *The ARFFS member/s carrying out the water reading duties establishes radio contact with the ATC Ground Controller.*
- *The ATC Ground Controller instructs/directs the ARFFS member/s to the location/s where the reading/s is/are required.*
- *The ARFFS member/s carries out the water readings as requested."*

The second-last point above states that the ATC ground controller is required to instruct or direct the ARFFS member on where to measure standing water. The investigators found this to be problematic as maintenance of the runway surface is not ATCs' primary function and their knowledge in this respect is questionable. By contrast, ARFF personnel perform several runway inspections daily and have a far more detailed knowledge of runway surfaces.

1.10.13 Runway end safety area (RESA)

The purpose of a RESA is to reduce the risk of damage to an aircraft while it is undershooting or overrunning the runway – either during landing or an aborted takeoff – by enhancing deceleration. It also facilitates the movement of rescue and fire-fighting vehicles. There was no RESA provided in the overrun area of runway 11 at FAGG, nor was this fact published in the AIP.

ICAO Annex 14, volume 1, chapter 3 requires the following as a standard:

"General

3.5.1 A runway end safety area shall be provided at each end of a runway strip where:

– the code number is 3 or 4; and
– the code number is 1 or 2 and the runway is an instrument one.

Dimensions of runway end safety areas

3.5.2 A runway end safety area shall extend from the end of a runway strip to a distance of at least 90 m.

3.5.3 Recommendation – A runway end safety area should, as far as practicable, extend from the end of a runway strip to a distance of at least:

– 240 m where the code number is 3 or 4; and

– 120 m where the code number is 1 or 2.

3.5.4 The width of a runway end safety area shall be at least twice that of the associated runway.

3.5.5 Recommendation – The width of a runway end safety area should, wherever practicable, be equal to that of the graded portion of the associated runway strip.

3.5.6 Recommendation – An object situated on a runway end safety area which may endanger aeroplanes should be regarded as an obstacle and should, as far as practicable, be removed.

3.5.7 Recommendation – A runway end safety area should provide a cleared and graded area for aeroplanes which the runway is intended to serve in the event of an aeroplane undershooting or overrunning the runway.

Note – The surface of the ground in the runway end safety area does not need to be prepared to the same quality as the runway strip. See, however, 3.5.11.

3.5.8 Recommendation – The slopes of a runway end safety area should be such that no part of the runway end safety area penetrates the approach or takeoff climb surface

3.5.9 Recommendation – The longitudinal slopes of a runway end safety area should not exceed a downward slope of 5%. Longitudinal slope changes should be as gradual as practicable and abrupt changes or sudden reversals of slopes avoided.

3.5.10 Recommendation – The transverse slopes of a runway end safety area should not exceed an upward or downward slope of 5%. Transitions between differing slopes should be as gradual as practicable.

3.5.11 Recommendation – A runway end safety area should be so prepared or constructed as to reduce the risk of damage to an aeroplane undershooting or overrunning the runway, enhance aeroplane deceleration and facilitate the movement of rescue and fire fighting vehicles as required in 9.2.30 to 9.2.32.

On runway 11, the overrun area (along the extended centre line) consisted of a grass-covered slope angled downwards at approximately 5°. There were two major upstanding obstacles in this area: the ILS localiser antenna on a concrete base 163 m beyond the stop-way end, and the aerodrome perimeter fence – wire mesh supported by wooden poles of about 15 cm in diameter.

The pilot managed to steer the aircraft to the right of the antenna but was unable to bring it to a stop on the slope. It crashed through the fence, suffering substantial damage to its structure.

The scheduled airlines using FAGG operated a variety of aircraft. These comprised mostly the Boeing 737-300/400/800 series, the MacDonnell Douglas MD-82, the Bombardier Dash 8-Q400 and CRJ-200/700, and the Embraer 135-LR.
Taking these aircraft types into consideration, the ICAO standard mandates that a RESA of 90 m should be provided at each end of the runway strip at FAGG (aerodrome code number 4). There was no RESA documented in the AIP for FAGG at the time of the accident.

A 60 m asphalt stop-way was located at the end of the runway 11. Between the edge of this stop-way and the localiser antenna was an open grassy area of 163 m sloping downwards at approximately 5°. The antenna was in line with the extended centreline of the runway and fell within the 240 m runway end safety area recommended in paragraph 3.5.3 of ICAO Annex 14, volume I for a code number 3 or 4 runway. Figure 25 below shows the antenna and part of this open area.

Figure 25(a): A view from behind the ILS localiser antenna looking towards the runway

Figure 25(b): A side view of the antenna.

1.10.14 Runway inspection by ARFF personnel

According to the FAGG ARFF daily log sheet of 7 December 2009, which commenced at 0400Z (the start of the ARFF shift), the first runway inspection was conducted at 0606Z. At 0813Z, another runway inspection was conducted and the runway surface was evaluated as "serviceable but wet". This information was communicated to the ATC. No water reading was taken on the runway surface prior to the landing of flight SA8625. The first water reading on the runway was conducted more than two hours after the accident, prior to the re-opening of the runway, when a reading of between 2 mm and 3 mm was measured. It should be noted that ARFF personnel were denied access to the runway by the ATC at 0713Z but were able to conduct an inspection one hour later at 0813Z. It started raining in the area at approximately 0700Z, two hours prior to the landing of flight SA8625.

Below: the ARFF occurrence log sheet for 7 December 2009.
(All times displayed in this log sheet indicate SA Standard Time = UTC+2 hours).

Date	**7 December 2009**
Time	**Occurrence**
06:00	Fire and rescue duty team reports for duty.
06:06	**FV2 (Foxtrot Victor 2, a fire vehicle), with one fire crew member on board, conducts morning runway inspection.**
06:08	One fire crew member on watch-room duty, all in order.
06:10	Vehicles and equipment checked, all in order.
06:38	Tested radios, phones, gate and alarm – all in order.
06:40	FV2 reports on radio that the apron, runway and taxiways are clean, serviceable.
09:13	**Runway inspection is denied by ATC via telephone conversation.**
09:33	Person 1 goes off watch-room duty.
09:34	Person 2 commences with watch-room duties.
10:13	**Runway inspection is conducted.**

10:20	**Reports runway serviceable but wet.**
11:00	Phase 3 called for Embraer, ZS-SJW, aircraft off runway – threshold 29.
11:06	Request for ECC that traffic department must assist with flow of traffic at accident scene. ZS-SJW on national road.
11:07	Request bus to pick up pax.
11:09	Survivors to fire station.
11:17	Pilot freed from the cockpit.
11:20	RD for foam under the aircraft.
11:23	RD reports all pax out of aircraft.
12:30	Second fire team reports for duty.
12:59	Head of Operations Airside requests a water reading.
13:01	Runway inspection is performed.
13:02	B1 fire & rescue at the fire station – George municipal fire services.
13:05	ATC calls and says there is a diversion 737, MN241.
13:09	**R3 reports runway 11/29 serviceable, 2-3 mm water reading, standing water.**
13:10	ATC calls with a diversion.
13:14	B1 Fire Rescue – 450ℓ concentrate.
15:38	R2 conducts runway inspection and water reading.
15:44	**R2 reports at the fire station with 2-3 mm standing water – serviceable**
16:27	Person off tower duty.
16:30	**FV2 runway inspection follows + water readings at intersection.**
16:35	**Water readings at 3 mm.**
17:50	FV2 conducts water readings at the intersection.
18:00	**Water readings at 3 mm at intersection.**

Source: Aerodrome Rescue and Fire-Fighting Services, Occurrence Book, Daily Log Sheet, ACSA George.

According to ICAO Annex 14, volume I, chapter 2, Aerodrome Data in Recommendations, 2.9.4 to 2.9.8, it is recommended that an inspection be carried out to monitor water on the runway.

"Water on a runway

2.9.4 Recommendation – Whenever water is present on a runway, a description of the runway surface conditions on the centre half of the width of the runway, including the possible assessment of water depth, where applicable, should be made available using the following terms:

DAMP — the surface shows a change of colour due to moisture.

WET — the surface is soaked but there is no standing water.

WATER PATCHES — significant patches of standing water are visible.
FLOODED — extensive standing water is visible.

2.9.5 Information that a runway or portion thereof may be slippery when wet shall be made available.

2.9.6 A runway or portion thereof shall be determined as being slippery when wet when the measurements specified in 10.2.3 show that the runway surface

friction characteristics as measured by a continuous friction measuring device are below the minimum friction level specified by the State.
Note – Guidance on determining and expressing the minimum friction level is provided in Attachment A, Section 7.

2.9.7 Information on the minimum friction level specified by the State for reporting slippery runway conditions and the type of friction measuring device used *__shall__* *be made available.*

2.9.8 Recommendation – When it is suspected that a runway may become slippery under unusual conditions, then additional measurements should be made when such conditions occur, and information on the runway surface friction characteristics made available when these additional measurements show that the runway or a portion thereof has become slippery."

In relation to the above (specifically Standards 2.9.6 and 2.9.7), no evidence could be found which indicated that the CARs, read in conjunction with the SA-CATS-AH, had defined the minimum friction level and had published it in the AIP as specified in ICAO Annex 14, volume I.

1.10.15 Runway and approach lights

The runway and approach lights were ON to assist the incoming aircraft with the approach and landing. There was no report of any anomaly experienced with the visibility or serviceability of the lights by the flight crew.

1.11 Flight recorders

1.11.1 Cockpit voice recorder (CVR)

The accident aircraft was equipped with a Honeywell CVR, part number 980-6022-001 and serial number CVR120-03737. This was a solid-state recording device with a storage capacity of approximately two hours. An external examination revealed that the unit was in a good condition, as can be seen in Figure 26. The underwater locator beacon (ULB) or pinger was undamaged. The unit was sent to the Air Accidents Investigation Branch (AAIB) audio laboratory in the UK for readout and evaluation, and all relevant data was transcribed in full. The recording lasted for 30 minutes and 17 seconds and included the approach and landing sequence of the accident flight.

Figure 26: The cockpit voice recorder recovered from the aircraft.

1.11.2 Digital flight data recorder (DFDR)

ZS-SJW was equipped with a Honeywell solid-state DFDR, part number 980-4700-042 and serial number SSFDR-07717. The unit was undamaged and there was no apparent impact damage to the ULB, which remained attached to its bracket. A recorder of this type can be downloaded directly without disassembly if there is no damage to the memory module connectors. The unit showed no signs of external damage and the memory board, was found to be in pristine condition. The memory modules, with a 25-hour recording capacity, were successfully downloaded and the data forwarded to Brazil (the State of design and manufacture) for analysis.

Figure 27: The flight data recorder recovered from the aircraft.

1.11.3 FDR data summary:

08:58:05	The aircraft entered the intermediate approach segment with a speed of around 185 kt indicated airspeed (KIAS) and the flaps retracted.
08:58:10	It rolled out on a magnetic heading of 110° and maintained this heading with a slight deviation of approximately 1° to either side until touchdown.
08:58:30	9° of flaps were selected. Airspeed was about 190 KIAS.
08:58:50	The glideslope was intercepted. Airspeed was about 190 KIAS.
08:58:58	The landing gear was selected to the down position.
08:59:00	22° of flaps was selected with the airspeed at about 185 KIAS.
08:59:27	The aircraft crossed the final approach fix.
08:59:34	Autopilot was disengaged, and airspeed maintained at about 170 KIAS.
08:59:40 to 09:00:10	The glideslope deviation moved from 0 to 1 dot high.
09:00:02	The thrust lever angle was moved to idle. Airspeed was at about 170 KIAS and pressure altitude was about 1 500 ft (878 ft AGL).
09:00:05 to 09:00:30	The aircraft pitch increased from -1° (nose down) to 3° (nose up) with the thrust levers still at idle. Glideslope deviation increased from 1 dot high to 2,5 dots high. Airspeed reduced from about 170 to 140 KIAS.

Figure 28: This animation snapshot depicts the aircraft at 581 ft AGL at 143 KIAS.

09:00:30	Full flaps of 45° were selected and thrust levers were moved forward, maintaining about 140 KIAS. Pressure altitude was 1 168 ft (546 ft AGL).
09:00:40	Flaps remained fully down. Pressure altitude was 998 ft (376 ft AGL).
09:00:45	Glideslope deviation returned to 1 dot high at about 900 ft pressure altitude (278 ft AGL).
09:00:55	Glideslope deviation returned to 0 dots at about 800 ft pressure altitude (178 ft AGL).
09:01:02	The aircraft crossed the threshold at a height of 50 feet on the radio altimeter with the speed at 143 KIAS (see Figure 29).

Figure 29: The aircraft 50 ft above the runway threshold at 143 KIAS.

09:01:04 Thrust levers were reduced to idle.

09:01:09 Air/Ground sensors transitioned to “ground” mode for a short period and returned to “air” mode (cycle time of 1,5 seconds). The airspeed indicated was 134 KIAS. (Figure 30 indicates the first touchdown point on the runway, with the aircraft in “ground” mode).

Figure 30: The touchdown point on the runway, with the aircraft in ground mode.

09:01:11 Air/ground sensors transitioned to “ground” and remained in that position for the rest of the landing rollout. Airspeed was about 130 KIAS. The ground spoilers also deployed, and remained so for the landing rollout.

09:01:15 First brake pressure increased four seconds after the aircraft remained in ground mode during the landing rollout. The average brake pressure during the rollout on the runway surface was 427 pounds per square inch (psi).

09:01:21 to
09:01:33 The longitudinal acceleration (g) displays a zigzag pattern that varies between -0,051g to -0,178g (average deceleration over this period was calculated to be -0,106g) with a variation in brake pressure of between 100 to 750 psi (see Figure 31 – applicable area between the two vertical lines; for a detailed DFDR graph, see Figures 32(a) and (b).

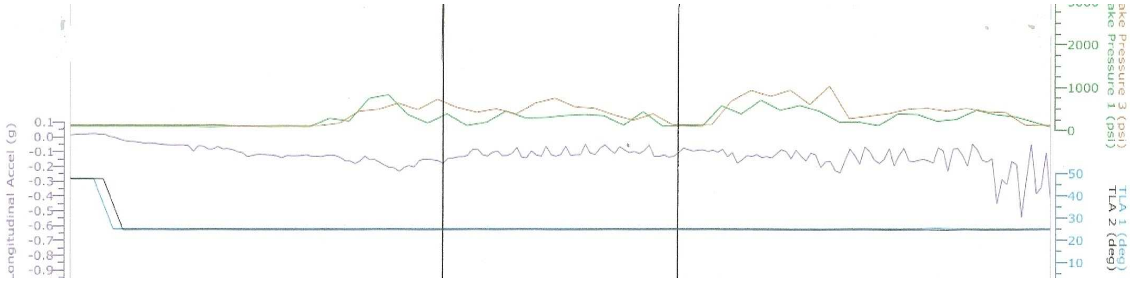


Figure 31: Longitudinal acceleration (g) of ZS-SJW during landing rollout.

09:01:33 to 09:01:35	Little to no brake pressure recorded.
09:01:41	A sudden increase in brake application, with a maximum pressure of 1 040 psi recorded towards the end of the landing rollout prior to the aircraft departing the 60 m stop-way asphalt surface.
09:01:42	Vertical acceleration pattern changed (in all likelihood due to the aircraft's departure from the runway/paved surface) at about 52 KIAS.
09:01:52	The DFDR stopped recording ten seconds after the aircraft left the pavement surface.

DFDR timings, longitudinal accelerometer data, and recorded groundspeed were used for various calculations. It was determined that the aircraft had first touched down in the area of the third landing marker. The aircraft then transitioned back into "air" mode for 1,5 seconds, after which it touched down again and remained in ground mode. The spoilers deployed immediately and remained deployed for the entire ground rollout. This was observed on footage from aerodrome surveillance cameras installed on the terminal building and positioned to cover the apron area.

A review of the aircraft systems data did not show any failures that would have degraded the stopping performance of the aircraft.

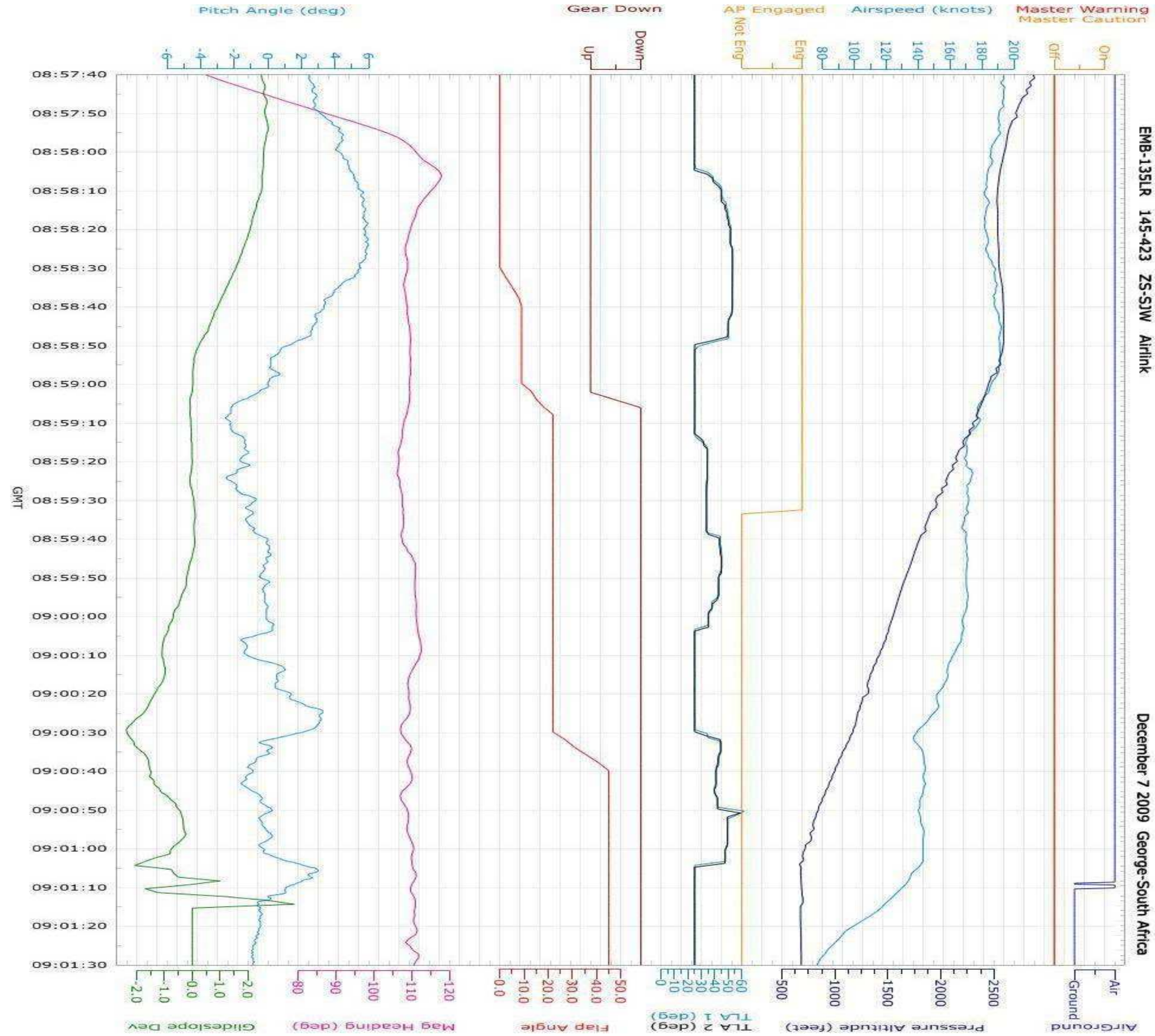


Figure 32(a): DFDR parameter data for the flight from approximately four minutes before landing until shortly after touchdown.

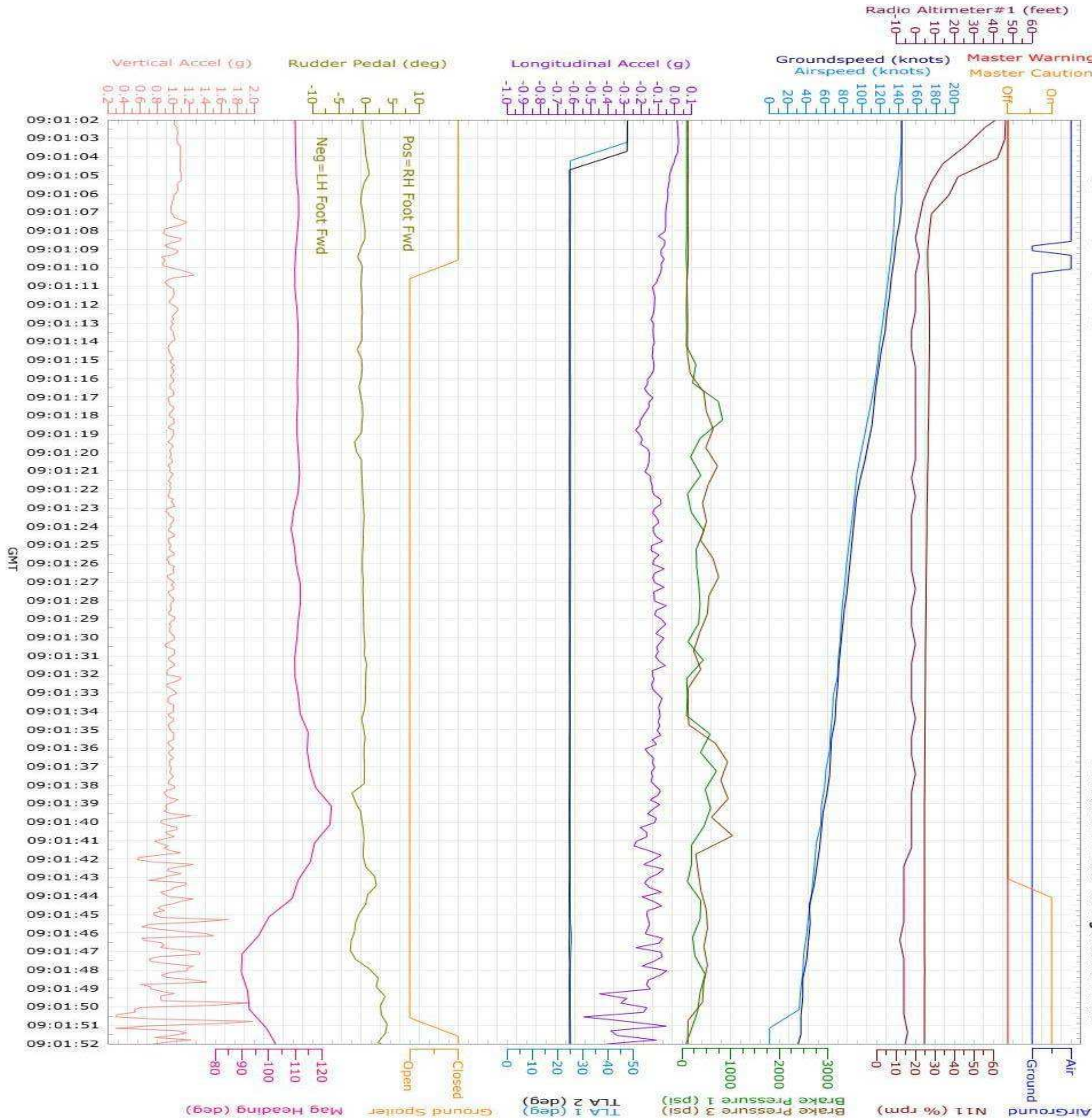


Figure 32(b): DFDR parameter data for the flight from eight seconds before landing until the unit stopped recording.

Figure 33: The landing sequence of the aircraft. Distances are estimates, based on DFDR data.

1.11.4 Tailwind component on final approach

The high IAS on final approach and a higher-than-normal rate of descent show that there was a tailwind component.

Explanation:

- A tailwind component produces a higher groundspeed.
- A higher groundspeed necessitates a higher rate of descent as height must be lost in less time from interception of the glideslope to touchdown.
- A higher rate of descent produces an increase in IAS.

The following data was obtained from the DFDR by comparing the aircraft's IAS with its groundspeed (GS). It was established that a significant tailwind component existed for the greater part of the intermediate and final approach sector of the flight.

DFDR data line	Time	IAS (kt)	Ground-speed (kt)	DME (nm)	Tailwind (kt)	Headwind (kt)	Notes
14	08:57:44	194	205	10,0	11		
22	08:57:52	190	209	9,6	19		
34	08:58:04	186	205	9,0	19		
42	08:58:12	182	202	8,5	20		
54	08:58:24	184	204	7,9	20		
62	08:58:32	188	208	7,4	20		
74	08:58:44	191	212	6,6	21		
86	08:58:56	191	212	6,0	21		Aircraft intercepts the glideslope
94	08:59:04	181	205	5,5	24		
102	08:59:12	176	195	5,1	19		
114	08:59:24	174	186	4,5	12		
122	08:59:32	171	181	4,0	10		Autopilot disengaged
134	08:59:44	170	175	3,5	4		
146	08:59:56	171	177	2,9	6		
154	09:00:04	169	173	2,5	4		
166	09:00:16	159	162	2,0	3		
178	09:00:28	146	148	1,5	2		
190	09:00:40	145	146	1,0	1		
202	09:00:52	141	139	0,5		2	
214	09:01:04	143	143	0	-	-	

According to the ATC transcript, no mention was made of a tailwind component on final approach for runway 11. The ATC obtains basic wind data from the automated weather observing system (AWOS) at the aerodrome, which at FAGG is surface data. It is therefore impossible for the ATC at FAGG to provide flight crew with upper wind data.

Wind direction and speed is provided to the controller in digital format and as an instantaneous two-minute and ten-minute average.

When the aircraft was between 4,5 DME GEI and 1 DME GEI, the tailwind component diminished rapidly to a point where it changed to a headwind seconds before the aircraft touched down.

1.12 Wreckage and impact information

1.12.1 Impact information

Tyre markings from the left and right main gear as well as the nose gear were evident to the right of the centreline towards the end of runway 11. The markings continued beyond the 60 m asphalt stop-way area and onto a grassy area that sloped downwards at approximately 5°. The pilot managed to avoid hitting the ILS localiser antenna on a concrete platform 163 m past the end of the stop-way by swerving to its right.

Figure 34: The tyre tracks indicating where the aircraft overran the runway surface onto the stop-way.

Figure 34 shows curved, light-coloured tracks from the tyres of the accident aircraft. These have the characteristics of viscous hydroplaning as described in the NTSB-AAR-73-13 report, of which a brief summary is contained in paragraph 1.18.8.

As can be seen, the wheels of the landing gear rolled between and alongside the last row of approach lights for runway 29. Information from the DFDR data indicates that the aircraft moved slightly left of the centreline before rolling to the right and departing from the runway surface.

After the aircraft left the runway to the right at the end of runway 11, it crossed the grassy area to the right (as seen from the cockpit) of the approach lights and rolled onto runway 29 and towards the ILS localiser antenna. It then struck and destroyed two approach lights in the second row and damaged a third. This set of lights comprised three frangible light towers, individually mounted on cast concrete pillars and arranged at right angles to the runway centreline.

Figure 35: The ILS localiser antenna and damaged approach lights.

The aircraft now turned slightly to the left, heading for the remaining approach lights, and struck and destroyed another three lights similar to the others. During the collision, the nose gear hit the concrete pillar of the centre light and collapsed.

Skidding on its nose, the aeroplane struck and destroyed the three central approach lights of the fourth row and damaged another. These four lights were similar in design to the others.

The aircraft then crashed through the aerodrome perimeter fence – wire mesh supported by wooden poles – destroying a 100 m section, including six poles.

After bursting through the fence, the aeroplane skidded down a 4,6 m high embankment, and came to rest in a nose-down attitude on the R404 public road (connecting Heralds Bay and George) that runs parallel to the fence on the eastern side of the aerodrome. The road had to be closed until the wreckage was recovered three days later. The aircraft travelled 278 m from the edge of the runway until the fence.

A small amount of debris, consisting mostly of landing gear door parts, was found on the grassy area near the edge of the embankment.

Figure 36: The damaged approach lights are visible in the foreground.

Figure 37: Final position of ZS-SJW.

1.12.2 Fuselage

No break-up of the aircraft occurred. However, there was substantial deformation of the lower front fuselage sections I and II, including the nose and cockpit. The nose section was completely destroyed up to station 2364.0. There was also considerable damage to the cockpit section between stations 2364.0 and 4154.5. This was caused when the nose gear collapsed after striking the concrete pillar supporting the approach light and when the aircraft skidded down the embankment onto the roadway.

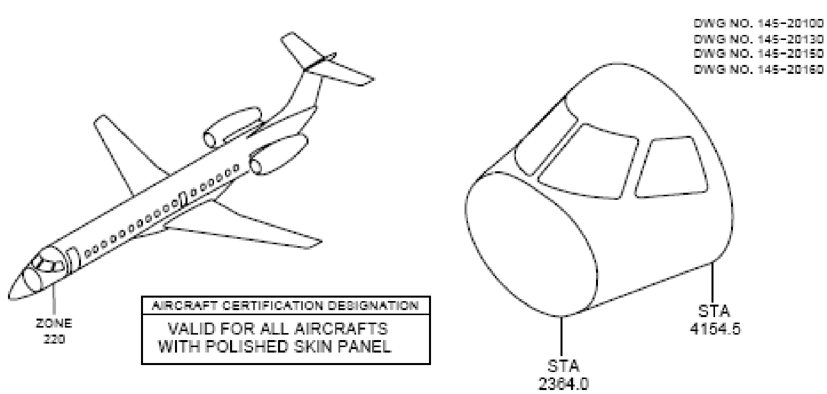


Figure 38: The damaged sections at the front of the aircraft.

The centre section of the aircraft sustained very little damage. Substantial damage was caused to the rear fuselage lower sections I and II, which excludes the vertical and horizontal stabilisers and the engines. This was located between stations 20793.0 and 25581.0.

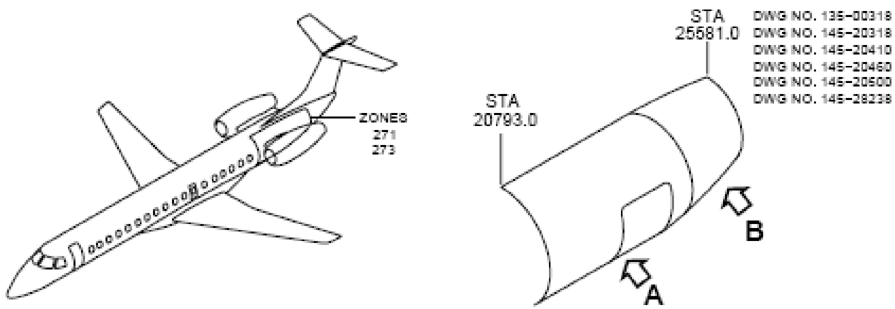


Figure 39: The damaged sections at the rear of the aircraft.

1.12.3 Wings

Both wings remained attached to the aircraft and all flying controls attached to them were undamaged. The flaps on both wings were found to be in the fully extended position (45° down). On the right wing the two outer Vortilon assemblies (four yellow bayonet-type assemblies installed below the wing to reduce wing tip vortices) were sheared off; those on the left wing were undamaged. The leading edges of both left and right wings sustained damage as a result of impact from the approach lights, support poles and perimeter fence poles. Damage to the upper and lower skin surfaces on the wings was limited.

Figure 40(a): Damage to the right wing leading edge.

Figure 40(b): Damage to the left wing leading edge.

1.12.4 Empennage/Stabilisers

No impact damage was visible on the horizontal stabiliser, elevators or vertical stabiliser.

1.12.5 Aircraft engines and auxiliary power unit (APU)

Visual examination of the two engines revealed no impact abnormalities. A very limited amount of organic material was found in the lower engine cowling area. There was no evidence that the engines had ingested any foreign objects. After the aircraft was recovered, the necessary panels were removed and the APU inspected. No impact damage was found. .

1.12.6 Emergency exit doors

Neither over-wing emergency exit door shows signs of damage. Only the left-hand door had been removed as an escape route as no passengers had been seated in seats 9 B, C, where the right-hand over-wing emergency exit door was located. The operation of the left-hand emergency escape door was normal. The cabin attendant managed to open the right front access door without difficulty. Neither of the cockpit sliding windows had been opened. They were inspected and operated and both were serviceable. The cockpit access door was removed by the ARFF personnel.

1.12.7 Cockpit

This was photographed to document switch and lever selections and positions. Instrument readings were not available, as the instruments could not be powered up during the on-site investigation. The flap lever was observed in the 45° position and the speed brake lever in the closed position. The landing gear selector lever was found in the down position. Several circuit breakers were in the deactivated (open) position. Both forward cockpit windows were shattered.

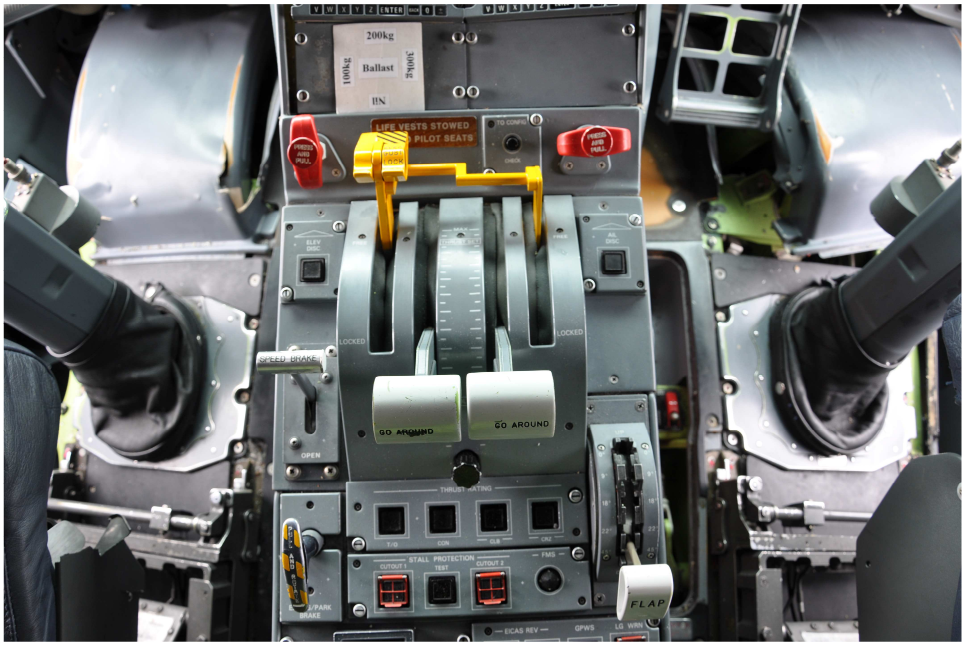


Figure 41: The lever selections in the cockpit after the accident.

1.12.8 Cockpit seats

Both seats experienced high vertical forces during the accident sequence. The first officer's seat was substantially more elevated than that of the PIC, with the control column being pushed up nearly all the way to the roof structure.

Figure 42: Deformation of the cockpit resulting from the collapse of the nose gear.

1.12.9 Tyres and brakes

All four tyres on the main landing gear displayed evidence of viscous hydroplaning and rubber reversion. All four remained inflated. No indication of pre-impact hydraulic leakage was found. The brake components in the cockpit area were damaged during the accident due to the deformation of the nose structure. Both nose wheel tyres were deflated due to damage caused by the wheel striking the concrete base of the approach light. Several of the main tyres had significant side impact damage, so their pre-accident condition could not be evaluated with precision. There was no anomaly or unserviceability with the braking system.

Figure 43: The two tyres on the left main gear assembly showed evidence of hydroplaning and side impact damage.

1.13 Medical and pathological information

1.13.1 None of the occupants on board was seriously injured.

1.13.1 None of the crew members suffered from any medical condition during their employment with the airline that rendered them unfit for flight.

1.14 Fire

1.14.1 There was no evidence of a pre- or post-impact fire.

1.14.2 The ARFF at FAGG responded swiftly following the activation of the crash alarm by the ATC and arrived at the accident scene within the three-minute time frame as required by ICAO Annex 14, volume I, chapter 9, paragraph 9.2.23. There was no fire to attend to and they therefore helped the passengers out of the aircraft to a demarcated area, secured and stabilised the accident site, and freed the two pilots by breaking down the cockpit access door.

1.15 Survival aspects

1.15.1 General

The passenger complement comprised 32 passengers, of whom two were infants and three crew members. The dynamic loads generated in the accident were within the range of human tolerance and none of the 35 occupants sustained any serious injuries.

1.15.2 Cockpit

The accident was survivable as the cockpit and cabin area remained intact and the pilots were wearing their four-point safety harnesses. The collapse of the nose gear and the impact sequence did, however, cause severe deformation to the cockpit's floor structure, trapping the right lower leg of the first officer. ARFF personnel were forced to use the jaws of life to free him, but he was not seriously injured.

1.15.3 Cabin

All passengers were wearing the aircraft-equipped safety harnesses (lap straps). The backrest in seat 7A collapsed partially and was found at a 45° angle. The passengers in seats 2A and 3A were travelling with infants who were seated on their laps and secured to their mothers' harnesses by infant safety harnesses (loop straps).

According to several of the passengers interviewed after the accident, the pilot gave the "brace" command once the aircraft had overrun the runway. This was confirmed by the CVR transcript, on which the pilot was heard to give the "brace" command seven times.

Figure 44: The cabin viewed from the front of the aircraft.

1.15.4 The evacuation

After the aircraft came to rest, the single cabin crew member, who was seated in front and facing the passengers, released her seat harness and retrieved the passenger address (PA) handset from the floor. She announced: "Everything is OK", and then tried to open the service door on the right-hand side at the front behind the cockpit. She was assisted by one of the passengers. The door opened without difficulty and the passengers in the front climbed out onto the road. The left emergency over-wing exit at seat 9A was removed by the passenger in this seat and some of the passengers in the rear evacuated via this exit. The right emergency over-wing exit was not removed as seats 9B and C were unoccupied. Most of the passengers who climbed out through the left exit walked up the embankment in a westerly direction towards the airport and could be accounted for. The passengers who exited through the service door scattered in both directions along the road and were helped by motorists who stopped at the scene. None of the passengers required any assistance from ARFF personnel to climb out the aircraft. The evacuation of passengers and cabin crew was completed within three minutes of the aircraft coming to a stop.

Due to the deformation of the cockpit floor structure, the cockpit access door could not be opened from either side, and the ARFF personnel had break down the door with rescue equipment to free the crew. . The PIC evacuated the cockpit first. The first officer was unable to move as his right lower leg was trapped due to the deformation of the floor and cockpit structure, and he had to be freed by ARFF personnel using the jaws of life.

Emergency locator transmitter (ELT)

The aircraft was equipped with a 406MHz ELT in its aft section. This was not damaged. According to available records (Telkom Radio) based in Cape Town, which monitors all emergency signals in southern Africa – no distress signal was received from the aircraft in question.

1.15.6 Aerodrome rescue and fire-fighting services (ARFF) response:

The ARFF at George aerodrome responded immediately after the activation of the crash alarm by the ATC and arrived at the scene within the three-minute time frame as recommended by ICAO Annex 14, volume I, chapter 9, quoted below:

"9.2.23 *Recommendation – The operational objective of the rescue and fire fighting service should be to achieve a response time not exceeding* <u>*three minutes*</u> *to any other part of the movement area in optimum visibility and surface conditions.*

Note 1. – Response time is considered to be the time between the initial call to the rescue and fire fighting service, and the time when the first responding vehicle(s) is (are) in position to apply foam at a rate of at least 50% of the discharge rate.

Note 3. – Optimum visibility and surface conditions are defined as daytime, good visibility, no precipitation with normal response route free of surface contamination e.g. water, ice or snow."

There was no fire to attend to and the ARFF's primary function shifted to assisting the passengers from the wreckage to a demarcated area, securing and stabilising the accident site, and freeing the pilots, who were trapped inside the cockpit.

1.16 Tests and research

1.16.1 The following components containing non-volatile memory (NVM) were removed from the wreckage:

- Central maintenance computer (CMC)
- Spoiler control unit (SCU)
- Brake control unit (BCU)

The BCU – part number 42-951-3, serial number 731 (manufactured April 2001) – was forwarded to the manufacturer in the USA to be downloaded. The unit passed a functional test with "No Fault Found". This means that no defect or malfunction was detected within the unit that could have jeopardised the operation of the main brake system.

The NVM, however, was found to be full and no data could be extracted for the accident flight. The unit was equipped with a -3 memory, which did not have the capacity of the updated -6 memory as called for in Service Bulletin (SB) No. 42-951-1-32-3, and therefore could not overwrite the data logged in the unit.

No engine indication or crew alerting system (EICAS) messages relating to the brake system were displayed, and no Master or Master Caution warnings were displayed or recorded by the DFDR during the flight until the aircraft exited the paved surface of the runway. At 09:01:43, a Master Caution was recorded, probably due to the damage sustained by the aircraft.

1.16.2 Passenger interviews

Several passengers were interviewed after the accident and a standardised questionnaire was completed for each person. Some passengers also provided the investigators with official statements. All concluded that it had been an uneventful flight with some turbulence en route. The landing had appeared normal, with some of the passengers describing it as a "soft landing". However, several stated that it had taken a while before the aircraft had actually "touched down" and the approach speed felt too fast. One person described the landing rollout as follows: "Once we had landed, we just kept on going. There was no feeling of slowing down at all." All passengers confirmed that the pilot had given the "brace" command when the aircraft failed to stop on the runway surface. As the aeroplane came to a halt, the actions and commands of the cabin attendant were quick and purposeful, and the passengers evacuated unassisted. Control of the passengers once clear of the aircraft appeared to have been problematic, however, and people had to wait a substantial time in the rain before being transported to the terminal building.

1.16.3 Main landing gear tyre examination

Inspection of the four main landing gear tyres during the onsite investigation displayed evidence of severe peeling associated with hydroplaning. All four remained inflated, however. The left main inner tyre's tread depth was measured as 0,5 mm. Due to a logistical problem, it was impossible to remove all four main tyres from the wreckage, so one tyre from each main gear assembly was removed – tyre No. 2, serial number 08284318, and tyre No. 4, serial number 09014331 – and forwarded to Dunlop Tyres in the UK for examination and evaluation.

Figure 45: The tread of the left main inner tyre showed an advanced state of wear.

Their report concluded the following:

"*Both tyres exhibit the appearance of hydroplaning as there is a partly scalding effect to the tread rubber; the surface of the tread rubber has some evidence of reversion and peeling of the compound. This happens where there is sufficient standing water on the runway and the conditions of a landing are such that the tread fails to displace that standing water and results in spin-down of the tyre and either dynamic or viscous aquaplaning occurs.*

As the tyre moves along the runway in a non-rotating condition, heat is generated due to friction between the water film and tread rubber, leading to the appearance of melted rubber. Whilst tyre serial number 08284318 was in an advanced state of tread wear, with just 1,5 mm of centre groove remaining, the same cannot be said for tyre serial number 09014331 as this tyre still had 3,5 mm of centre groove depth remaining, which should have been sufficiently deep enough to channel the standing water away from the tread. The degree of melted rubber and shallowness of the flat spot would indicate a loss of tyre contact with the runway surface at relatively low speeds and that viscous hydroplaning may have occurred. Viscous hydroplaning occurs at lower speeds than dynamic aquaplaning and is primarily due to some form of contamination such as oil present within any standing water on the runway. Further to the above, a low friction coefficient of the runway surface under wet conditions could also have been a contributory factor. The writer, however, does not have any pictorial evidence of the runway at the time of the incident and the above conclusions are based on appearance of the tyres only. Any laboratory analysis on the area of the flat spot would be corrupted by the fact that the aircraft appeared to overshoot the runway onto none paved areas such as grass, mud, etc."

A copy of the examination report is attached as Annexure G.

1.16.4 The approach flown by the crew

The crew was cleared by ATC for the ILS approach runway 11. At 08:59:05, Link 625 called ATC and said: *"Regional Link 625 is clear, is established localiser runway 11 at 9 500 ft, field in sight"* (i.e., visual approach with ILS selected).

According to the operations manual of the operator, a stabilised approach for an ILS approach would be at the outer marker or 1000 ft above the runway threshold. Flying an ILS that changed to a visual approach, the requirement would have been to be stabilised at 500 ft above the runway threshold.

Maximum flap extended speed (V_{FE}) was reached at 145 KIAS, and the flaps were selected to the full down (45°) position. The flaps reached 45° at 376 ft above the threshold elevation, with the speed being captured at 145 KIAS. The aircraft crossed overhead the threshold at 50 ft above the runway surface (according to the radio altimeter (RA) indication) at 143 KIAS. At this stage, the speed was approximately 15 kt above V_{REF}. (Operator requirement: *"Speed between* V_{REF} *+ {adjustment knots} and* V_{APP}*"*)

It took nine seconds for full air-ground transition from a height of 50 ft above the runway threshold.

1.16.5 Touchdown and ground rollout

Based on the DFDR data, the following took place:

At 09:01:09, the aircraft air-ground sensors transitioned to "ground" mode for a period of 1,5 seconds, then returned to "air" mode. The aircraft touched down at a point near the third landing marker.

The aircraft transitioned back into air mode to a height of approximately two feet above the runway surface after the first ground transition. In its Approach and Landing Reduction (ALAR) Toolkit, the Flight Safety Foundation (FSF) divides a bounce into two categories:

Light – when the height reached is five feet or less.
High – when the height reached is above five feet.

At 09:01:11, the aircraft air-ground sensors transitioned to "ground" mode and remained so for the rest of the rollout. The ground spoilers deployed simultaneously and remained in the open position until 09:01:52, by which time the aircraft had departed the runway surface. The IAS at the time of deployment was about approximately 130 KIAS.

At 09:01:15, four seconds after the second transition, with the aircraft remaining in ground mode, the first brake pressure increases were observed. A distance of about 300 m was covered during this period. During the ground rollout, the average brake pressure was approximately 427 psi with an average deceleration of -0,106g.

From 09:01:33 to 09:01:35, little to no brake pressure was recorded. According to the crew, at no stage of the ground rollout following the first application of brake pressure had the PF released the brake pedals. During the latter part of the landing roll the PNF also assisted with applying brake application. The possibility that the park brake was also applied by the crew during this phase of the rollout could not be ruled out, as the PNF recalled seeing the "Park Brake On" light illuminating on the annunciator panel.

At 09:01:42, the vertical acceleration pattern changed (probably due to the departure of the aircraft from the stop-way asphalt surface). The airspeed at this stage was approximately 52 KIAS.

During the last phase of the landing rollout, as the crew saw they were not going to stop on the runway surface, the PF steered the aircraft to the right of the runway centreline to avoid the ILS antenna structure 163 m beyond the 60 m stop-way area on the extended centreline. Tyre tracks with the characteristics of viscous hydroplaning, clearly indicate the deviation on the runway surface (see Figure 34). It was further noted that the maximum braking pressure captured on the DFDR was 1 040 psi. This was recorded towards the departure end of runway 11 (stop-way area) for one second at 09:01:41 with the airspeed at 56 KIAS.

1.16.6 Inspection of runway 11/29 at FAGG

The runway was subjected to a rehabilitation process from July to November 2009 which included the repair of several patches where the asphalt had been milled and replaced. The full width and length of the runway, including both runway stop-ways, was then sprayed with a bitumen fog-spray.

According to available information, the original specification called for the application of a bitumen spray: SP 2000, a proprietary rejuvenating fluid consisting of bitumen and solvents. The product is described as a polymerised bitumen rejuvenator with mastic filler. It was applied to the parallel taxiway (Alpha and Delta).

The specification was then changed for the runway to bituminous fog-spray (SS 60) due to friction concerns with the product SP 2000, which displayed properties that might have induced the onset of hydroplaning. According to the aerodrome licence holder, the “change to fog-spray was in the main due to the curing time of SP 2000, which was much longer that the SS 60 fog-spray”.
The investigators conducted a visual inspection of the runway, by walking its length, the day after the accident and on four occasions thereafter. During three of these inspections, the runway surface was dry and was evaluated by friction experts. On one occasion, it was wet due to rain. The following tests were performed during one dry inspection:

i. Runway friction tests;
ii. Runway surface profile tests, using a laser surface profiler vehicle;
iii. Runway macro-texture tests, using the sand-patch method.

The measured macro-texture of the runway was found to be 0,47 mm, which was below the ICAO recommended value of 1 mm for a new surface. This was a rehabilitated surface and no recommendation could be found in document ICAO Annex 14 on macro-texture value for such a surface. The tests did show, however, that the surface was less than 50% below the recommended value for that of a new surface, and this would have had a direct effect on water displacement during wet weather operations, especially those involving the landing of high-speed aircraft.

The visual assessment of the macro-texture found that it was reasonably uniform across the width and length of the runway. The voids were filled with bitumen from the fog-spray.

Rubber deposits from spinning tyres were observed in the touchdown zones of both runways 11 and 29. There was little difference in the macro-texture of the rubber-coated surface and the uncoated surface. The similarity in appearance and texture between the rubber-coated and uncoated surfaces did raise a concern about the nature of the runway macro-texture: should the rubber deposits be removed, it might have had very little, if any, effect on the macro-texture of the surface.

Figure 46: The texture of the tyre markings and adjacent runway surface

1.16.7 Aircraft braking tests on a wet runway surface at FAGG

Background to the test conducted on 12 March 2010

Following the accident in question, the SACAA Accident and Incident Investigation Division (AIID) issued an emergency safety recommendation that called for a restriction on aircraft operations above 5 700 kg maximum takeoff weight (MTOW) during wet weather conditions at FAGG. After this, the following Notice to Airmen (NOTAM) was issued by the regulating authority, limiting operations at George aerodrome under wet weather conditions:

"(B0200/10)
A) FAGGB) 1002231150 C) 1004121000 EST
E) ALL COMMERCIAL TFC EXCEEDING 5700KG TO USE REDUCED DECLARED DIST OF 77 PERCENT OF EXISTING LENGTH (=1540M) IN PER CALCULATIONS WHEN RWY WET. ANTISKID AND THRUST REVERSE OR BETA FUNCTIONS TO BE OPR ON ACFT.
A RWY IS WET WHEN MORE THAN 25 PERCENT OF SFC APPEAR REFLECTIVE DUE TO WATER OR IS COVERED WITH WATER.
B00152/10
A) FAGG
B 1002130001 C)1004121000 EST
AD CLSD FOR COMMERCIAL TFC EXCEEDING 5700KG WHEN RWY WET. A RWY IS WET WHEN MORE THAN 25 PERCENT OF SFC APPEAR REFLECTIVE DUE TO WATER OR IS COVERED WITH WATER."

Pressure was put on the SACAA to review these restrictions. On 12 March 2010, a local airline conducting daily scheduled domestic flights in and out of FAGG made available a Boeing 737-400 with crew to perform a landing and a rejected takeoff (RTO) test in order to determine the actual braking action of the aircraft under wet conditions on the runway. These tests were conducted at night after normal scheduled operations, and the results were compared with the information in the aircraft flight manual (AFM).

The airline's report stated:

"The tests included the following criteria:

- *A test was required to be performed on a wet runway. (Due to rainy conditions that prevailed at the time of these tests, the runway was assessed as wet).*
- *No passengers were allowed on board the aircraft.*
- *A circuit was flown and the aircraft was landed on runway 29 to determine the landing distance.*
- *The rejected takeoff (RTO) was performed from 100 kt on runway 29.*

Landing distance test results

According to the Boeing 737-400 AFM the aircraft should have stopped within ±1 103 m (3 620 ft). The distance to stop that was achieved during the test flight was ±1 199 m (3 932 ft). The position of the aircraft's nose wheel was plotted by ground personnel on the runway after the aircraft came to a stop on the runway. The result presented an underperformance of 95 m (312 ft) or 8,6%. However, the landing was 29 m (95 ft) past the threshold and if this is deducted to compare the theoretical landing distance (ground roll distance) it equates to a 6% underperformance, which was within the acceptable limits. Initial braking action was described as good, but according to the pilot the last 213 m (700 ft) was moderate to bad due to the fact that the anti-skid released twice. It should be noted that thrust reversers were utilised during this test.

Rejected takeoff (RTO)

Following the landing test, the aircraft was parked for a period of approximately 40 minutes to allow adequate brake cooling as per the AFM. This was monitored by technical personnel before push back was commenced for the RTO test. The aircraft was accelerated by means of maximum thrust to 100 kt before the RTO drill commenced. The aircraft's speed peaked at 102 kt. Braking was initially moderate according to the pilot's previous career experience (one high speed RTO in a Boeing 737 in dry conditions as well as training in simulator). For the last 610 m (2 000 ft) of the RTO the braking action can only be described as poor, as the anti-skid was releasing all the time. Further to this, the effect of small pools of water could be felt.

According to the AFM the aircraft should have stopped within 975 m (3 200 ft). The outcome, however, was 1 254 m (4 113 ft), which equates to an underperformance of 278 m (913 ft) or 28%.

The big underperformance in the RTO results compared to the landing distance result can be related to the pilot's visual observation that the runway was significantly wetter with small pools of standing water on the runway 762 m (2 500 ft) from the threshold of runway 29. Evidence of the effect thereof was the constant release of the anti-skid in this position – obviously detection of no wheel spin up. From 70 kt down to zero, the braking action was assessed as very poor."

*NOTE: Both the landing test and RTO test referred to above were supported by the application of reverse thrust to decelerate the aircraft under the wet runway surface conditions.

The following weather conditions prevailed at the time of the tests:

Temperature	:	19℃
Wind	:	180°/6 kt
Visibility	:	5 000 m in light rain (from south-west)
Weather	:	Scattered cloud at 800 ft, overcast at 2 000 ft
Pressure	:	1 010 hPa

From 1800Z (20h00) until 2200Z (24h00), the recorded rainfall at the aerodrome was 3,0 mm and for the entire 24-hour period it was 4,4 mm (see Figure 47, courtesy of the SAWS).

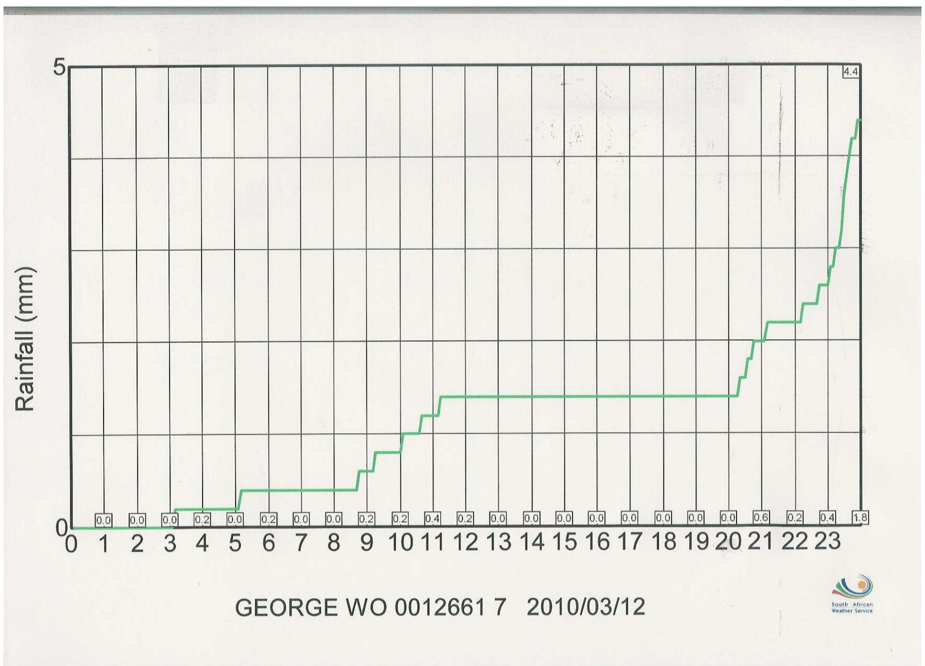


Figure 47: Rainfall data chart for FAGG on 12 March 2010.

Further excerpts from test report:

<u>Aircraft data</u>

"The aircraft that was utilised for the test was a Boeing 737-400. The aircraft had no recorded deferred defects and had no history of flight control, hydraulic, brake or anti-skid problems. The calculated takeoff weight was just below 40 000 kg (88 185 lbs)."

<u>Crew</u>

"The crew members who conducted the test were current and experienced on the Boeing 737-400. The pilot-in-command (PIC) had 30 years' flying experience of which 15 years were with the operator on the Boeing 737-2/3/4/800 type aircraft. An additional Captain was on the jump seat to act as a safety pilot and to log the

details. (Total crew: 3 pilots).

The Operator that conducted the above-mentioned tests did so in order to test the integrity of the NOTAM that was issued by the regulating authority following the accident in question, as it had a substantial implication on their operational capabilities with reference to George aerodrome during wet weather operations.

Evaluation of the test results confirmed that the NOTAM and its contents should remain in force, as the aircraft experienced reduced braking performance during wet weather conditions (wet runway surface).”

1.17 Organisational and management information

1.17.1 The operator of flight SA8625 was in possession of a valid Air Service Licence and Air Operating Certificate (AOC). The accident aircraft was dually authorised to operate under the AOC.

1.17.1.1 Approach briefing

The operator’s operations manual aircraft SOPs “Landing Procedures”, page B1/EMB135-2-52-53 (effective 1 August 2006), indicate that the approach briefing must be carried out by the PF and he or she must address the following items:

a) *Descent distance and time.*
b) *Detailed discussion about the STAR and Approach Procedure based on the applicable charts.*
c) *The approach – visual or instrument, that is expected.*
d) *Meteorological conditions and runway conditions at destination (LDA, contamination, prevailing winds, lightning, etc.)*
e) *The setting of the radios, the selection of radio aids, when and how to identify them, how to set courses, altitudes and heights, MFD terrain display, radar altimeter, etc.*
f) *Jeppesen Approach Chart shall be reviewed in the “briefing strip” sequence, starting from the top right corner, going through Heading, Plan View, Profile View and Minimums. In the event of an expected instrument approach the following aspects must be covered in the briefing:*

   (i) Safe Altitudes:
   - *Minimum En-route Altitude (MEA)*
   - *Minimum Off-route Altitude (MORA)*
   - *Minimum Safe Altitude (MSA)*
   - *Initial Approach Altitude*
   - *Radar Minimum Terrain Clearance Altitudes*

   (ii) Pattern entry procedure.
   (iii) Instrument let down procedure, including headings to steer, timing rates of descent, and altitudes in the pattern, crossing altitudes and minima.
   (iv) Failures on final approach.
   (v) Go around and missed approach procedure. The missed approach procedure must be discussed in detail and both pilots must be totally aware of what to do should the need of a missed approach procedure ever arise.
   (vi) Alternate course of action and an alternate is declared.

(vii) Fuel considerations.
(viii) Anticipated runway turn-off point, taxiways and single/all engine taxi to parking bay.
(ix) Crew duties:

- *Identification of relevant facilities.*
- *Any frequency changes to be made during the approach.*
- *Calculation of any relevant timing and rates of descent.*
- *Standard call-outs.*

g) For visual approaches the briefing can be shortened to include:
(i) Go around and missed approach procedure. The missed approach procedure must be discussed in detail and both pilots must be totally aware of what to do should the need of a missed approach procedure ever arise.
(ii) Subsequent actions after a possible missed approach. Consideration of a diversion or second approach, depending on the fuel on board, weather and all relevant factors.
(iii) Use of reverse thrust (if available) or only ground idle.
(iv) Anticipated runway turn-off point, taxiway and single/all engine taxi to parking bay.

h) Once all the items have been addressed, the PF will request to read the "DESCENT CHECKLIST TO THE LINE". After ensuring that all the items have been performed the PNF must call out "DESCENT CHECKLIST COMPLETED TO THE FIRST LINE". The approach must be planned to allow a stabilised approach before touchdown. It must be kept in mind that this is the last opportunity to do major reprogramming of the FMS. Once below 10 000 ft, entries into the FMS by PF must be limited to basic data such as "Direct To".

NOTE: It is highly recommended that the briefing be performed with the active participation of both pilots. Techniques such as reading back or passing questions to each other enhance this participation. Briefings consisting of mechanical repetition of a memorised speech without having the mind set on the subject are useless."

1.17.1.2 Descent, approach and before-landing checklist

This is performed using the cockpit checklist depicted below:

DESCENT

CHALLENGE	ACTION
Windshield Heating	PUSHED IN
Approach Briefing	COMPLETED
Speed Bugs	SET
PRESSURIZATION Panel	SET
External Lights	ON
Pax Signs	SET

APPROACH

CHALLENGE	ACTION/RESPONSE
PASS SIGNS Panel	SET
Altimeters	SET/X-CKD
Approach Aids	SET/X-CKD

BEFORE LANDING

CHALLENGE	ACTION
Landing Gear	DOWN
FLAPS	___SET
Lights	AS RQRD
AP/YD	OFF

NP-4 REVISION

1.17.1.3 Stabilised approach

Requirements:

A stable approach can be defined as an approach where the aircraft is in full landing configuration on a stable path, with stable thrust set, at a stable pitch attitude and speed at (V_{APP} {Approach speed} = V_{REF} + ½ headwind + full gust).

The definition of a stable approach according to the FSF ALAR Tool Kit (excerpt from briefing note 8.1 – Runway Excursions and Runway Overruns, table 1):

"All flights must be stabilised by 1 000 ft above airport elevation in instrument meteorological conditions (IMC) and by 500 ft above the airport elevation in visual meteorological conditions (VMC). An approach is stabilised when all the following criteria are met:

1. *The aircraft is on the correct flight path;*
2. *Only small changes in heading/pitch are required to maintain the correct flight path;*
3. *The aircraft speed is not more than V_{REF} +20 kt indicated airspeed and not less than V_{REF};*
4. *The aircraft is in the correct landing configuration;*
5. *Sink rate is no greater than 1 000 ft per minute;*
   If an approach requires a sink rate greater the 1 000 ft per minute, a special briefing should be conducted;
6. *Power setting is appropriate for the aircraft configuration and is not below the minimum power for approach as defined by the aircraft operating manual;*
7. *All briefings and checklist have been conducted;*
8. *Specific types of approaches are stabilised if they also fulfil the following:*
   Instrument landing system (ILS) approaches must be flown within one dot of the glideslope and localiser; (Further expansion regarding Category II and III

approaches and circle to land operations);

9. *Unique approach procedures or abnormal conditions requiring a deviation from the above elements of a stabilised approach require a special briefing."*

In the operator's efficiency manual, volume B, part 1/EMB135, operations manual aircraft SOP, B1/EMB135-1-8 (effective 1 August 2006), a stabilised approach is defined as follows:

"A Stabilised Approach for an ILS Approach

Would be at the Outer Marker or 1 000 ft above the runway threshold with the following conditions:

- *Within ½ a dot of localiser and glideslope deviation.*
- *Speed between V_{REF} + (adjustment knots) and V_{APP}.*
- *Aircraft configured for landing (landing flaps, gear down).*
- *Vertical speed less than 900 ft per minute.*
- *Thrust set to maintain the rate of descent / IAS.*

A Stabilised Approach for a Visual Approach would be:

- *Minimum height to complete the final turn is 500 ft.*
- *Within 10° of runway centreline.*
- *Heading within 10° of runway heading.*
- *On the glide path (PAPI or VASI if glideslope indications are not available).*
- *Speed between V_{REF} and V_{APP}.*
- *Aircraft configured for landing (landing flap, gear down).*
- *Vertical speed to be less than 900 ft per minute.*
- *Thrust set to maintain the rate of descent / IAS.*

Go-around decision:

The 1 000 feet stable / 1 000 feet not stable call is mandatory during all IMC approaches. For a precision approach the 1 000 feet call will be made above airfield elevation and for non-precision approaches the 500 feet call is made above the minimum decision altitude (MDA).

A missed approach must be initiated if any of the following occurs:

- *No visual contact by the missed approach point (MAP) or decision altitude (DA);*
- *The approach is not stable below 1 000 ft AGL in IMC and 500 ft in VMC and any time thereafter;*
- *ILS deviation exceeds limits;*
- *Wind shear;*
- *The approach is unsafe for any reason;*
- *In a monitored approach the "landing" call by decision altitude or minimum descent altitude (MDA); or*
- *Non-precision Monitored Approach calls and CANPA unstable and out of any of the parameters for the approach.*

Missed approach mentality (operations manual aircraft, SOP, B1/EMB135-2-10)

There have been many accidents in commercial aviation caused by the decision to *land when all evidence signalled that the safest alternative was a missed approach. The approach must be planned with the missed approach in mind. In other words: the crew must plan a missed approach and not a landing. The landing is the alternative. This statement may not look significant, but it is. This mentality must be emphasised during training and during normal operation. The missed approach must be briefed in detail and both pilots must be totally aware of what will happen if a missed approach is carried out.*

1.17.1.4 Precision and non-precision approach

The operator's flight operations manual, section 1, pp1-188, paragraph 1.12.4.2, provides the following information to pilots:

"The pilot-in-command shall not continue any precision and non-precision approach unless he/she is satisfied that the precision and non-precision approach can be safely completed, considering the current weather conditions based on the actual weather and visibility prescribed in 1.12.4.2.4 for the aerodrome, including expected wind shear as authorised. Once the pilot-in-command is satisfied that the precision and non-precision approach can be safely completed, the pilot-in-command shall not descend below the approved system minima prescribed in 1.12.4.2.1, or the circling minima prescribed in 1.12.4.5. and the required visual reference is obtained as prescribed 1.12.4.2.3.

The pilot flying shall initiate the go-around and comply with the published missed approach procedure if the required visual reference is not obtained at the missed approach point at or above the prescribed system minima.

1.12.4.2.1 System minima

An operator must ensure that system minima for non-precision approach procedures, which are based upon the use of ILS without glide path (LLZ only), VOR, NDB, SRA and VDF, are not lower than the MDH (minimum descent height) values given in the table below.

Facility	*Lowest MDH*
ILS (no glide path – LLZ)	*250 ft*
SRA (terminating at ½ nm)	*250 ft*
SRA (terminating at 1 nm)	*300 ft*
SRA (terminating at 2 nm)	*350 ft*
VOR	*300 ft*
VOR / DME	*250 ft*
NDB	*300 ft*
VDF (ODM and OGH)	*300 ft*

1.12.4.2.2 Minimum descent height

An operator must ensure that the minimum descent height for a non-precision approach is not lower than either:

(a) the OCH/OCL for the category of aeroplane; or
(b) the system minimum.

1.12.4.2.3 Visual reference

A pilot shall not continue an instrument approach below MDA/MDH (Minimum Descent Altitude / Height) or DA/DH (Decision Altitude / Height) unless at least one of the following visual references for the intended runway is distinctly visible and identified to the pilot.

- *a) Elements of the approach light system;*
- *b) The threshold;*
- *c) The threshold markings;*
- *d) The threshold lights;*
- *e) The threshold identification lights;*
- *f) The visual glideslope indicator;*
- *g) The touchdown zone or touchdown zone markings;*
- *h) The touchdown zone lights;*
- *i) Runway edge lights; or*
- *j) Other visual references accepted by the Commissioner.*

1.17.1.5 Landing technique:

The operator's efficiency manual, volume B, part 1/EMB135, operations manual aircraft SOP, B1/EMB135-2-58/59, paragraph 2.9.6, provides the following information to pilots:

- *a) The landing configuration (gear down and landing flaps) should be established early on the final approach or at the outer marker on an ILS approach.*
- *b) Airspeed, power and descent rate should be stabilised early.*
- *c) Avoid power-off approaches.*
- *d) Fly the aircraft on a stable glide path towards the touchdown point. Great changes in airspeed require great changes in thrust and altitude.*
- *e) Speed must be kept within +10 knots, relative to the target approach speed.*
- *f) Unnecessary N1 changes of more than 5% will destabilise the approach. Avoid excessive rates of descent during final approach. Descent rates in excess of 1 000 ft/min on short final should be avoided.*
- *g) If an excessive rate of descent develops, a missed approach must be performed immediately. Make sure that the aircraft is properly trimmed during the approach. This maximises elevator authority for the flare or in the event of a missed approach.*
- *h) Cross the threshold at V_{REF}, as the aircraft approaches the touch-down point, reduce the rate of descent and slowly reduce thrust levers to idle so that they are at idle when the aircraft touches down.*
- *i) Normally a 2-3 degree pitch change will be enough for the flare.*
- *j) Plan to touch down as close as possible to the 300 m point.*
- *k) Do not allow the aircraft to float in ground effect, which unnecessarily increases the landing distance.*
- *l) Apply backpressure on the yoke after the main gear touches down to smoothly ease the nose-wheel onto the runway.*
- *m) Apply forward pressure on the yoke after the nose-wheel touches down to maximise directional controllability.*

2.9.7 After Landing

To maximise braking performance on dry or wet runways apply continuous *pressure on the brake pedals. The ANTI-SKID system will modulate the brakes for an optimum braking performance.* ***DO NOT PUMP THE PEDALS.*** *Do not fall victim to the temptation to exit the runway too quickly requiring heavy braking. This type of practice reduces the life of the brakes. Carbon brakes wear faster when they are cool, so avoid sudden crisp braking with cool brakes. The steering handle is very responsive and using it may cause the aircraft to taxi erratically causing passenger discomfort."*

1.17.2 The aircraft was in possession of a valid certificate of airworthiness and was maintained by a SACAA-approved aircraft maintenance organisation (AMO) based at O.R. Tambo International Airport (FAJS).

1.17.3 The aerodrome owner:

George aerodrome (FAGG) was in possession of a valid aerodrome licence issued by the Commissioner for Civil Aviation on 30 January 2009. The licence was valid for one year, from 1 February 2009 until 31 January 2010.

The Civil Aviation Regulations of 1997, Part 139, stipulate the following with reference to the renewal of an aerodrome licence:

"Part 139.02.17

(1) An application for the renewal of an aerodrome licence shall be –

(a) made to the Commissioner in the appropriate form as prescribed in Document SA-CATS-AH; and
(b) accompanied by –

(i) the updated operations manual referred to in regulation 139.02.3, if required by the Commissioner;
(ii) proof of adequate funding;
(iii) particulars of non-compliance with, or deviations from –
(aa) the appropriate aerodrome design, operation or equipment standards prescribed in this Part; or
(bb) the appropriate airspace classification requirements prescribed in Part 172; and
(iv) the appropriate fee as prescribed in Part 187.

(2) The holder of the licence shall at least 60 days immediately preceding the date on which such licence expires, apply for the renewal of such licence."

1.17.4 A civil, as well as an electrical infrastructure, on-site inspection was conducted by aerodrome inspectors from the Air Safety Infrastructure Division of the SACAA on 1 November 2009. This was done five days prior to the completion of the rehabilitation project and 90 days before the expiry of the aerodrome licence. Two inspectors performed the inspection, one concentrating on the civil aspects and the other on the electrical infrastructure. A checklist (CA139-18) was used to perform the civil infrastructure inspection, which, looked at the runway surface, taxiways and apron areas, and its report did not identify any non-compliances at the aerodrome. Moreover, it did not record that any additional tests (i.e., runway texture, runway slope or friction tests) had been conducted in the presence of the inspector, nor was any additional testing requested or witnessed subsequent to the inspection.

1.17.5 The investigating team found that this checklist (CA139-18) lacked critical information. The scope of work performed during the rehabilitation process of the runway did not fall within the framework of the checklist and therefore could not be properly addressed in the inspection report. One such critical aspect was the assessment of the runway friction data, which was conducted five days after the SACAA inspection and which was not incorporated on the checklist.

1.17.6 The inspection was supported by three other inspections conducted on the aerodrome's facilities, namely:

i. Aerodrome rescue and fire-fighting;
ii. Apron services;
iii. Quality management.

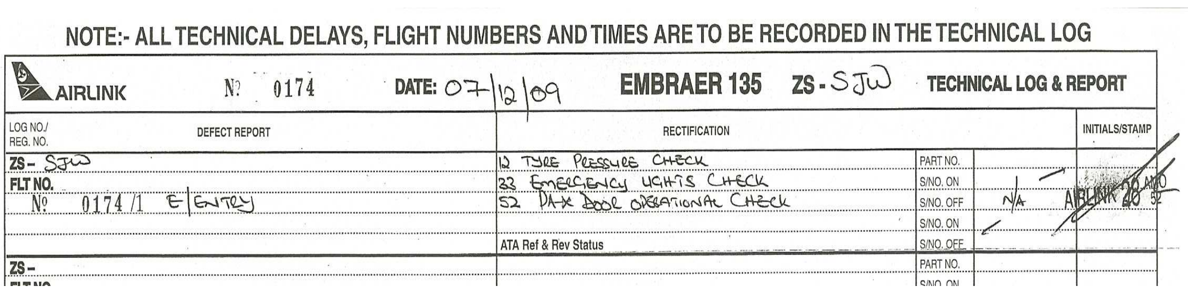
1.17.7 Following the evaluation of the reports as mentioned above, the aerodrome licence was renewed for a further period of one year, with effect from 1 February 2010.

1.17.8 Dispatch and transit check (7 December 2009)

Due to the nature of the accident, the investigators placed great importance on the aircraft's tyres, and focused on the inspections and transit checks conducted on the condition of the tyres prior to the aeroplane being dispatched from its home base as well as the transit checks that were required as far as the condition of the tyres of the aircraft was concerned. The reason for the emphasis on the aircraft tyres is that it was the only medium between the aircraft and the runway surface, and therefore of great importance to the investigation process.

Dispatch check:

Figure 48 shows the entry made in the aircraft's technical log, prior to being dispatched from its home base (FAJS), indicating that the tyre pressures had been checked by maintenance personnel and found to be within the prescribed limits.



NOTE:- ALL TECHNICAL DELAYS, FLIGHT NUMBERS AND TIMES ARE TO BE RECORDED IN THE TECHNICAL LOG

AIRLINK № 0174 DATE: 07/12/09 EMBRAER 135 ZS-SJW TECHNICAL LOG & REPORT

LOG NO./ REG. NO.	DEFECT REPORT	RECTIFICATION			INITIALS/STAMP
ZS- SJW		12 TYRE PRESSURE CHECK	PART NO.		
FLT NO.		33 EMERGENCY LIGHTS CHECK	S/NO. ON		
№ 0174 /1	E/ENTRY	52 PAX DOOR OPERATIONAL CHECK	S/NO. OFF	N/A	AIRLINK 28
			S/NO. ON		
		ATA Ref & Rev Status	S/NO. OFF		
ZS-			PART NO.		

Figure 48: Entry in technical log of ZS-SJW.

During the transit check at FACT, the aircraft was refuelled and an external safety inspection carried out. The Embraer operations manual – SOP reference B1/EMB135-2-18/19/20 – was consulted to ensure that the required procedures had been followed. The manual stipulates the following;

"2.7 Pre-Flight Procedures:

Stipulate: Both the Captain and the First Officer must actively take part in the pre-flight preparation and briefings. (Crew only document).

2.7.4 Refuelling:

a) *The aircraft should be positioned on the apron approximately 30 minutes before scheduled chock-off time. Sector fuel area available for all sectors and should be discussed by both pilots. The final to be carried is the decision of the Captain.*
b) *The Captain is ultimately responsible for the refuelling of the aircraft. He may delegate this task to a person qualified in refuelling the EMB 135.*

2.7.5 External Safety Inspection:

The External Safety Inspection must be carried out prior to every flight."

(The following headings, pertaining specifically to the aircraft's wheels and tyres, were extracted from the inspection list.)

<u>"Nose Section:</u>

Wheels and Tyres - CONDITION

<u>Wings:</u>

Wheels and Tyres - CONDITION"

According to the available information, the refuelling procedure was supervised by an aircraft maintenance engineer (AME) based at FACT. He also performed an external safety inspection of the aircraft and recalled that the brake wear indicator pins were within limits and the tyres were in a good condition. The aircraft was dispatched without any problems. The technical log, however, did not made provision for the AME to sign off such a transit check.

The on-site investigation found that both the nose wheel tyres were deflated as a result of impact damage, and all four main tyres were still inflated. The four main tyres displayed evidence of hydroplaning and rubber reversion, and two of the four main tyres had a thread depth of approximately 0,5 mm.

1.18 Additional information

1.18.1 Hydroplaning

The terms "hydroplaning" and "aquaplaning" are found in many publications. They are the same phenomenon, and in this report "hydroplaning" is preferred.

Definition

Hydroplaning or aquaplaning by the tyres of an aircraft occurs when a layer of water builds between the rubber tyres of the aircraft and the runway surface, leading to a loss of traction and thus preventing the aircraft from responding to control inputs such as steering, braking or accelerating. If it occurs along all the main wheels, the aircraft becomes, in effect, an uncontrolled sled.

Additional information on hydroplaning can be found in Annexure H attached to this report.

1.18.2 Critical speeds

For the aircraft in question, the critical hydroplaning speeds with the required tyre pressure of 145 psi (pounds per square inch) are shown below:

$$\textit{Critical speed 1} = 8{,}6 \times \sqrt{145} = 103\ kt$$

$$\textit{Critical speed 2} = 7{,}7 \times \sqrt{145} = 93\ kt$$

Both critical speed formulas were used as the manufacturer does not clearly indicate that one has preference over the other, or is more pertinent to the aircraft type. There might be variation from one aircraft model to another as tyre sizes and pressures differ from model to model, with different tyres having to carry different loads.

The IIC obtained expert opinion from the author of a study into hydroplaning of modern aircraft tyres, and was informed that the critical hydroplaning speed is strongly influenced by the type of tyres fitted. The study indicated that the critical hydroplaning speed for the bias-type tyre fitted to the accident aircraft could have been as low as $6{,}8 \times \sqrt{P}$ (where "P" is the tyre pressure in psi).

According to the tyre manufacturer, the accident aircraft had been fitted with the bias-ply type tyre.

The critical speed may therefore have been as low as $6{,}8 \times \sqrt{145} = 82$ kt

The tyre damage indicated that hydroplaning had indeed occurred. At what speed it happened, however, could not be determined with certainty. Using the formulae developed by NASA and the NRL, it is evident that there is a 20-knot window, which indicates that the critical hydroplaning speed for the type of tyres fitted to the accident was between 82 and 103 kt.

1.18.3 Runway construction

Three runway construction characteristics play a direct role in hydroplaning.

The first is the intended runway friction, which determines the materials used and resulting micro- and macro-textures, as described earlier. Each regulating authority establishes its own guidelines in this regard. In the USA, the FAA guidelines on the runway pavement surface and what level of friction it should have are provided in Advisory Circular (AC) 150/5320-12C.

The second factor affecting hydroplaning is camber, the downward slope from the centreline of the runway. This precludes water from pooling on the runway, and helps to prevent hydroplaning. A problem can occasionally occur when crosswinds cause water to pool on the upwind side, producing asymmetric hydroplaning, where only the wheels on one side skid. Unless corrected swiftly, the aircraft can veer to the side of the runway.

The third factor is runway grooving, which works together with cambering to drain the water from the surface. The grooves affect runway friction by reducing to a certain extent the area of contact available to the tyres, but its advantages far outweigh this drawback. The design of the grooves is specified by the relevant civil aviation authority. The FAA's AC 150/5320-12C specifies the groove width, depth and spacing. The grooves have to run the length of the runway and must be transverse to the direction of aircraft landing and taking off. The SACAA does not have any specifications in this regard.

1.18.4 Provision of safety information during an emergency – language

The operator's normal and emergency operating procedures call for provision of safety information to passengers, in preparation for any planned emergency landing or ditching, in English only. Information obtained indicated that all the passengers on flight SA8625 understood English and none had any trouble understanding the evacuation instructions due to the use of English.

1.18.5 Provision of safety information – recommended brace-for-impact position

The passengers of flight SA8625 were directed by the PIC to "brace" prior to impact. The CVR transcript confirmed that the PIC gave the brace command seven times prior to the aircraft crashing through the perimeter fence. Most of the passengers assumed the brace position. However, the actions and positions taken may not all have been appropriate. For example, several held onto the sides of the seat-back in front of them to brace themselves. In a study assessing passengers' knowledge of brace positions, it was found that about 50% of passengers, including frequent flyers, did not know how to assume the correct brace position, and that the most common unsafe position cited was sitting upright rather than bending forward.

On flight SA8625, the safety information cards in the seat pockets in front of each passenger displayed only one brace position: bending forward and holding one's head with both hands. In addition, it was reported that the brace position depicted on the safety information cards was accepted by the SACAA as adequate.

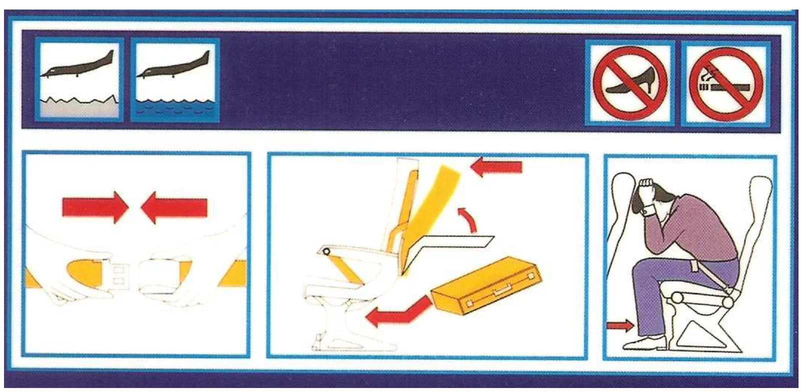


Figure 49: Extract from the on-board safety card reflecting one brace position only.

Transport Canada (TC), the FAA, the UK CAA, and Australian CAA recommend at least two brace positions:

i. In high-density, economy class seating: occupants bend forward against the seat-back in front of them);
ii. In (low-density, business or first-class seating: occupants place their heads face-down on their knees, and wrap their arms behind and under their legs.

1.18.6 Flight Safety Foundation – Approach and Landing Accident Reduction report

The FSF had made an in-depth study into approach and landing accidents, and subsequently produced the approach and landing accident reduction (ALAR) Tool Kit, summarising its findings and recommending preventive action to reduce accidents in various categories.

A briefing note included in the tool kit notes that 20% of 76 approach and landing accidents and serious incidents worldwide between 1984 and 1997 were runway overruns or excursions. The tool kit suggests several prevention strategies to address these, focusing on policies, standard operating procedures, performance data, and crew awareness. It recommends establishing a policy to encourage a go-around where warranted, establishing a policy to prohibit landing outside the touchdown zone, creating procedures for identifying the amount of runway remaining, and enhancing crew's awareness of the relationship between crosswind limitations and runway conditions.

An additional briefing note deals with human factors in these type of accidents, pointing out that repetitive briefing, done as a formality, has limited value over time. Briefings need to address the specific circumstances of the approach that may present a threat to the safety of the flight. The briefing note also points out the failure of crews to recognise a changing situation, specifically changes in wind direction, and, if need be, modify a plan of action. This may be due to a reluctance to seek additional information or verify landing data as a situation progresses, or a lack of time to observe, evaluate and control the attitude and flight path of the aircraft.

1.18.7 International weather-related landing occurrences:

Several weather-related landing overrun accidents were reviewed during the investigation:

(i) Northwest Airlines Boeing 747-100, Miami, Florida, 15 December 1972
(ii) American Airlines MD-83, Little Rock, Arkansas, 1 June 1999
(iii) Qantas Boeing 747-400, Bangkok, Thailand, 23 September 1999
(iv) Hawaiian Airlines DC-10, Tahiti, 24 December 2000
(v) Air France Airbus A340, Toronto, Canada, 2 August 2005
(vi) Boeing 737-300, Chicago Midway International Airport, 8 December 2005
(vii) Bristol Airport, UK, 29 December 2006 (three separate aircraft).
(viii) Boeing 737-200, Durban International Airport, South Africa, 18 June 2008

In the overview of the Australian Transportation Safety Bureau (ATSB) report on the Boeing 747-400 at Bangkok, they noted:

"In terms of overall accident statistics, runway overruns are a relatively common event. Of the 49 accidents involving Western-built, high-capacity jet aircraft reported during 1999, 11 were landing overruns. Landing overruns typically occur when the runway is wet or contaminated and/or the aircraft is high and fast during final approach. This number did not include those accidents where a mechanical failure or hard touchdown was the initiating event, or those accidents involving a loss of directional control on a water-affected runway. The 11 overrun accidents included:

- *Five overruns in which the aircraft landed long and/or fast on a water-affected runway;*
- *Two overruns in which there was an apparent or assumed normal touchdown on a water-affected runway;*

- *Two overruns in which the landing was long and/or fast. "Poor" weather was reported, but no information was available on the runway conditions;*
- *One overrun in which the landing was long but no weather details were provided.*
- *One overrun for which no details were provided.*

In each instance, water on the runways was due to rain, not snow or ice. Six of the 11 accidents involved passenger-carrying operations.

A study of accident and movement data for airports in western Europe examined 91 runway overruns and veer-offs. The study concluded that there was a fourfold increase in accident risk for aircraft operating on water-affected runways compared to dry runways.

Observations
Runway overruns remain a relatively common event in accidents involving Western-built, high-capacity jet aircraft. Frequently, long and/or fast landings and water-affected runways were factors in these accidents."

There were several similarities that could be drawn from the accidents above:

(i) Aircraft landed during conditions of heavy rain associated with thunderstorm activity at, or in close proximity to, the aerodrome.
(ii) Aircraft were high on the approach or glideslope.
(iii) Aircraft were not properly configured for landing.
(iv) The pilots made the decision to continue with the landing, with the option of a go-around.
(v) The aircraft landed deep.
(vi) The aircraft were not properly configured after touchdown (i.e. deployment of spoilers and improper application of reverse thrust).
(vii) The runway was contaminated.

1.18.8 Bristol International Airport (BIA), UK

On 29 December 2006, in three separate incidents, three aircraft flying in wet weather experienced difficulty in braking on an ungrooved runway surface and had difficulty in maintaining directional control. These incidents differed slightly from the others listed in that a programme of runway resurfacing was underway and there were temporary ungrooved asphalt surfaces on parts of the runway. Moreover, a NOTAM had been issued, stating that the runway "may be slippery when wet".

The pilot of a Boeing 737-800 managed to bring the aircraft to a stop just 200 m before the end of the runway surface. He stated that as the aircraft passed over the ungrooved runway surface the wheels had "locked up" and believed that the anti-skid system had not functioned properly due to the slipperiness of the surface.

The crew of an ATR-72 that landed 25 minutes later experienced difficulty in maintaining directional control as the speed decayed below 75 kt and the aircraft started drifting to the left of the centreline. The crew was unable to correct the condition and the aircraft departed from the paved surface onto the grass where it came to rest. The PIC stated that all the control inputs he had made to correct the situation had had no effect and he realised that the aircraft was hydroplaning.

Approximately nine hours after the ATR 72 had landed, the pilot of an Embraer 145 reported that soon after touchdown he experienced difficulty in maintaining the centreline. The left main gear ran off the runway pavement onto the grass surface for a distance of 85 m before the pilot gradually regained control and was able to steer the aircraft back towards the middle. The aircraft came to a halt with all the wheels on the runway surface. According to the pilot, they had skidded away completely from the centre section of the runway.

All three aircraft experienced similar conditions:

(i) They landed on a wet runway during rainy conditions;
(ii) They landed with a cross-wind component;
(iii) They reported reduced braking action on the ungrooved runway area.

The following day the airport authorities issued a revised NOTAM on the runway condition:

"due to rwy maint the rwy sfc btn the int of twys delta and foxtrot will be slippery when wet. variable friction co-efficient readings will be experienced throughout the rwy length and are avbl on request. acft handling difficulties may be experienced during crosswind conditions."

The ATC was in position to provide the crews of these aircraft with the friction coefficient of the runway, yet had merely communicated it as "good". The pilot of the Boeing 737-800 indicated that he found the information from the ATC to be misleading. Prior to the landing of the ATR 72, the runway friction was again measured by aerodrome authorities using a Mu-Meter. (The report provides friction values, but does not state whether these were measured at 65 km/h or 95 km/h. However, by evaluating the data, it can be concluded they were probably conducted at 65 km/h.) The crew of the Embraer 145 was informed by ATC that the braking action over the runway was "good", yet the crew was unable to maintain runway centreline.

1.18.9 Runway overrun accident – Miami, Florida, USA

On 15 December 1972, a Boeing 747-100 aircraft operated by a commercial airline collided with a flock of seagulls shortly after takeoff from Miami International Airport. It returned to the aerodrome and was cleared for the ILS approach for runway 27L. The wind was reported as 160° at 10 kt and the crew encountered light rain on the approach.

The runway had an asphaltic (bituminous and crushed lime rock mixture) surface with no gradient. The crown of the runway was graded 1% for 28 ft from the centreline, 1,5% for the next 14 feet and 2% for the remaining 33 ft to the runway edge. The accident occurred 38 days after the runway was opened to traffic after being resurfaced.

The FAA and NASA were requested to assist the NTSB gather data on the wet runway friction coefficient at the aerodrome. The NASA diagonal-braking vehicle was used to measure the slipperiness of the runways at varying depths of water on the surface, approximating conditions of steady and light rain (0,01 to 0,04 inches of water on the runway surface). The overall wet stopping distance ratio (SDR) was 3.22. The SDR on wet runway landing requirements specified by the FAA (reference number 121.195) was 1.92.

The report indicates that dynamic as well as viscous hydroplaning occurred in varying degrees along the runway surface. Scrub marks were evident over a substantial distance of the runway, which was associated with viscous hydroplaning. The following excerpt describes its characteristics:

"The term 'scrub' marks used in the report refers to marks of the tyre footprint found on the runway, which marks are lighter in colour than the surrounding surface. They are created by the release of water under pressure and the attendant heat from the tyre footprint. The degree of definition of the scrub mark is dependent upon other factors such as gross weight, speed, and the degree of friction and heat created by tyre skid. Scrub marks are commonly associated with viscous hydroplaning, whereas such marks are not present during dynamic hydroplaning.

The National Transport Safety Board determines that the probable cause of this accident was the ineffective braking capability of the aircraft on the wet runway because of the low coefficient of friction of the new runway surface, and insufficient engine reverse thrust and malfunction of the No. 3 engine reverser resulted in a directional control problem and the restricted use of No's 1 and 2 engine reversers."

Report reference No.: NTSB-AAR-73-13.

1.18.10 Overrun accident – Port Williams, Chile

On 20 February 1991, a British Aerospace BAE 146-200 aircraft operated by a commercial airline landed at Guardiamarina Airport in Port Williams, Chile. There had been a rain shower a few minutes prior to landing, and the aircraft, unable to stop on the asphalt runway, skidded more than 1 000 m into the Beagle Channel. Of the 60 passengers on board, 40 survived.

The BAE 146 accident in Port Williams and the EMB-135 accident at FAGG have four major similarities:

(i) Both runways were subjected to rehabilitation/maintenance work where a fog-spray was applied to the surface.
(ii) Both accidents occurred approximately one month after the maintenance work was completed.
(iii) In both accidents the runway surface was wet due to a recent rain shower.
(iv) Neither aircraft was equipped with thrust reversers.

The BAE 146 landed on runway 08 at Port Williams, which was 1 500 m long and had a downslope of 1,32%.

One month before the accident occurred, the runway was subjected to surface maintenance. During this process, a slurry seal was applied to 8 700 m² of the surface, mainly along the centreline of the runway but not along its entire length, and 3 to 4 m to both sides of the centreline.

After this, a fog-spray treatment was applied to the entire surface of the runway (50 160 m²), including those areas that had already received a slurry seal treatment.

In both accidents, the pilots applied maximum braking with full flaps extended and spoilers deployed.

The DFDR indicated that the BAE 146 had touched down at 112 kt and the speed at the end of the runway was 70 kt. The landing speed of ZS-SJW at FAGG was slightly higher and the speed at the end of the runway was 59 kt. However, the runway at FAGG was 500 m longer and had an upslope of 0,4%.

The contributory factors in the report of the BAE 146 accident were listed as:

(i) Landing with a tail wind component;

(ii) Downward-sloping runway;

(iii) Wet runway surface;

(iv) Poor braking action.

All aircraft systems were found to be fully functional during the landing roll. Apart from the fact that maintenance on the aerodrome was highlighted, there was no in-depth discussion in the report on the runway surface.

1.18.11 Departure off runway surface, Durban Airport, Report No. CA18/3/2/0659

On 18 June 2008, a Boeing 737-200, with six crew members and 87 passengers on board, veered partially off the runway after ground looping through 200° to the right following a deep landing in heavy rain. Nobody was injured in the incident.

The probable cause was attributed to incorrect landing technique, resulting in a deep landing and a subsequent ground loop.

The significance of the report was that it issued two safety recommendations to the SACAA pertaining to runway friction and wet runway conditions. These were:

"(i) It is recommended that the SACAA should, in compliance with the recommendations of Annexure 14, volume 1, section 7, define the minimum friction level and publish it in the Aeronautical Information Publication (AIP).

(ii) It is recommended that the SACAA should, in compliance with the recommendation of Annex 14, chapter 2, develop regulations with respect to the inspection of wet runways."

During the investigation into ZS-SJW, the appropriate division within the SACAA was requested to provide the investigators with evidence that the recommendations issued in the report (CA18/3/2/0659) had been actioned. No proof of such action could be obtained at the time the report was concluded.

1.18.12 Poor runway friction levels following application of fog-spray in Norway.

During early July 1995, the runway at Aalesund aerodrome, Vigra, Norway, was subjected to fog-spray treatment at night with an air temperature varying between 7 and 8 °C. Pilots reported experiencing slippery conditions when landing in wet weather conditions on the finished surface.

The fog-spray used, Neomex 40, was applied on continuous graded asphalt (Ab11). This differs from the one used at FAGG by its added solvent, which made it act as a rejuvenator. The application rate was 0,4 ℓ/m². Due to the intervention of non-skilled personnel, a second application of 0,4 ℓ/m² took place along the centreline area of the runway.

The problem was identified and a report issued. The following is an excerpt:

"When the area along the centreline, central parts of the runway were viewed, it appeared more shiny then the rest of the runway. In this shiny part, wheel tracks from aircraft landing and taking off appeared. A structural change in the upper layer took place when aircraft were landing and braking.

This structural change cannot alone be the cause since, according to information received, during dry conditions good skid resistance was experienced. The most probable theory was that the structural change combined with moisture and/or water on the runway surface causes slippery conditions as reported by several crews after landing.

On 9 August 1995 it was decided to wet the runway surface by making use of the fire services. The first crew that landed immediately after the runway was wetted, reported; "The anti-skid system worked violently.
A NOTAM, "Slippery when wet", was issued by the Norwegian regulating authorities.

Immediate corrective action was taken and steel brush sweepers, usually used for snow-cleaning, were used aggressively to improve the runway surface texture. Following these actions, no further incidents or accidents were reported at the aerodrome."

1.18.13 Runway excursion incident, Boeing 737-800, Hobart, Australia

On 24 November 2010, a Boeing 737-800 on a scheduled domestic flight from Melbourne to Hobart was involved in a runway excursion on landing at Hobart.

"The aircraft was cleared for the ILS approach runway 12. The crew were informed the runway was wet, but understood that the braking was good. Based on the reported weather, aircraft weight and airport conditions, the co-pilot calculated that a landing with the flaps set at 30° and the use of auto brakes 3 would provide sufficient braking for the landing distance available. The crew reported that there had been rain during the day; however, at the time of the approach the conditions were clear. The touchdown and initial deceleration was reported to be normal, with the thrust reversers and auto-braking operating correctly. At about 60 kt, the PIC took over control of the landing and braking. At that point, the aircraft was about three-quarters of the way through the landing roll, with the thrust reversers stowed and the autobrakes disengaged. He stated that soon after taking the control he did not get the braking response he expected. The PIC increased the braking pressure until he could not apply any more. The co-pilot reported that the last 1 000 ft (300 m) of the runway, the aircraft felt as if it were sliding or aquaplaning. The aircraft came to a stop, with the cockpit about 4 m beyond the end of the runway. They informed ATC of the overrun and taxied the aircraft to the gate.

The runway and stopway were inspected and no damage was found. Once the aircraft was shut down, the PIC inspected the tyres and brakes and determined that there was no damage. Recorded information: the flight data recorder (FDR) was removed from the aircraft for download and analysis. The data indicated that the aircraft touched down about 660 m (2 200 ft) along the 2 251 m (7 385 ft) runway, with a computed airspeed (CAS) of 143 kt. Based on that data, there was about a 10 kt tailwind at the time of the landing. The brakes were applied and the aircraft decelerated to 60 kt (CAS) about 1 800 m (5 900 ft) along the runway. Significant *brake pressure was applied in the last section of the landing roll.*

Hobart Airport consisted of one runway aligned 12/30, with a length of 2 251 m (7385 ft). The runway was level, with a grooved surface. The runway at Hobart was scheduled for a full resurfacing in 2012/2013. To lengthen the life of the runway it was resealed with a spray treatment called 'Liquid Road' in February 2010, to prevent the runway surface breaking up. Some sections of the runway had broken up and required patching; the patching was not grooved. On 16 September 2010, another crew of the aircraft operator had reported to the airport operator that the runway was slippery and performed as if it were ice-affected. After the report, the runway condition was reviewed by an airport pavement engineer and found to be satisfactory. On the day of the incident, the crew of another aircraft reported to ATC that the runway was slippery. However, the report was not passed onto the crew of the incident aircraft. After the incident, the runway and stopway area were inspected.

SAFETY ACTION

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

Aircraft Operator

As a result of this occurrence, the aircraft operator issued a flight crew operation notice (FCON), which informed flight crews of the incident and that in wet conditions, there had been less than the expected braking action reported at Hobart. Due to these reports, the FCON detailed modified wet runway takeoff and landing procedures for Hobart.

As a result of the occurrence, the airport operator conducted a review of the runway condition. On 25 November 2010, a Notice to Airmen (NOTAM) was issued stating that the runway may be slippery when wet, based on pilot reports of aquaplaning in heavy rain. On 10 December 2010, the NOTAM was reissued stating that the runway was not grooved and the En-Route Supplement Australia entry for Hobart Airport was amended to state that the runway was ungrooved. The operator also elected to remove the majority of the "liquid road" on 8 m either side of the runway centreline. This was completed on 11 January 2011. They have also brought forward a planned full resurfacing of the runway to November 2011."

1.18.14 Determination of friction characteristics of wet paved runways

Reference: ICAO Annex 14, volume I, attachment A, guidance material supplementary to Annex 14, volume 1 (ZS-SJW investigators' emphasis in bold).

"*7.1 The friction of a wet paved runway should be measured to:*

a) verify the friction characteristics of new or resurfaced paved runways when wet (chapter 3, 3.1.24);
b) assess periodically the slipperiness of paved runways when wet (chapter 10, 10.2.3);
c) determine the effect on friction when drainage characteristics are poor (chapter 10, 10.2.6); and

d) determine the friction of paved runways that become slippery under unusual conditions (chapter 2, 2.9.8).

7.2 ***Runways should be evaluated when first constructed or after resurfacing to determine the wet runway surface friction characteristics.****. Although it is recognised that friction reduces with use, this value will represent the friction of the relatively long central portion of the runway that is uncontaminated by rubber deposits from aircraft operations and is therefore of operational value. Evaluation tests should be made on clean surfaces. If it is not possible to clean a surface before testing, then for purposes of preparing an initial report a test could be made on a portion of clean surface in the central part of the runway.*

7.3 Friction tests of existing surface conditions should be taken periodically in order to identify runways with low friction when wet. ***A State should define what minimum friction level it considers acceptable before a runway is classified as slippery when wet and publish this value in the State's aeronautical information publication (AIP). When the friction of a runway is found to be below this reported value, then such information should be promulgated by NOTAM****. The State should also establish a maintenance planning level, below which, appropriate corrective maintenance action should be initiated to improve the friction. However, when the friction characteristics for either the entire runway or a portion thereof are below the minimum friction level, corrective maintenance action must be taken without delay. Friction measurements should be taken at intervals that will ensure identification of runways in need of maintenance or special surface treatment before the condition becomes serious. The time interval between measurements will depend on factors such as: aircraft type and frequency of usage, climatic conditions, pavement type, and pavement service and maintenance requirements.*

7.4 For uniformity and to permit comparison with other runways, friction tests of existing, ***new or resurfaced runways should be made with a continuous friction measuring device provided with a smooth tread tyre. The device should have a capability of using self-wetting features to enable measurements of the friction characteristics of the surface to be made at a water depth of at least 1 mm.***

7.5 ***When it is suspected that the friction characteristics of a runway may be reduced because of poor drainage, owing to inadequate slopes or depressions, then an additional test should be made****, but this time under natural conditions representative of a local rain. This test differs from the previous one in that water depths in the poorly cleared areas are normally greater in a local rain condition. The test results are thus more apt to identify problem areas having low friction values that could induce aquaplaning than the previous test. If circumstances do not permit tests to be conducted during natural conditions representative of a rain, then this condition may be simulated.*

7.6 Even when the friction has been found to be above the level set by the State to define a slippery runway, it may be known that under unusual conditions, such as after a long dry period, the runway may have become slippery. When such a condition is known to exist, then a friction measurement should be made as soon as it is suspected that the runway may have become slippery.

7.7 When the results of any of the measurements identified in 7.3 through 7.6 indicate that only a particular portion of a runway surface is slippery, then action *to promulgate this information and, if appropriate, take corrective action is equally important.*

7.8 When conducting friction tests on wet runways, it is important to note that, unlike compacted snow and ice conditions, in which there is very limited variation of the friction coefficient with speed, ***a wet runway produces a drop in friction with an increase in speed.*** *However, as the speed increases, the rate at which the friction is reduced becomes less. Among the factors affecting the friction coefficient between the tyre and the runway surface, texture is particularly important. If the runway has a good macro-texture allowing the water to escape beneath the tyre, then the friction value will be less affected by speed.* ***Conversely, a low macro-texture surface will produce a larger drop in friction with increase in speed. Accordingly, when testing runways to determine their friction characteristics and whether maintenance action is necessary to improve it, a speed high enough to reveal these friction/speed variations should be used.***

7.9 Annex 14, volume I, requires States to specify two friction levels as follows:

a) a maintenance friction level below which corrective maintenance action should be initiated; and
b) a minimum friction level below which information that a runway may be slippery when wet should be made available.

Furthermore, States should establish criteria for the friction characteristics of new or resurfaced runway surfaces. Table A-1 provides guidance on establishing the design objective for new runway surfaces and maintenance planning and minimum friction levels for runway surfaces in use."

1.18.15 Previous landings by the accident aircraft

The DFDR data for three landings by ZS-SJW that took place the day prior to the accident (6 December 2009) were also downloaded and reviewed, as well as the two landings on the day of the accident prior to the overrun accident at FAGG. It should be noted that a different crew flew the aircraft on 6 December 2009.

The landing at FACT (Figure 54), the departure destination for the aircraft prior to the landing at FAGG, was also conducted on a wet runway surface. The PF stated that during the landing at Cape Town he had experienced some hydroplaning but had been able to control the aircraft and bring it to a safe stop within the runway surface available. It was evident from the DFDR data that good braking action was obtained during brake application, with a deceleration of approximately -0,2g being obtained over a five-second time-frame, with an average brake pressure of approximately 800 psi. This was followed by a further deceleration of approximately -0,14g for another five seconds. The runway was 1 200 m longer than that at FAGG.

It should be noted that during landings #2 (Harare), #4 (Upington) and #5 (Cape Town), for several seconds after touchdown (ground mode) no brake pressure was applied to slow down the aircraft. The runways in question were, however, substantially longer than that at FAGG, and dry in both Harare and Upington. The runway lengths and elevation of each aerodrome are listed below each of the parameter graphs. During landing #1, the brake pressure went up to approximately 1 200 psi and during landing #3 it went as high as 2 000 psi. For the other three, average brake pressure was about 1 000 psi.

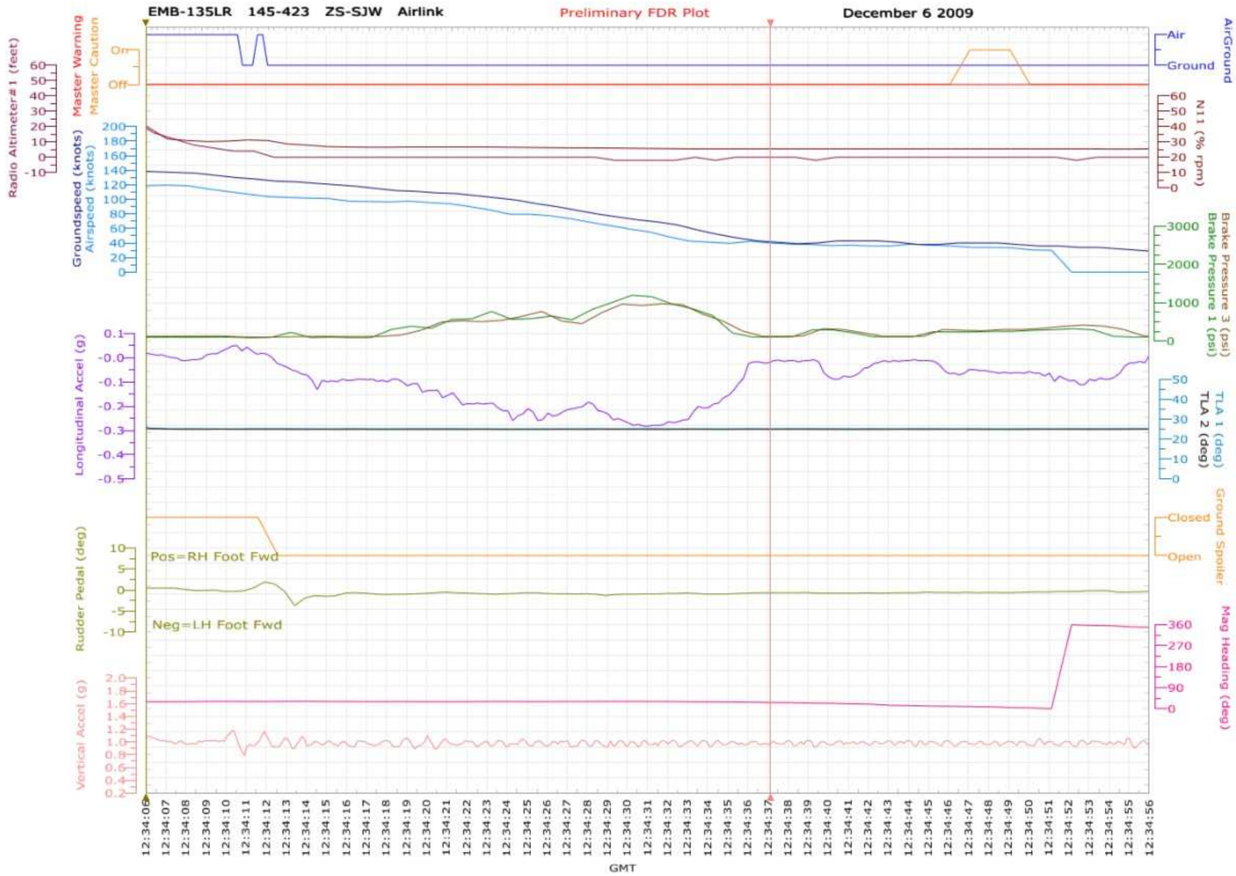


Figure 50: Landing #1, O.R. Tambo International Airport, 6 December 2009.
Runway 03R, length 3 400 m, elevation 5 558 ft.

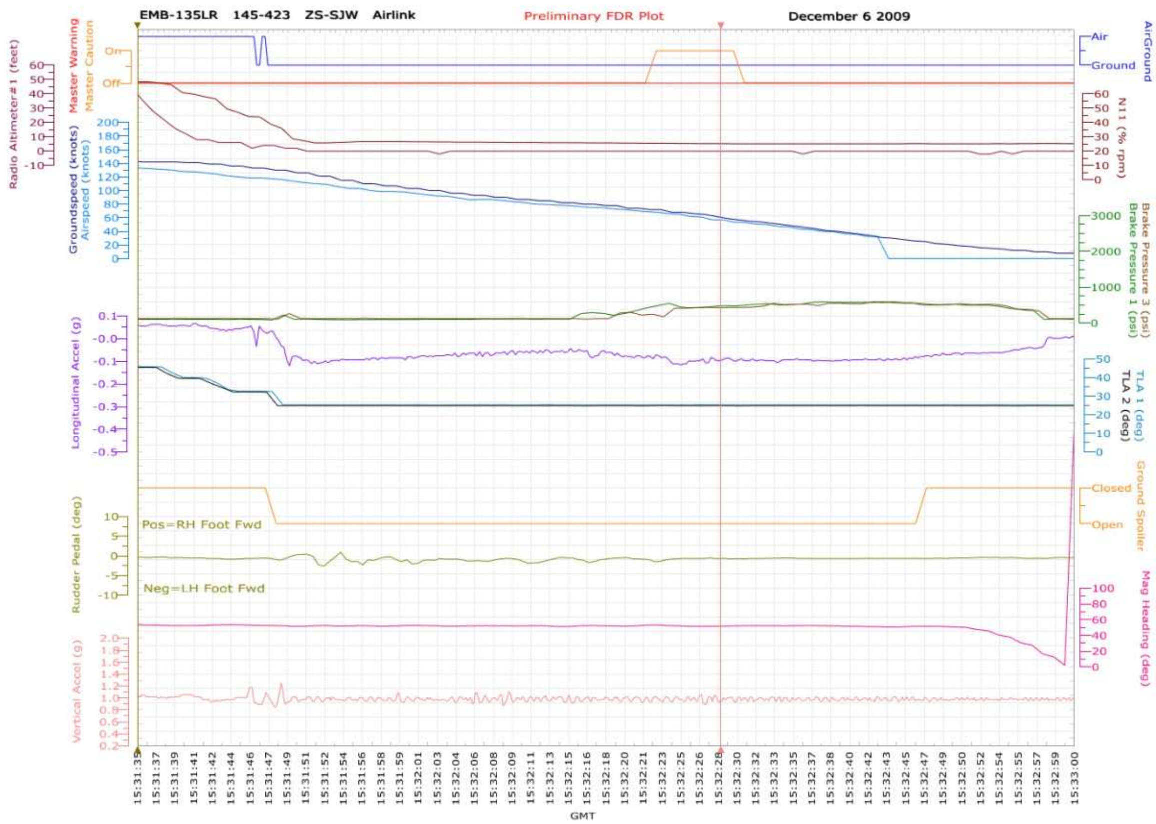


Figure 51: Landing #2, Harare International Airport. 6 December 2009.
Runway length 4 725 m, elevation 4 901 ft.

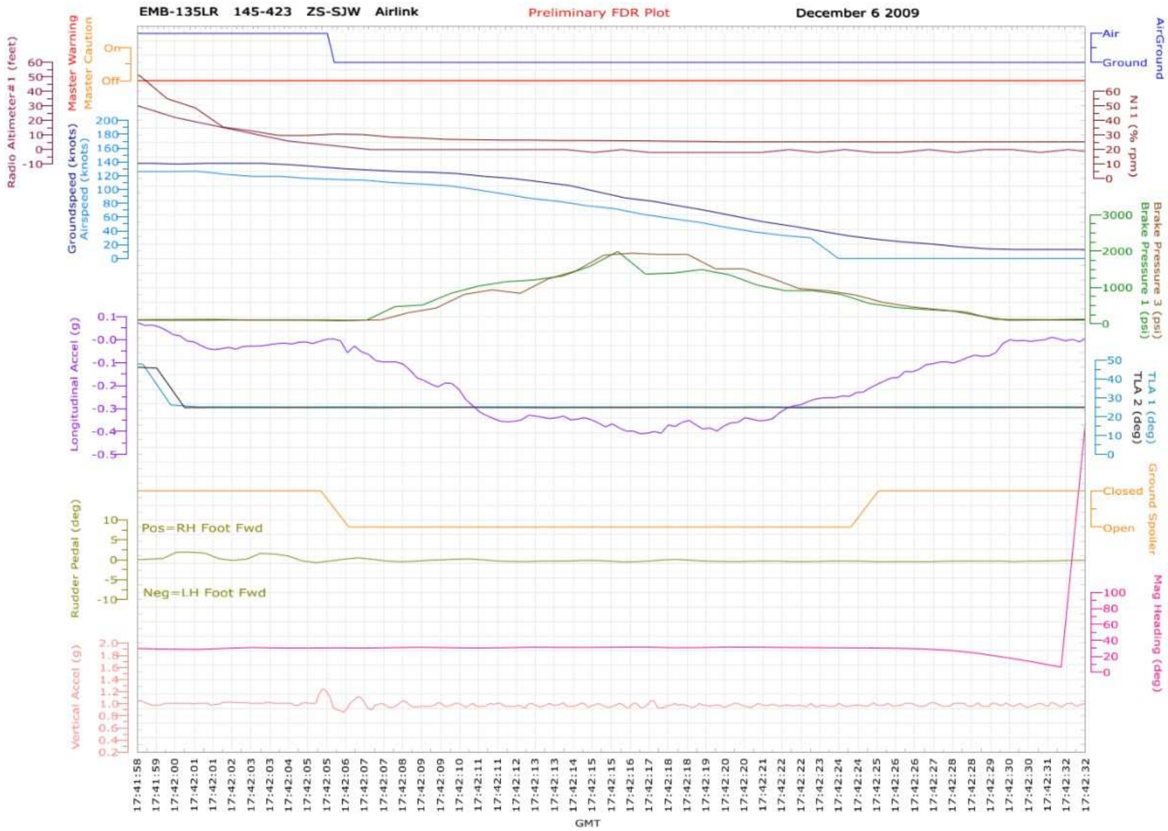


Figure 52: Landing #3, O.R. Tambo International Airport, 6 December 2009.
Runway 03R, length 3 400 m, elevation 5 558 ft.

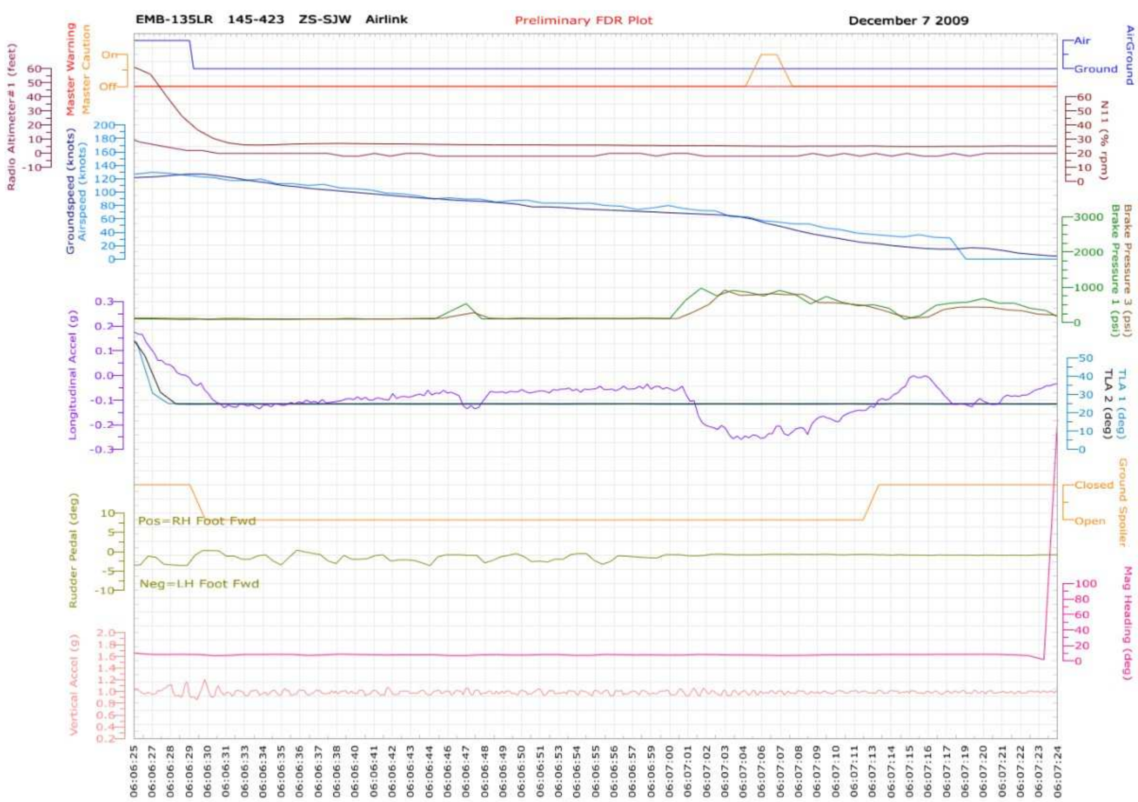


Figure 53: Landing #4, Upington International Airport, 7 December 2009.
Runway length 4 900 m, elevation 2 791 ft.

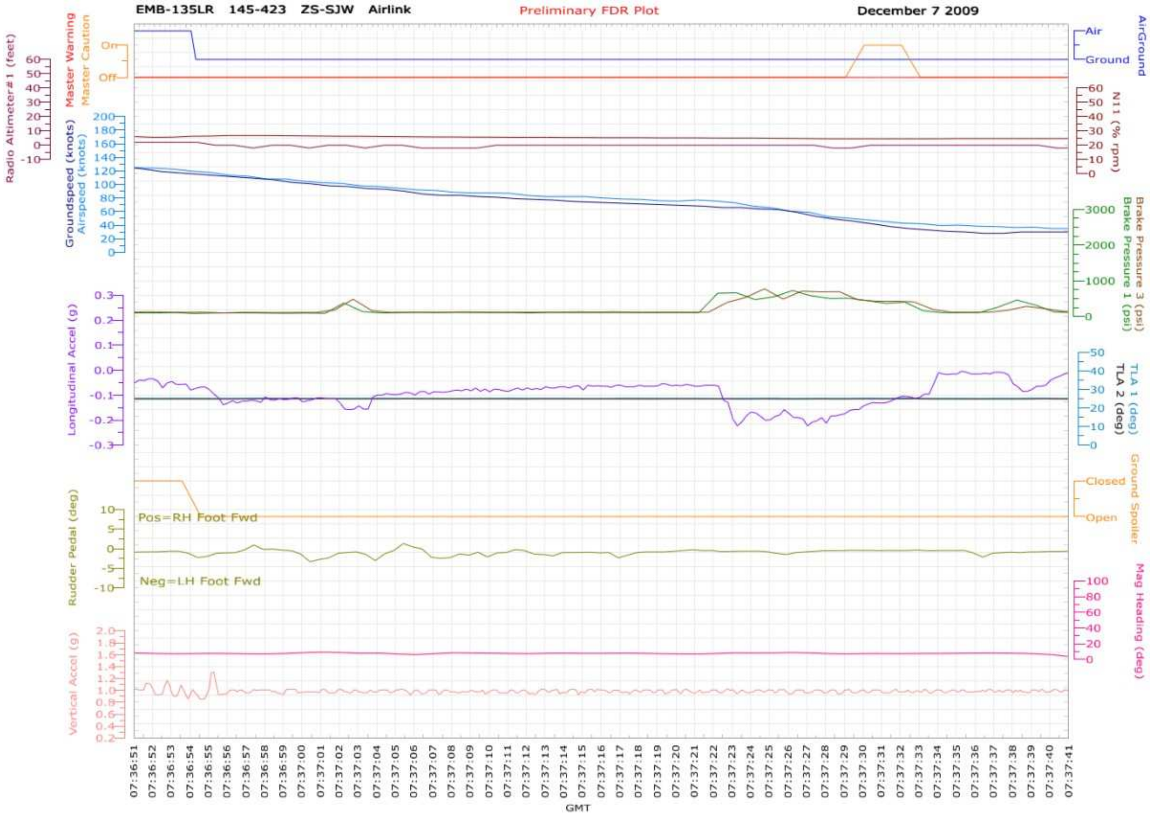


Figure 54: Landing #5, Cape Town International Airport, 7 December 2009.
Runway length 3 200 m, elevation 151 ft.

1.18.16 Runway overrun accidents

Studies addressing runway overrun accidents have been conducted by many institutions. The following is an excerpt from one conducted by the Dutch Nationaal Lucht- en Ruimtevaartlaboratorium (NLR).

"The NLR Air Transport Safety Institute in the Netherlands has studied 400 landing overrun accidents of commercial transport aircraft that took place during the period 1970 - 2004 (35 years). During the study it was estimated that approximately 796 million landings were conducted worldwide with passenger and cargo aircraft with a takeoff mass of 5 500 kg or higher. The estimated landing overrun accident rate for the study period was 0,5 per million landings worldwide. The study also found that the landing accident overrun rate between jets and turboprop aircraft was not statistically significant at the 5% level, which meant that the probability of a landing overrun accident of a jet aircraft is not different from a turboprop aircraft.

The objectives of the study were to identify the most important risk factors associated with landing overrun accidents and to see if there were any trends in landing overruns.

There are a number of factors that influence the landing performance. To understand this we should need to know what is a "good" landing.

In short a "good" landing has the following characteristics:

1. *It starts with a stabilised approach on speed, in trim and on glide path.*
2. *During the approach the aircraft is positioned to land in the touchdown zone.*

3. Over the threshold the aircraft crosses at the correct height and speed.
4. The approach is ended by a flare without any rapid control column movements, which is followed by a positive touchdown without floating.
5. After touchdown of the main gear, the spoilers (if available) are raised (manually or automatically), the brakes are applied (manually or automatically), (if available) the thrust reversers or propeller reverse thrust is selected and the nose lowered.

Important: These actions should all be conducted without delay and according to the standard operating procedures. However, not many landings are conducted like this every day and deviations from this good practice occur often without any serious consequences. However, when there are large deviations from the "good" practice it can become more difficult to stop the aircraft on the runway.

There appears to be significant increases in landing overrun risk when one of the following factors is present during landing:

1. Non-precision approach
2. Visual approach
3. Excess/high approach speed
4. High on the approach
5. Touching down far beyond the threshold (long landing)
6. Significant tailwind present
7. Wet/flooded runway surface, and/or
8. Snow/ice/slush covered runway
9. Late or no application of available stopping devices

The highest risk increase occurred when the aircraft touched down far beyond the threshold (long landing), followed by excess approach speed.

Over the period of 35 years, the landing overrun accident rate has reduced considerably. This reduction is most likely the result of a number of factors including:

1. Improvement in braking devices (anti-skid, auto-brakes etc)
2. Better understanding of runway friction issues
3. Safety awareness campaigns"

1.18.17 Embraer 135/145 aircraft hydroplaning susceptibility

The investigators established that between 12 October 1999 and 1 July 2010, a total of 27 overrun occurrences with the Embraer 135/145 had been reported to the aircraft manufacturer. It should be noted that these included incidents, serious incidents and accidents and not all had resulted in damage to the aircraft. According to the manufacturer, the Embraer 135/145 fleet had accumulated a total of 14 294 656 flight cycles as at 1 July 2010.

According to the NLR-ATSI air safety database, the rate of landing overruns in all commercial passenger/cargo operations between 1995 and 2009 was one landing overrun in 1,8 million landings, compared with the Embraer 135/145 rate of one landing overrun in two million landings. Thus the landing overrun rate of the Embraer 135/145 fleet is not significantly worse or better than the overall industry average (there is no difference at the 5% significance level).

There is a possibility that the inclusion of updated data could raise the rate slightly as four known landing overruns occurred with the Embraer 135/145 family of aircraft in 2010 – the latest figures available. However, finalised figures for 2010 were not available at the time of writing, so no data later than 2009 was included in the estimation.

1.18.18 Condition of the aircraft tyres (post-crash)

Both nose wheel tyres were found to be deflated, a fact attributed to impact damage. However, they displayed adequate tread depth. All four main tyres, which remained inflated, showed evidence of viscous hydroplaning. Two of the main tyres displayed a tread depth of approximately 0,5 mm.

Figure 55(a): The nose wheel tyres.

Figure 55(b): The left main gear tyres.

Figure 55(c): The right main gear tyres.

The Dunlop Aircraft Tyres general practices manual contains the following information on tyre wear limits:

<u>"3. Tyre Inspection (Wear Limits)</u>

A. Introduction

(1) *You must examine tyres installed on an aircraft regularly for wear as a part of routine maintenance. Replace a tyre which is worn more than the limits specified (Ref, Para. 3.B. to G.).*

B. Retreadable Tyre

(1) Replace a retreadable tyre when it is worn to these limits:

(a) The first time the wear (where the wear occurs most quickly) is down to the bottom of a groove at a point on the tread circumference, or

(b) The first time the fabric can be seen at a point on the tread circumference (although the remaining tread is satisfactory).

<u>NOTE</u>: Usually a tyre is not retreadable if it is worn more than the above limits.

C. Non-Retreadable Tyre

(1) Remove and discard a non-retreadable tyre if it is worn to these limits:

(a) For a bias (cross-ply) tyre, the first time the casing ply can be seen (at the location where the wear occurs most quickly).

(b) For a radial-ply tyre, the first time the nylon belt can be seen (at the location where the wear occurs most quickly).

D. Tyre with Nylon Fabric included

(1) In some types of high speed tyre, the tread can include nylon fabric to give more strength. This fabric shows in the tread pattern as the tyre wears during the life of the tread.
(2) Replace a tyre with nylon fabric included when it is worn as specified in para. 3.B. or 3.C., as applicable.

E. Tyre in Very Wet Operational Conditions

(1) Very wet operational conditions could cause aquaplaning during a landing. For such conditions, replace a tyre the first time the wear shows a groove depth of less than 2 mm (0,08 in.) at a point on the tread circumference.

(The investigating team had requested Dunlop Aircraft Tyres to provide them with the definition of *"Very Wet".* At the time this report was concluded, no such response had been obtained from them.)

F. Multi-dimple Tyre

(1) Replace a multi-dimple tyre the first time the tread in a row of dimples is worn to the bottom of the dimples.

G. Twin-contact Tyre

(1) Replace a twin-contact tyre the first time the centre of the crown shows signs (roughness of marks) that it has touched the ground."

1.18.19 Aircraft movements at FAGG on 7 December 2009

The table below shows a summary of movements from 0700Z until 1612Z. *(Source: aerodrome licence holder representation document)*

Hour (Z)	Rainfall (mm)	Flight No.	Arrival/ Departure	Aircraft registration	Aircraft type	Time	Runway used
0700 - 0800	2 mm	RNX821	Arrival	ZS-TRF	MD-82	0722	29
		Private	Arrival	ZS-MMG	Gulfstream	0751	29
0800 - 0900	1 mm	CAW909	Arrival	ZS-OTF	B737-400	0800	29
		EXY501	Arrival	ZS-JES	F-28	0819	11
		RNX822	Departure	ZS-TRF	MD-82	0840	11
		Private	Departure	ZS-MMG	Gulfstream	0843	11
		EXY502	Departure	ZS-JES	F-28	0853	11
		CAW910	Departure	ZS-OTF	B737-400	0858	11
0900 - 1000	2 mm	**SA8256**	Arrival	**ZS-SJW**	**ERJ-135**	0911	11
1000 - 1100	6 mm						
1100 - 1200	0,8 mm	EXY813	Arrival	ZS-NMH	CRJ-2	1131	11
		CAW241	Arrival	????	B737-200	1141	11
1200 - 1300		SFE012	Arrival	ZS-NYM	Pilatus C12	1218	11
		REJ639	Arrival	ZS-OTM	ERJ-135	1255	11
1300 - 1400	6,4 mm	SFE210	Departure	ZS-NYM	Pilatus C12	1322	11
		REJ638	Departure	ZS-OTM	ERJ-135	1341	29
		CAW231D	Departure	ZS-OLA	B737-200	1343	29

		EXY901	Departure	ZS-NMH	CRJ-2	1351	29
1400 - 1500	6,2 mm	CAW901	Arrival	ZS-OTF	B737-400	1427	11
		CAW241D	Departure	ZS-NNH	B737-200	1435	11
		EXY505	Arrival	ZS-JES	F-28	1444	11
		Private	Departure	N526EE	Gulfstream 5	1446	11
		REJ900	Arrival	ZS-OTN	ERJ-135	1451	11
1500 - 1600	6,4 mm	EXY509	Arrival	ZS-NLV	CRJ-7	1514	11
		CAW902	Departure	ZS-OTF	B737-400	1522	11
		EXY506	Departure	ZS-JES	F-28	1539	11
1600 - 1700	0,8 mm	EXY510	Departure	ZS-NLV	CRJ-7	1612	11

The table shows all the aircraft movements from the time it started raining at the aerodrome at 0700Z. Amongst these were two Embraer 135s, similar to the accident aircraft. The ZS-SJW accident took place at 0901Z. By the time the other Embraers landed, significantly more rain had fallen.

1.18.20 Post-accident intervention by the aerodrome licence holder

Following the accident in question, 1 800 m of the runway length at FAGG was resurfaced, with the task being completed on 26 May 2010. Twenty millimetres of the original surface was milled out and replaced with the same depth of ultra-thin friction course (UTFC). This met the minimum requirements for a new runway surface as stipulated in ICAO Annex 14, chapter 3, paragraph 3.1.25, by displaying an average surface texture depth of at least 1 mm. From the time this resurfacing project was completed until the accident report was concluded, no incidents associated with the runway surface were reported to the AIID of the SACAA.

1.19 Useful or effective investigation techniques

1.19.1 None.

2. ANALYSIS

The investigation of the ZS-SJW accident focused on the following:

- General
- The approach
- The landing
- The aircraft (performance and associated systems)
- The runway surface;
- The runway end safety area (RESA)
- Meteorological conditions
- Survivability
- Civil aviation authority oversight
- Assessment

2.1 General

The pilots were properly certificated and qualified under the Civil Aviation Regulations to perform the flight. No evidence indicated any medical or behavioural conditions that might have adversely affected their performance during the accident flight. There was no evidence of flight crew fatigue.

The accident aircraft was properly certificated, and was equipped, maintained, and dispatched in accordance with industry practices.

No evidence indicated any failure of the engines, structures or systems that would have affected the aircraft's performance during the accident landing. However, the advanced state of wear displayed by two of the four main tyres was regarded as having had a significant effect on the wet-runway braking effectiveness of the aircraft, which is highly dependent on tyre tread and design.

The pilots received weather updates *en route* from FACT to FAGG as well as on the approach for the landing, when ATC provided them with regular wind checks on the final approach phase of the flight. He also advised the crew that "it looked like there is rain to the west but overhead the field it is overcast at about 10 000 ft". The investigating team concluded that the pilots had adequate initial and updated weather information throughout the flight, which was supported by ATC communication advising them during the final segment of the approach that the runway was wet.

Numerous investigation reports and studies have been written on runway overrun accidents, with a few being described in this report. These accidents occurred during both day and night approaches and involved well-trained crews. Despite the experience and professionalism shown by so many pilots, these types of accidents continue to occur.

Although most overrun accidents, including this one, have unique elements, there are also many similarities. Throughout the industry, the experience gained by studying these accidents has been used to develop awareness programmes and improve training procedures. Despite efforts by the operator, the accident at FAGG highlights several of the common problems that these programmes and training procedures aim at preventing, which is a concern. There is a clear indication that although much is learned from previous accidents, the aviation industry seems unable to develop adequate tools to prevent these accidents from occurring.

Some or all of the following conditions were present in all of these accidents:

- The crews were on approach behind or in front of other aircraft that were landing or intending to land;
- A cumulonimbus cloud or monsoon storm was approaching or was over the landing area at the time of landing;
- There was heavy rain;
- The runway was wet due to the rain;
- The runway was slippery, affecting the braking forces generated by the aircraft's tyres and delaying wheel spin-up;
- Poor braking action was either reported by previous aircraft or was experienced by the crew of the accident aircraft;
- There was a strong crosswind, tailwind, or a combination of both;
- The aircraft deviated from the target or approach speed and glideslope;
- There was a wind-shear, perhaps associated with downdrafts;
- The approach was not stabilised;

- A missed approach or baulked landing was not considered or attempted;
- The aircraft landed long or floated for some time before touchdown;
- The after-touchdown actions by the crews were non-standard;
- The crew was subjected to sudden reduced visibility, which they had not anticipated properly and for which they were unprepared (a common occurrence).

What was lacking in several of the studies reviewed was the condition of the runway surface and the associated braking friction coefficient and data during wet conditions. In fact, there is little information available generally on runway characteristics, friction coefficients, and micro and macro surface texture.

2.2 The approach

The pilots involved in this accident had landed many times at FAGG in wet weather in an Embraer 135, and were familiar with the aerodrome. Confident in their ability to perform a safe landing, they continued with the approach and landing. However, this was their first wet weather landing at FAGG since the conclusion of the rehabilitation project on runway 11/29.

At 08:47:13Z, ATC cleared the aircraft for an ILS approach for runway 11. At 08:59:05Z, the pilots radioed the ATC: *"Regional Link 625 is clear, is established localiser runway 11 at 9 500 ft, field in sight".* According to the PF, he saw the runway as he broke through the cloud at a height of between 800 ft and 1 000 ft above aerodrome level (AAL) and about 7 nm DME on final approach. From this point, the aerodrome remained visible.

The airspeed remained at about 15 kt above the V_{REF} speed during the final approach phase of the flight. At 09:00:30 the PF requested full flaps (45°) at a pressure altitude of 1 168 ft or 546 ft AAL at a speed of 140 KIAS, which was within the flap maneuvering speed limit as contained in the operations manual SOP B1/EMB135-2-57. Ten seconds later, at 09:00:40, the flaps were in the fully down position. At that stage the pressure altitude was 998 ft, which accounted for a height of approximately 376 ft AAL.

The PF was aware of the fact that the speed remained above the target speed (V_{REF}) for the remainder of the approach. This could be attributed to the tailwind encountered during final approach. The fact that the aircraft was fully configured for landing (landing flaps, gear down) below 500 ft AAL had a distinct effect on the final approach speed even though the vertical profile had been corrected by the time the aircraft reached the target height of 50 ft above the runway threshold. The excess threshold speed inevitably resulted in a longer landing than expected. The crew, however, continued with the visual approach with the ILS selected. The operator had clear guidelines on a stabilised approach in the operations manual, SOP B1/EMB135-1-8, which were not met in totality. However, they continued with the approach and subsequent landing. At no stage during the approach was there any discussion between the two flight crew members (CVR data) of them considering performing a go-around.

2.3 The landing

The aircraft was at the target height of 50 ft above the runway threshold at 143 KIAS (V_{REF} + 15 kt). The aircraft first touched down on runway 11 at 09:01:10.1

at a speed of 132 KIAS within the touchdown zone past the 305 m (1 000 ft) landing point. It transitioned back into air mode for 1.5 seconds and touched down again at 128 KIAS. The brief air-ground transition could be attributed to the excessive threshold speed, with the aircraft floating as the excess speed dissipated. High speeds during the approach have a profound influence on the airborne distance once the aircraft has crossed the threshold. From 09:01:11.6, the aircraft remained on the ground and the spoilers deployed immediately, remaining deployed throughout the rollout.

Braking action was delayed by approximately four seconds after the aircraft settled onto the runway surface. Brakes decrease stopping distance most effectively when they are applied at high speed; any delay in brake application after touchdown considerably increases stopping distance because the highest speed during the ground roll (the most distance travelled per unit of time) occurs immediately after touchdown. Interrupted brake application at lower speeds is less important because the aircraft is not consuming as much runway. During wet or slippery runway conditions, which degrade an aircraft's landing performance, rapid braking is even more critical. The delayed brake application resulted in more than 300 m of runway being used, reducing the remaining distance available to decelerate to a safe stop.

According to available information, the aircraft was subjected to a 5 kt headwind component on touchdown. Passengers described the landing as smooth, which was not ideal given the wet runway surface. The recommended practice during wet weather operations is that the aircraft should be flown onto the runway positively and the various deceleration systems – brakes, auto-brakes, ground spoilers and thrust reversers – activated without delay. According to the approved flight manual figures applicable to the landing weight, the aircraft should have been able to stop in the distance available. The runway was 2 000 m long, had an upslope of + 0,4% and had a 60 m asphalt surface stop-way at the end.

According to the PF, once he applied the brakes, he did not release them again. Towards the latter stage of the landing roll, the PNF also applied the brakes to help the PF, with little or no effect.

According to the DFDR, the longitudinal acceleration between 09:01:22 and 09:01:35 displayed deceleration values of between -0,051g and -0,178g (average deceleration was -0,106g), whereas levels of more than -0,15g were required to stop the aircraft. The DFDR graphic data of this time frame shows a zigzag pattern, reflecting the anti-skid of the aircraft constantly activating and releasing. This had a direct effect on the braking action of the aircraft, which significantly underperformed during a critical deceleration phase of the landing rollout. The Embraer 135 is designed and certified to be operated safely without thrust reversers or auto-braking. It was therefore fully reliant on its braking system, including the spoilers assisted by aerodynamic drag (full flap selection of 45° and the fuselage) to come to a stop.

The brake pressure from 09:01:16 to 09:01:39 – the period that the aircraft was on the runway surface – displayed an average of 427 psi. If the next two seconds are added to include the aircraft's travel on the 60 m asphalt stop-way, the average brake pressure goes up to 438 psi. During operations on a dry runway surface, the brake pressure can go as high as 3 000 psi. The maximum brake pressure during the rollout, as shown on the DFDR data, is 1 040 psi for one second, recorded shortly before the aircraft left the paved stop-way and rolled onto the grass. The flight crew indicated that they applied maximum braking, but the anti-skid system limited the actual brake pressure to prevent the wheels from locking and they were unable to stop the aircraft on the runway surface available. The ground rollout distance over this time frame – 09:01:16 to 09:01:41 – was about 1 100 m.

The main landing gear tyres displayed evidence of hydroplaning as well as rubber reversion. The investigators were unable to establish with certainty at what stage of the landing rollout this phenomenon occurred but believed it to be towards the end, during the possible activation of the park brake. The scrub markings on the runway surface in the latter stages of the landing rollout indicate that substantial heat was generated between the tyre footprint and the runway surface, which can only occur when water is present on the surface. Tyres skidding on a thin layer of water heat up the water so that scrub markings form on the surface, and these could be associated with hydroplaning.

The braking effectiveness of the aircraft was also influenced by the condition of the main tyres. Two of the four main tyres displayed more than 80% wear, with the result that there was little to no tread to displace the water. The NASA technical note TN D-2770, *"An investigation of the influence of aircraft tyre-tread wear on wet-runway braking"*, already referred to in this report, states that once tyre wear passes 80% wear, braking effectiveness drops noticeably, and tyres should be replaced before the thread is worn completely smooth and safety requirements are compromised. (The minimum tyre tread depth is clearly defined for motorists in order not to compromise safety). The report also states that small amounts of water on the runway can have a significant effect on braking effectiveness.

Several factors can cause hydroplaning on a wet runway. They include:

- The presence of standing water due to poor drainage, inadequate camber and surface unevenness;
- The micro- and macro-texture of the runway surface (the texture provides paths for water to escape beneath the tyres); and
- A low friction coefficient of the surface when wet.

Water drainage becomes more critical as the speed of the aircraft increases, the tread depth of the tyres decreases, and water depth increases. All three contribute to hydroplaning.

The aircraft rolled off the end of runway 11 to the right of the centreline at a speed of approximately 59 KIAS and left the end of the 60 m asphalt stop-way at 52 KIAS. The PF steered to the right of the centreline when he realised that the aeroplane was not going to come to a halt on the runway surface. At the end of the stop-way, the terrain began sloping down at an angle of approximately 5°. The aircraft collided with the runway 29 approach lighting support structures at about 40 KIAS. There was no RESA at the end of the runway and the aircraft travelled for a further 278 m before bursting through the aerodrome perimeter fence, slipping down an embankment and coming to rest on the R404 road.

2.4 The aircraft

All aircraft systems were serviceable and worked as designed throughout the approach and landing of flight SA8625, and no mechanical malfunction contributed to the accident. The anti-skid braking system, along with the ground spoilers of the aircraft, operated correctly, with the wheels spooling up on touchdown and allowing the spoilers to deploy.

Although the crew braked as hard as possible, they were unable to apply sufficient brake pressure to stop the aircraft before the end of the runway. The deceleration obtained was on average -0,106g, whereas levels of more than -0,15g were required to stop the aircraft in the distance available. As a result of this, the serviceability of the braking systems was reviewed. The Embraer 135 is not fitted with thrust reversers and is therefore fully reliant on the braking system of the aircraft (which includes the spoilers) to come to a stop. It was found, however, that the systems worked as they were designed to do. DFDR data revealed that the anti-skid system significantly reduced the pressure applied to the brakes, keeping it at an average pressure over the entire landing roll of just 388 psi. For brakes to function optimally, skidding has to be prevented, as it increases the required distance to bring the aircraft to a stop.

Examination of the four main tyres indicated that hydroplaning had indeed occurred, as these tyres displayed evidence of reversion and peeling of the compound. This occurs when there is sufficient water on the runway and the tyre tread fails to displace the standing water, causing spin-down of the tyre and hydroplaning. As the tyres moves along the surface without rotating, the friction between the water film and the rubber generates heat, resulting in a thin layer of melted rubber on the runway surface. Scrub marks, which are lighter in colour than the tarmac, could be seen towards the end of runway 11 and on the 60 m asphalt stop-way (see Figure 34) as the aircraft started to change heading prior to departing the asphalt surface. These markings can also be associated with viscous hydroplaning, an observation referred to on page 3 of the Dunlop tyre report, a conclusion that was based purely on the appearance of the tyres.

Hydroplaning is primarily due to some form of contamination, which can include standing water on a runway surface. It was found that two of the four main tyres displayed an advanced state of wear, and would therefore have been almost unable to displace standing water during the landing rollout. The tread on the other two main tyres was in much better condition. During the landing at FACT, the departure aerodrome for the flight to FAGG, the aircraft also landed on a wet runway, and the PF stated that they had experienced a certain amount of hydroplaning here too.

2.5 The runway

The most significant change during the runway rehabilitation programme was the application of a bitumen emulsion fog-spray – SS 60 stable mix bitumen emulsion – to the surface during October 2009. The application of fog-spray can be considered as a relatively inexpensive way to extend the service life of a pavement surface.

The rehabilitation project was reviewed and the following observations were made.

(i) The subcontractor earmarked to apply the product SP 2000 during the rehabilitation withdrew from the project. After the evaluation of the runway friction values obtained from friction tests on 1 September 2009, during which a small patch on the western side of runway 29 was treated with SP 2000, the subcontractor informed the contractor that they regarded their product as unsuitable for the purpose it was intended for. They also expressed the opinion that the possibility of hydroplaning could not be ruled out during wet weather operations if the product were applied. A new service provider was appointed and the SP 2000 was replaced by SS 60 stable mix bitumen emulsion fog-spray. A total of 50 200 litres of this new product to the runway at an average application rate of 0,53 ℓ/m² at the end of October 2009. It was applied to the entire runway surface, including both 60 m stop-ways. No evidence could be obtained to demonstrate that the SS 60 was tested in the same way as the SP 2000 prior to being applied.

(ii) Six days after the application was completed, on 6 November 2009, a friction test was performed. This was conducted at various runway intervals and distances from the centreline at a speed of 65 km/h on a dry runway surface. The results showed an overall runway friction value of 0,40, which was below the *"minimum friction level of 0,43"* as contained in ICAO Annex 14, volume I, attachment A, table A-1: Friction levels for new and existing runway surfaces.

The friction data was made available to the aerodrome licence holder by the service provider, who in turn made it available to the regulating authority. No corrective actions, including the issue of a NOTAM or any engineering intervention, were forthcoming from either the regulating authority or the aerodrome licence holder following these test results, even though the results did not meet the minimum friction levels and posed a serious risk to landing and departing aircraft.

Attachment A, guidance material supplementary to ICAO Annex 14, volume I, sub-heading 7.3, contains the following in this regard (investigators' emphasis in bold):

"Friction tests of existing surface conditions should be taken periodically in order to identify runways with low friction when wet. A State should define what minimum friction level it considers acceptable before a runway is classified as slippery when wet and publish this value in the State's aeronautical information publication (AIP). ***When the friction of a runway is found to be below this reported value, then such information should be promulgated by NOTAM.*** *The State should also establish a maintenance planning level, below which appropriate corrective maintenance action should be initiated to improve the friction. However, when the friction characteristics for either the entire runway or a portion thereof are below the minimum friction level, corrective maintenance action must be taken without delay."*

(iii) Of significance in the rehabilitation process was the fact that the project team had anticipated that the runway friction would be low after the application of fog-spray. Their report (Consulting Engineering Project Report GG/09/18/AB, April 2010, paragraph 7.1) states the following:

"*Following the request from the aerodrome management at the airport and in line with normal practice after construction, friction tests were conducted on the runway surface on 6 November 2009, 6 days after the final fog-spray has been applied. The tests were conducted by a service provider using a Griptester Mark 2 at 65 km/h. As expected, the results were disappointingly low due to the fact that the bitumen residue was still very fresh and tender. Even though only 0,5 litre per square metre bituminous fog-spray has been applied (resulting in a film thickness of 0,15 mm), the micro texture has sufficiently been affected to prevent the necessary friction development in a short period of time.*

Caution

It has however also been found that fog-spray negatively affects the friction conditions of the surface immediately after construction and such construction activities should be NOTAMed well in advance for proper safe operational reasons. Longer breaking distance would need to be considered by pilots for at least three weeks after construction, it seems."

(iv) The landing and rejected takeoff (RTO) tests conducted on 12 March 2010, after the ZS-SJW accident, by the crew of a Boeing 737-400 aircraft displayed an aircraft underperformance of 6% on the landing test and 28% on the RTO test. The primary aim of the Boeing crew was to bring the aircraft to a stop in the shortest possible distance in both cases. The primary purpose of these tests had been to challenge the NOTAM issued by the regulating authority after the accident in question, requiring an increased safety margin for operations in wet runway conditions. Significantly, the aircraft remained on the runway surface for the entire RTO test (the Boeing was accelerated from the threshold to 100 KIAS whereafter the RTO procedure was followed and deceleration commenced). These tests were conducted after an additional two runway friction tests on 9 December 2009 and 15 February 2010, resulting in runway friction levels of 0,77 and 0,70 respectively. These levels were above the design objective level and maintenance level respectively.

It should be emphasised that the Boeing 737-400 had two fundamental advantages over the Embraer 135: it was equipped with thrust reversers, which were used by the crew during the two tests, and an auto-brake system. The weather conditions at the time of the accident in question and the Boeing 737-400 test were very similar: light rain in the general area and 3 mm of rain measured at FAGG. The PIC of the Boeing mentioned in his report that they encountered puddles of standing water as they decelerated and he could feel the anti-skid system activating. According to the aerodrome licence holder, extra water was poured onto the runway on the evening of the test, adding to the rain that had fallen. This was not communicated to the crew of the Boeing 737-400 nor the team from the regulating authority, during the pre- or post test briefings.

The friction tests conducted on 9 December 2009 and 15 February 2010 indicated good coefficient of friction, yet the aircraft exceeded the AFM limitations during both tests on the wet runway surface. These two tests by the Boeing crew should be regarded as significant to the investigation, as they highlight two important factors:

(a) The similarity to what was experienced at Bristol aerodrome in the UK on 29 December 2006, when the friction coefficient of the runway was indicated as "good", yet several aircraft experienced difficulty in braking during the wet runway surface conditions. Even though good friction values were obtained during the post-accident tests at FAGG and making use of the CFME (GripTester) on 9 December 2009 and 15 February 2010 respectively, such tests provided no guarantee that reduced braking would not have been experienced during wet weather operations by landing aircraft at FAGG on a fog-spray-enriched runway surface.

(b) The Boeing crew had the option of utilising thrust reversers, as their primary objective was to bring the aircraft to a stop in the shortest possible distance. Even though all deceleration devices on board were activated during these two tests, the aircraft was unable the meet the AFM limitations due to reduced braking effectiveness on the wet runway surface. Should the thrust reversers on the Boeing have been disabled during these two tests, it is believed that the stopping distances would have been considerably longer. The conclusion drawn from the tests was that the runway friction coefficient did not allow the aircraft to perform within AFM limitations and the NOTAM issued by the regulating authority after the ZS-SJW accident thus remained in force.

Additional observations:

(i) The application of the SS 60 fog-spray to the runway surface degraded the micro- and macro-texture of the runway by filling the voids between the aggregate and binding to the micro- and macro-texture. The macro-texture test performed on 15 February 2010 provided an average texture value of 0,47 mm, less than half of the target texture depth of 1 mm as called for by ICAO Annex 14, volume I, paragraph 3.1.25 for a new surface. Although this was not a new surface, the absence of any guidance material by the regulating authority (the State) on the status of a used or rehabilitated surface meant that no comparisons could be drawn on what was regarded as acceptable or within limits, and the FAA guidance material had to suffice.

The bituminous fog-spray thus reduced the macro-texture available for water to dissipate from the runway. It should be kept in mind that water is not a compressible substance and needs to flow off the runway surface (or be channelled in the case of a grooved runway surface) as soon as possible to allow for proper tyre-to-runway contact. The presence of water will decrease the braking force that the aircraft tyres can generate. Surface texture, especially existing micro and macro-texture, has a significant influence on the wet surface friction characteristics of pneumatic tyres. An engineering report addressed to the aerodrome licence holder (the details of which were also contained in the Project Report Ref. No. GG/09/18/AB, April 2010) indicated that the micro-texture of the runway had been sufficiently affected to prevent the necessary friction development following the application of 0,5 ℓ/m² bituminous fog-spray to the runway surface, which resulted in a film thickness of 0,15 mm). This report was associated with the poor results of the friction test conducted six days after the final fog-spray application.

(ii) The unevenness of the runway surface allowed puddles of water to form. This observation was also contained in the report compiled by the crew of the Boeing 737-400 who performed the landing and RTO test at FAGG on 12 March 2010. Importantly, the rainfall measured at the aerodrome during this test – 3 mm – was approximately the same as that at the time of the accident flight, making the observation by the Boeing crew of standing water on the runway surface of great significance. Attachment A, guidance material supplementary to Annex 14, volume I, section 5, sub-heading 5.5, states the following: *“Deformation of the runway with time may also increase the possibility of the formation of water pools. Pools as shallow as approximately 3 mm in depth, particularly if they are located where they are likely to be encountered at high speed by landing aeroplanes, can induce aquaplaning, which can then be sustained on a wet runway by a much shallower depth of water.”*

The rehabilitation of the runway surface allowed for patching to be performed to localised failed areas (milling and paving), as well as crack sealing and surface treatment (application of bituminous fog-spray). Runway unevenness was not addressed. The surface in the vicinity of the intersection was especially prone to puddles due to the lack of camber.

(iii) The slotted area on the runway (see paragraph 1.10.5) was a known problem area, with slots being machined into the surface as far back as 1989 to help with water drainage. Most of the slots between 2 m and 4 m from the centreline had closed up due to movement of the surface caused by the shifting weight of aircraft . The outer section of the slots was found to be undamaged and as a result was able to drain water away adequately.

(iv) There was a lack of proper grooving along the runway surface to assist in water run-off during rain.

Subsequent to the accident, the aerodrome licence holder brought forward a planned resurfacing of the runway, which was concluded on 26 May 2010. A length of 1 800 m of the runway was resurfaced with a 20 mm thick, ultra-thin friction course (UTFC), which enabled the surface to met the requirements of ICAO Annex 14, volume I, chapter 3, Physical Characteristics of Runways.

"3.1.22. The surface of a runway shall be constructed without irregularities that would result in loss in friction characteristics or otherwise adversely affect the take-off or landing of an aeroplane.

3.1.23. The surface of a paved runway shall be so constructed as to provide good friction characteristics when the runway is wet.

3.1.25. Recommendation – The average surface texture depth of a new surface should be not less than 1,0 mm."

Only after the aerodrome licence holder implemented this corrective action was the NOTAM cancelled by the regulating authority.

2.6 Runway end safety areas

FAGG was a licensed aerodrome, and the runway dimensions met the requirements of a code number 4 aerodrome. This, according to ICAO Annex 14, sub-heading 3.5, means that a runway safety area (RESA) at least 90 m long has to be present beyond the end of each runway.

In the words of the relevant ICAO description:

"A runway end safety area should be so prepared or constructed as to reduce the risk of damage to an aeroplane undershooting or overrunning the runway, enhance aeroplane deceleration and facilitate the movement of rescue and fire-fighting vehicles."

It was found that according to the AIP, there was no published RESA on the aerodrome chart of FAGG at the time of the accident.

The distance from the end of the runway to the perimeter fence was approximately 278 m and the terrain sloped down towards the road at a 5° angle. The fact that the pilot managed to avoid the ILS localiser antenna 223 m beyond the runway end (163 m past the stop-way end) limited the damage to the aircraft and the injuries to its occupants, which could have been much worse.

Had a RESA been constructed for runway 11 in accordance with the ICAO requirements, an obstacle-free overrun area, free of hazardous ruts, depressions, and other surface variations, would have extended almost to the perimeter fence.

Alternative solutions do exist for runways that cannot meet the RESA standard or where the area beyond the RESA does not meet the ICAO requirement of a 240 m overrun area beyond the runway strip. One is to install a type of soft-ground aircraft arresting system, such as the Engineered Materials Arresting System (EMAS). This technology provides an alternative for runways where natural obstacles, such as bodies of water or sharp drop-offs, make the construction of a standard safety area impracticable.

The effectiveness of the EMAS was demonstrated in the case of American Eagle flight 4925 accident when the aircraft departed a 2 560 m runway but was stopped 75 m into a 122 m EMAS. According to FAA AC 150/5220-22: Engineered Materials Arresting System for Aircraft Overruns, most aircraft runway overruns *"come to rest within 300 m (1 000 ft) of the runway end and between the extended edges of the runway".* The investigation team supports the installation of an EMAS, especially for those runways in which the safety area is less than the minimum standard specified in ICAO Annex 14. If runway 11 had been designed with a RESA built to ICAO requirements, or an alternative means of compliance such as an EMAS, the damage to ZS-SJW might have been significantly reduced.

2.7 Weather conditions

Rain began to fall in the area of the aerodrome approximately two hours before flight SA8625 landed at FAGG. At the time of the accident, 3 mm had fallen at the aerodrome, and the total rainfall for the day was 31,8 mm. This was the first substantial rain since completion of the runway rehabilitation project. The crew of a Boeing 737 at the holding point for takeoff pending the arrival of flight SA8625 stated afterwards that there was a light drizzle as the accident aircraft landed. The crew of flight SA8625 indicated that the cloud base was approximately 1 000 ft AAL in light rain/drizzle, and switched on the windshield wipers during the approach. The ATC provided the crew with a wind check about a minute before landing, indicating the wind to be from the east (090°) at 5 kt, and advising them that the runway was wet. The landing was effectively into the prevailing surface wind. The weather conditions did not pose any difficulty for the crew.

This situation differed from most of the other overrun accidents studied by the investigators, which were associated with heavy rain or thunderstorm activity just before landing or during the approach phase of the flight. Apart from the fact that the runway surface was wet, the actual weather conditions were not regarded as playing a major part in the approach.

It should be borne in mind that the landing at FACT, the departure point of flight SA8625 for FAGG, was also performed on a wet runway due to rain in the area, and the same pilot flew the aircraft during both these sectors and landings.

However, the investigators noted significant differences between these two landings:

(i) The landing weight of the aircraft at FACT was substantially less than at FAGG.
(ii) The runway at FACT was substantially longer (3 200 m) than that at FAGG (2 000 m).
(iii) The runway at FACT had not been subjected to a recent rehabilitation project where a bituminous fog-spray sealant had been applied to the surface.

It is believed that the severe drought in the area, described as the worse in over 130 years, mitigated the occurrence of other similar accidents or incidents after the rehabilitation project and before the SA8625 accident.

2.8 Survivability

After the runway overrun, the aircraft collided with 11 frangible approach lights for runway 29. Frangible structures, because of their ability to break, distort or yield on impact with aircraft, present less risk than rigid ones. In this accident, all 11 approach lights failed as designed during the impact sequence, reducing the risk of serious or even fatal injury to the occupants.

The wooden support poles of the aerodrome fence were not designed in the same way, but did not pose serious risk as they collapsed easily.

The accident occurred at the aerodrome boundary, which allowed for swift response by ARFF personnel. The absence of a fire, the training and actions of the crew, and the quick response of the passengers, also contributed to a successful evacuation. The passengers followed the instructions of the cabin crew member, who opened the right-front service door once the aircraft had come to rest, and most passengers deplaned from there onto the roadway. One passenger removed the left over-wing emergency escape hatch and deplaned from there.

The lower cockpit structure was severely damaged when the nose gear collapsed after striking a concrete runway approach light, but the cockpit seats did not fail. Certain concerns that could have been potential risks to the survivability of the occupants were highlighted during the investigation:

(i) The pilots were trapped inside the cockpit and could only be freed once ARFF personnel had broken down the cockpit access door. The sliding windows on either side, which act as emergency exits for the cockpit crew, were not opened, although they were serviceable. It was not possible for the crew to make use of the blow-out panel on the lower part of the cockpit door, due to the deformation of the floor, which was forced upwards by the collapse of the nose gear.

(ii) The safety information card issued by the operator did not provide any information for younger passengers, people travelling with infants, or pregnant women on how to take up a safe brace position. The card displayed only one example of the brace position, showing an adult. Several children as well as two passengers travelling with infants were on board. None of these, nor anyone else, was seriously injured, however.

It is imperative that operators emphasise to passengers the importance of reading the safety information card, as emergency situations frequently do not allow any time for cabin crew to demonstrate certain vital safety actions. Overrun accidents provide a good example of this.

The accident was found to be within the tolerance of the human body. Structural integrity was not compromised and all the occupants were properly restrained.

2.9 Civil Aviation Authority oversight

It was found that the appropriate division within the regulating authority had conducted an aerodrome licence renewal audit at the facility, 90 days prior to the expiry date of the aerodrome licence. This inspection was conducted while the rehabilitation project was still ongoing. The civil infrastructure section of the audit did not reveal any non-compliance that would have affected the status of the aerodrome. This raised certain concerns with the investigating team, as the application of a bituminous fog-spray treatment to the runway surface was feared to endanger aircraft safety, a fact substantiated by the results of a runway friction test conducted on 6 November 2009 with a GripTester friction-measuring device, and which did not meet the minimum friction level.

The fact that no non-compliances were listed could be attributed to the fact that the audit team did not require any additional testing to be conducted on the runway and acted purely on the data required from the checklist (CA139-18). The investigation team found the checklist to be lacking critical content, especially with reference to the rehabilitation process of a runway, which falls outside its scope. The checklist did not require any additional test data, such as a runway friction test, to ensure that aircraft safety was not compromised.

The process of obtaining friction data:

The friction test was conducted on 6 November 2009, whereafter the service provider made the data available to the contractor. The latter forwarded it to the project consulting engineering company, which passed it on to the aerodrome licence holder on the day of the accident. The data was therefore made available to the regulating authority for analysis only after the accident occurred.

This process took more than 30 days, during which certain role players knew that the minimum friction level as contained in Attachment A, guidance material supplementary to Annex 14, volume I, section 8, was not met, yet the process of passing on the data was not expedited, nor was the regulating authority informed to ensure immediate corrective actions were forthcoming.

Attachment A, guidance material supplementary to Annex 14, volume I, section 7 shown below is very clear on the actions that should be followed by the State should such a shortcoming be detected as it has a direct effect on the safe operation of aircraft.

"7.3 When the friction of a runway is found to be below this reported value, then such information should be promulgated by NOTAM. The State should also establish a maintenance planning level, below which, appropriate corrective maintenance action should be initiated to improve the friction. However, when the friction characteristics for either the entire runway or a portion

thereof are below the minimum friction level, corrective maintenance action must be taken without delay."

It was further noted that no guidance material was available from the regulating authority whereby the minimum friction levels were clearly defined and published in the AIP as called for in Attachment A, guidance material supplementary to Annex 14, volume I, section 7. This was substantiated by the fact that there is no designated division within the authority to maintain oversight of runways and ensure that all related aspects are met and monitored, and immediate corrective actions are taken where appropriate.

The regulating authority also has no runway friction tests evaluation division making use of its own CFME device(s) to ensure that test requirements are met. In the case of FAGG, instead of outsourcing this friction-testing function to an external service provider, and so obtaining direct access to such data, it relied on data made available to it by the aerodrome licence holder.

It was further noted that runway friction tests using a CFME device are limited to a very small number of licensed aerodromes in South Africa. This raises a concern about the safety of other licensed aerodromes and runways, including those accommodating Part 121 operators.

The process followed at the time of the accident, whereby the runway friction tests are conducted by an external service provider, who provides the results to the client (usually the aerodrome licence holder), who in turn makes the information available to the regulating authority, who then has to analyse them, was found to be tedious and time-consuming. Of concern is that the process delays the implementation of any corrective actions that might be required to ensure aircraft safety is not compromised. The accident in question demonstrated this exact shortcoming, with no proactive actions forthcoming from the regulating authority.

It was further noted that two safety recommendations were issued to the regulating authority during the first half of 2009 following a serious incident involving a Boeing 737-200 that partially slid off the runway during landing in rain on 18 June 2008. The report clearly indicates that the authority had not defined the minimum friction levels during wet weather conditions nor was it published in the AIP as required by ICAO Annex 14, volume I, section 7. At the time of writing this report, these recommendations are still pending and they have therefore been included under sub-heading 4, "Safety Recommendations".

2.10 Assessment

Following a comparison of the runway friction test data obtained during the test of 1 September 2009 (pre-application of fog-spray SS 60) and the tests of 6 November 2009 (post-application of fog-spray SS 60), it was noted that the application of a bituminous fog-spray had a profound effect on the runway friction coefficient, resulting in low runway friction. This was a condition anticipated by the aerodrome rehabilitation project team. Despite this information being available to several role-players, no corrective actions followed to ensure that aircraft operations were not endangered at the aerodrome. Thirty-six days after the fog-spray treatment was completed, ZS-SJW overran the runway while landing in wet conditions.

A runway friction test was conducted two days after the accident and another on 15 February 2010. The results of both tests reflected a good runway friction value. However, the results of a landing and RTO test by a Boeing 737-400 crew on 12 March 2010 indicated a runway surface friction coefficient that did not allow the aircraft to perform within its AFM limitations; in particular, a 28% underperformance was obtained during the RTO test, despite thrust reversers being activated. It is believed that if the thrust reversers had been disabled, the underperformance would have been much higher. The primary purpose of the test was to challenge the NOTAM issued by the regulating authority after the ZS-SJW accident. As it could not prove the contrary, the NOTAM remained in force.

The accident aircraft was found to have crossed the threshold at the required 50 ft AGL and touched down within the touchdown zone, albeit past the 305 m (1 000 ft) ideal touchdown point, following a visual approach with the ILS selected for runway 11. The deeper-than-anticipated touchdown was associated with an access threshold speed of V_{REF} + 15 kt (143 KIAS), which could be attributed to the tailwind component encountered on the approach. This increased the groundspeed and also necessitated a higher rate of descent. On touchdown, the surface wind was approximately on the nose at 5 kt.

Effective braking, which can only be accomplished if there is good tyre-to-runway surface contact, was required to decelerate the aircraft to a safe stop. The four main tyres displayed evidence of heat and peeling of the tyre compound, indicative of hydroplaning. The manufacturer, who did not have the opportunity to see the runway surface, analysed the tyres and confirmed that hydroplaning had occurred. Once a tyre hydroplanes, there is very little or no runway surface contact. Significantly, the anti-skid system failed to prevent the hydroplaning. The system is designed to limit the brake pressure being applied in order to prevent the skid. Despite the pilot applying maximum pressure on the pedals, the average brake pressure over the landing rollout while on the runway surface was only 427 psi, while the system was capable of obtaining brake pressures as high as 3 000 psi on a dry surface. The low pressure indicates that the system was trying to prevent wheel lock-up.

The braking effectiveness of the aircraft was reduced by the advanced state of wear of two of the four main tyres. According to a study conducted by NASA (Reference: TN D-2770, dated April 1965: An investigation of the influence of aircraft tyre-tread wear on wet-runway braking), braking effectiveness of an aircraft tyre during wet runway conditions is highly dependent on tyre tread. The study found that as tyre tread wear passed 80%, braking effectiveness dropped markedly. This indicates that aircraft tyres should be replaced before the thread is worn completely smooth if safety requirements are not to be compromised.

It was further noted that the average longitudinal deceleration of the aircraft from 09:01:22 to 09:01:35 was -0,106g, which was inadequate to decelerate the aircraft to a safe stop before the end of the runway. Of significance is the fact that the PF took four seconds before applying brakes after the aircraft remained in contact with the runway surface. As manual braking was the only method to stop this type of aircraft, the distance covered prior to brake application by the PF was several hundred metres, which further reduced the effective braking distance.

Following the accident, the investigating team issued safety recommendations to the ICAO (Runway Safety Department or Runway Friction Task Team) via the National Department of Transport (NDoT) for further study into CFME and its accuracy during wet runway conditions. This followed contradictions between the results of two CFME tests and those obtained during a special test landing and RTO performed under wet weather conditions by a Boeing 737-400.

The two CFME tests were conducted after the accident, dated 9 December 2009 and 15 February 2010, which indicated a runway surface with a wet friction coefficient above the design objective level. The runway surface had been bitumen-enriched as a result of the fog-spray SS 60 applied during the rehabilitation process. On 12 March 2010, a South African-based operators that flew into George aerodrome daily made a Boeing 737-400 available to perform a landing as well as an RTO test under wet runway surface conditions. Both tests resulted in a longer stopping distance than required in accordance with the AFM limitations. During both tests the crew used the thrust reversers optimally, yet the aircraft underperformed by 6% during landing and 28% during the RTO respectively. The tests demonstrated that the runway friction coefficient during wet weather operations did not meet the desired objective, and reduced braking effectiveness was experienced. In sum, the underperformance of the aircraft was associated with a reduced runway friction coefficient during wet weather operations, ensuring that the aircraft was unable to decelerate within its certified limits. According to the results of the two CFME tests referred to above, the Boeing 737-400 should have been able to perform within its certified limits, yet it did not.

The recommendations were as follows:

(i) The ICAO should review the use of friction-measuring devices for detecting minimum friction levels (*"slippery when wet"*) on asphalt (bitumen-rich) runway surfaces.

(ii) ICAO should, through their guidance material, explain why fog-sprays and enrichment coats are unsuitable for runways with an asphalt surfacing.

(iii) The ICAO should review the accuracy of friction-measuring devices and the interpretation of test results.

The recommendations were further supported by the evaluation of the three incidents that occurred at Bristol aerodrome on 29 December 2006, where ATC had advised the crews that braking action was "Good" after CFME tests conducted on the runway earlier in the day. In spite of this, three aircraft experienced reduced braking action and difficulty maintaining directional control during landing.

3. CONCLUSION

3.1 Findings

The Crew

3.1.1 The pilot-in-command (PIC) was the holder of a valid airline transport pilot's licence and had the aircraft type endorsed in his logbook. He was also the pilot flying (PF) at the time of the accident.

3.1.2 The PIC was in possession of a valid aviation medical certificate issued by a CAA-accredited medical officer.

3.1.3 The first officer (FO) was the holder of a valid airline transport pilot's licence and had the aircraft type endorsed in his logbook.

3.1.4 The FO was in possession of a valid aviation medical certificate issued by a CAA accredited medical officer.

3.1.5 During the transit check at FACT, the refuelling procedure was supervised by an AME, who also performed an external safety inspection of the aircraft and found it serviceable for dispatch.

3.1.6 The flight crew informed ATC that they had the aerodrome in sight two minutes and four seconds before touchdown. This was at 08:59:05Z.

3.1.7 The two flight crew members' combined number of landings at George aerodrome in an Embraer 135 prior to the accident flight was 241.

3.1.8 The cabin attendant was in possession of a valid licence and was appropriately qualified to perform her duties.

The Aircraft

3.1.9 The Certificate of Airworthiness of the aircraft was valid.

3.1.10 The last maintenance inspection on the aircraft prior to the accident flight was certified on 11 November 2009.

3.1.11 A total of 65 hours and 46 minutes had been flown since the last maintenance inspection.

3.1.12 The mass and balance of the aircraft was within the prescribed limits as stipulated in the AFM.

3.1.13 The aircraft was not equipped with thrust reversers or an auto-brake system.

3.1.14 Two of the main tyres had a tread depth of less than 2 mm, and all four main tyres displayed evidence consistent with hydroplaning.

3.1.15 The BCU non-volatile memory that was downloaded did not indicate any malfunction with the brake system that could have contributed to, or have caused, the brake system to fail during the landing.

3.1.16 The ground spoilers deployed following the second touchdown, where after the aircraft remained in permanent "ground" mode. The spoilers remained deployed for the entire landing rollout.

3.1.17 No evidence indicated any failure of the aircraft's engines, structures or systems that would have affected the aeroplane's performance during the accident landing.

Approach and Landing

3.1.18 The final sector speed of the aircraft was high due to a tailwind component on the approach.

3.1.19 Flaps transitioned to the full down position below the 500 ft AGL approach window.

3.1.20 The aircraft speed over the threshold was 143 KIAS, which was 15 kt above the calculated VREF speed.

3.1.21 The aircraft touched down for the first time pass the third runway marker, within the touchdown zone.

3.1.22 The aircraft then transitioned back into air mode for a period of 1.5 seconds where after it touched down again and remained in permanent ground mode.

3.1.23 A delay of 4 seconds followed in the application of the brakes by the PF after the aircraft remained in permanent ground mode.

3.1.24 With the aircraft in permanent ground mode the ground spoilers deployed immediately.

Weather

3.1.25 The runway was wet during the landing due to a recent rain shower that had passed over the aerodrome. The rainy conditions persisted for most of the day.

3.1.26 The total rainfall measured at the aerodrome from the time it started to rain at 0700Z until the accident at 0901Z was approximately 3,0 mm.

3.1.27 The last wind check provided by the ATC prior to the landing was 090° at 5 kt. The official SA Weather Services indicated the wind to be from the east (070°TN + 25° {variation} = 095°M) at 2 kt.

3.1.28 This accident occurred during the worst period of drought in the George area for over 130 years.

Aerodrome

3.1.29 The aerodrome was subjected to a rehabilitation programme between 25 July and 6 November 2009. During this period, the runway surface was sprayed with 50 200 litres of bitumen fog-spray.

3.1.30 A section of the runway surface near the intersection contained slots, 1.4 m apart, to the right of the centreline of runway 11 and for a distance of 120 m. Several of the slots had closed up.

3.1.31 No evidence was obtained to indicate that the replacement product "SS 60 stable mix bitumen emulsion" used in the treatment of the entire runway surface had been tested in a manner similar to the product SP 2000 ("polymerised rejuvenator bitumen seal") before being applied.

3.1.32 The last runway inspection conducted by aerodrome personnel prior to the accident was at 0813Z. The ATC was informed that the runway was "serviceable but wet".

3.1.33 No water reading was taken on the runway surface prior to the landing of flight SA8625. The first water reading was conducted more than two hours after the accident, before the re-opening of the runway, and measured between 2 mm and 3 mm.

3.1.34 Aerodrome rescue and fire-fighting personnel responded within the three-minute time frame as called for in document ICAO Annex 14, chapter 9, paragraph 9.2.23, as well as in ICAO doc 9137-AN/898, parts 1 and 7.

3.1.35 There was no runway end safety area (RESA) at the end of runway 11 (approach for runway 29) as required by ICAO Annex 14, paragraph 3.5.1 and 3.5.2 for this category of aerodrome.

3.1.36 The necessity for the provision of RESAs was not adequately addressed in part 139 of the Civil Aviation Regulations of 1997 (as amended), nor enforced with respect to FAGG.

3.1.37 The regulating authority conducted an aerodrome licence renewal audit at FAGG on 1 November 2009, during which no non-compliances were identified. This audit was performed three months prior to the expiry date of the aerodrome licence, and while the maintenance process was still in progress. This was not in compliance with the requirements for the renewal of an aerodrome licence, according to the provisions contained in part 139 of the Civil Aviation Regulations.

3.1.38 The aerodrome was issued with an aerodrome licence valid for one year – from 1 February 2009 until 31 January 2010 – by the regulating authority.

3.1.39 The average runway friction value obtained from the test conducted on 1 September 2009, following the test trial of the product SP 2000, reflects an average friction level of 0,69, which was below the design objective level but above the maintenance level.

3.1.40 The SACAA as Regulator had opted not to comply with the Standards and Recommended Practices contained in ICAO Annex 14, volume I, section 7, which requires that the State should define the minimum friction level of a wet runway surface and publish it in the State's Aeronautical Information Publication (AIP). (Compliance should have been with 2.9.5 and 2.9.6 of ICAO Annex 14 – Aerodrome, volume I).

3.1.41 No runway friction test was conducted on the day of the accident. The test that was conducted two days after the accident showed an average friction level of 0,77, which was above the design objective level.

3.1.42 The test conducted on 15 February 2010 showed an average friction level of 0,70, which was below the design objective level but above the maintenance level.

3.1.43 The accident occurred 37 days after the runway rehabilitation process (the application of fog-spray to the runway surface) was completed.

Injuries/Survivability

3.1.44 The cockpit access door could not be opened from inside the cockpit and had to be removed by rescue and fire-fighting personnel using special rescue equipment.

3.1.45 Although both cockpit emergency sliding windows were serviceable, neither was opened from the inside by the cockpit crew.

3.1.46 Both cockpit crew members were properly restrained with their four-point safety harnesses.

3.1.47 The cabin crew member opened the service door (right front) and one of the passengers removed the left emergency over-wing exit, which allowed for disembarkation of the occupants.

3.1.48 Ten occupants on board the aircraft were admitted to hospital for a routine medical check-up, with no serious injuries being reported.

3.1.49 There was no officially published RESA in the overrun area of runway 11 at FAGG.

3.1.50 The PIC gave the “brace” command seven times prior to the aircraft crashing through the aerodrome perimeter fence.

3.1.51 The safety card on board the aircraft depicted only one brace position. The illustration was presumed to be an adult.

3.1.52 The aircraft’s occupants were immediately assisted by members of the public who had stopped at the accident scene, as well as aerodrome rescue and fire-fight (ARFF) personnel, who responded promptly.

Air Traffic Control

3.1.53 The ATC on duty in the George control tower at the time of the accident was in possession of a valid licence and was appropriately qualified to perform his duties.

3.1.54 The ATC informed the crew of SA8625 that the runway surface was wet when he cleared the aircraft for landing on runway 11. This was in line with the requirements as called for in ICAO Annex 11 and ICAO doc 4444, chapter 12: Phraseology.

3.1.55 The ATC activated the crash alarm when he realised that the aircraft was not going to stop within the available runway surface, whereupon the ARFF personnel responded promptly.

Rejected takeoff test at FAGG

3.1.56 On the evening of 12 March 2010, a Boeing 737-400 crew performed a rejected takeoff (RTO) test at FAGG during wet runway conditions. The aircraft underperformed by 28%.

3.1.57 The rainfall measured at the aerodrome during the period of the RTO test was similar to that measured on the day of the accident – approximately 3 mm.

Post-accident intervention by the aerodrome licence holder

3.1.58 On 26 May 2010, 1 800 m of the runway length, which excluded 100 m at each threshold, was resurfaced with a 20 mm thick, ultra-thin friction course (UTFC).

Following this intervention, the NOTAM was cancelled by the regulating authority.

3.2 Probable cause/s

3.2.1 The crew were unable to decelerate the aircraft to a safe stop due to ineffective braking of the aircraft on a wet runway surface, resulting in an overrun.

3.3 Contributory factors

3.3.1 The aircraft crossed the runway threshold at 50 ft AGL at 143 KIAS, which was 15 kt above the calculated V_{REF} speed.

3.3.2 Although the aircraft initially touched down within the touchdown zone the transition back into air mode of 1.5 seconds followed by a 4 second delay in applying the brakes after the aircraft remained in permanent ground mode should be considered as a significant contributory factor to this accident as it was imperative to decelerate the aircraft as soon as possible.

3.3.3 Two of the four main tyres displayed limited to no tyre tread. This was considered to have degraded the displacement of water from the tyre footprint, which had a significant effect on the braking effectiveness of the aircraft during the landing rollout on the wet runway surface.

3.3.4 Non-compliance with ICAO Standard 2.9.5 of ICAO Annex 14, volume I, Aerodromes: *"Information that a runway or portion thereof may be slippery when wet shall be made available."*

3.3.5 Non-compliance with ICAO Standard 2.9.6 of ICAO Annex 14, volume I, Aerodromes: *"A runway or portion thereof shall be determined as being slippery when wet when the measurements specified in 10.2.3 show that the runway surface friction characteristics as measured by a continuous friction measuring device are below the minimum friction level specified by the State."*

3.3.6 Although ICAO Standard 10.2.3 of ICAO Annex 14, volume I, Aerodromes: *"Measurements of friction characteristics of a runway surface shall be made periodically with a continuous friction measuring device using self-wetting features"* were met, no corrective action in the form of NOTAM was issued timeously to ensure aircraft safety was not jeopardised as called for in ICAO Annex 14 even though the test data was available.

3.3.7 Non-compliance with ICAO Standard 10.2.4 of ICAO Annex 14, volume I, Aerodromes: *"Corrective maintenance action shall be taken when the friction characteristics for either the entire runway or a portion thereof are below a minimum friction level specified by the State."*

3.3.8 There were inadequate procedures within the regulating authority to prioritise and analyse the results of the runway friction test conducted 30 days prior to the accident in question by an external service provider.

3.3.9 A significant contributory factor to this accident was the failure by the appropriate role-players to take immediate remedial action following the 6 November 2009 CFME test results. These results were found to be below the minimum friction level of 0.43 as called for in ICAO Annex 14, volume I.

Attachment A, guidance material supplementary to ICAO Annex 14, volume I, states:

"7.3 Friction tests of existing surface conditions should be taken periodically in order to identify runways with low friction when wet. A State should define what minimum friction level it considers acceptable before a runway is classified as slippery when wet and publish this value in the State's aeronautical information publication (AIP). When the friction of a runway is found to be below this reported value, then such information should be promulgated by NOTAM. The State should also establish a maintenance planning level, below which, appropriate corrective maintenance action should be initiated to improve the friction. However, when the friction characteristics for either the entire runway or a portion thereof are below the minimum friction level, corrective maintenance action must be taken without delay."

4. SAFETY RECOMMENDATIONS

4.1 Interim safety recommendations

After an understanding developed about the cause of the accident, it became clear that one of the factors involved was the condition of the runway surface. This resulted in the AIID issuing three interim safety recommendations to the Commissioner for Civil Aviation (CCA). These were implemented as deemed necessary by the CCA.

4.1.1 These recommendations were:

- A NOTAM be issued restricting the use of runway 11/29 at FAGG by large transport aircraft (> 5 700 kg) when the runway is wet;
- The NOTAM to remain in force until such time as adequate friction/texture treatment, such as grooving, has been implemented over the entire runway length and width; and
- ACSA be required to conduct a risk assessment on the lack of a RESA on runway 29 at FAGG and if found necessary, to incorporate some form of arresting mechanism.

4.1.2 Action implemented by the aerodrome licence holder:

- The aerodrome owner has implemented a resurfacing project at FAGG, ensuring that the runway surface meets the requirements defined by the Aerodromes Department of the SACAA in all respects.

4.2 Additional safety recommendations

Notwithstanding the abovementioned interim safety recommendations, the following additional safety recommendations are proposed:

Recommendations addressed to the Director of Civil Aviation:

4.2.1 It is recommended to the Director of Civil Aviation that the Air Safety Infrastructure Division establish its own runway friction test division, or establish an independent agency that would acquire its own runway friction test apparatus that meets ICAO doc 9137 requirements. This should be done to ensure that independent friction tests are conducted regularly at all licensed aerodromes to ensure compliance.

The current system, where an external service provider is contracted by the aerodrome licence holder to perform the function, threatens to compromise runway safety and the responsibility of the regulating authority, judging by the problems encountered at FAGG. Although the friction tests were conducted in good time, several weeks passed before the results were passed to the regulating authority for analysis and a proper assessment of the runway surface could be made.

The accident in question was a good example of the consequences of the delay in obtaining information. The runway friction data from the 6 November 2009 test was made available by the consulting project engineers to the aerodrome licence holder only on the day of the accident, 7 December 2009. After the aerodrome licence holder had received the data, it was then forwarded to the regulating authority for consideration. By this time, the accident had already occurred. If proactive measures had been in place, the regulating authority might have been in a position to issue a NOTAM indicating that the runway surface was *"slippery when wet",* prior to the accident in question, as called for in ICAO Annex 14, volume I, attachment A, section 7, paragraph 7.3. In short, the friction data was available several weeks before the accident occurred, but nobody took the appropriate corrective action. This investigation identified the absence of such a division and an appropriate friction-measuring device as a major shortcoming from a regulatory perspective.

4.2.2 It is recommended that the regulating authority, in collaboration with Part 121 operators, conduct a feasibility study into adding hydroplaning to the simulator curriculum were technical capacity exist to do so. It should be borne in mind that the simulator curriculum in force has been scientifically developed and that adding hydroplaning as a discipline should not jeopardise training in critical emergency conditions that could affect the safety of the flight.

4.2.3 The Air Traffic Services Division of the SACAA should correct, without delay, the errors described below on the George aerodrome chart as published on the SACAA website and in the AIP:.

(i) The runway slope on the chart reflects the values + 0,04% or – 0,04% SLOPE, depending on what runway direction is applicable or considered. The values should be amended to read **+ 0,4 %** or **– 0,4%** (see calculation below). The values should be corrected on two places on the chart: alongside the runway display and in the SLOPE column at the bottom of the chart.
Runway length 2 000 m,
Change in elevation 648 - 622 = 26 ft / 3,28 = 7,93 m
Gradient 100 x 7,93 / 2000 = 0,396% (0,4%).

(ii) On the left-hand, lower side of the chart, the latitude value is given as 35° 00' S. This position was found to be an error and should read 34° 01' 00" S.

4.2.4 The revision of Part 139 of the Civil Aviation Regulations of 1997 and its associated SA-CATS-AH document is required to ensure compliance with the provisions and international best practices as contained in ICAO Annex 14, volume I and associated documents.

Part 139 was found to be lacking in content, especially in terms of guidance material, when compared with international best practice. It contains very little information on the maintenance standards that must be met at Category (reference code number 3 and 4) aerodromes and runways. Part 139 constantly refers the reader to the SA-CATS-AH document, which in turn refers to the ICAO Annex 14 document(s) and supporting documents. This is an indication that the State is not setting clear guidelines to aerodrome licence holders on the minimum standard that must be maintained for runway friction conditions, the micro- and macro-structure of the surface, and RESAs.

4.2.5 The Air Safety Infrastructure Division must amend the regulatory requirements to ensure that all reference code number 3 and 4 runways have a 300 m RESA or a means of stopping aircraft that provides an equivalent level of safety as called for in ICAO Annex 14, paragraphs 3.5.1 and 3.5.2.

Although there was no RESA published for runway 11, there were no non-frangible objects along the route followed by the accident aircraft until 163 m from the end of the runway stop-way. This established a *de facto* RESA that exceeded the currently stipulated standard by 90 m. Regardless of this, the investigation revealed that it was the terrain beyond this point that largely contributed to the damage incurred by the aircraft and the injuries to the crew and passengers.
The investigating team believes that the aerodrome could benefit from a properly maintained RESA in accordance with ICAO Annex 14 recommended practices as well as FAA runway safety area (RSA) standards (Advisory Circular 150/5300-13, Airport Design). This safety action would remove all non-frangible objects and create a surface graded to reduce the risk of damage to an aircraft up to a distance of 300 m beyond the end of the runway.

It is acknowledged that a 300 m RESA may be impracticable on the overrun area of runway 11 due to the ILS localiser antenna structure and the R404 public road running parallel to the aerodrome perimeter fence, 280 m beyond the end of the runway. An alternative means of compliance, such as an Engineered Material Arresting System (EMAS) to provide a level of safety equivalent to a 300 m RESA, should therefore be considered.

It is the opinion of the investigation team that an EMAS installed at the departure end of runway 11 could have stopped the accident aircraft and prevented it from bursting through the perimeter fence. Figure 56 shows an aircraft arrested by an EMAS, which consisted of covered blocks of crushable concrete and was located directly beyond the end of the runway. The concrete is design to slow and stop an aircraft that overruns the runway.

Figure 56: A Cessna Citation 550 that overran the runway at Key West International Airport, Florida, USA. Note the crushable concrete blocks.

The pictures below reflect an EMAS test that was conducted at Jiuzhai Huanglong Airport in China, using a Boeing 737-300. As can be seen from the pictures, it worked perfectly, with very little to no damage to the aircraft.

Figure 57: A Boeing 737-300 overrun onto EMAS structure at Jiuzhai Huanglong Airport, China.

Figure 58: A view of the aircraft from behind.

At the time of writing, EMAS is not a regulatory requirement in South Africa and has not been installed at a single aerodrome in South Africa. Considering the proven advantages of the system, and the nature of the SA8625 accident at FAGG, it is recommended that the system be implemented without delay at the country's major aerodromes in the interest of aviation safety. Compliance with EMAS would require that these aerodromes have the appropriate safety measures in place to avoid a similar accident to the one involving SA8625. The EMAS is considered a much safer system then a prepared RESA, as a RESA is just a cleared space that is not designed to stop the aircraft and may end in disaster.

4.2.6 It is recommended that the Air Safety Infrastructure Division be strengthened to ensure that adequate skills and knowledge are available to ensure that there is comprehensive safety oversight of the certification of aerodromes and the maintenance of certification standards. This could include the establishment of an office that deals primarily with runway safety. Ultimately, this office should be responsible for all runway safety initiatives.

4.2.7 It is necessary to draft clear guidance material for the aviation industry on the use of fog-spray and seals on licensed runways in South Africa.

Part 139 of the Civil Aviation Regulations of 1997, as amended, read in conjunction with all the relevant guidance material as stipulated in SA-CATS-AH (Aerodromes and Heliports), does not provide any such material for the industry and its stakeholders.

The application of fog-spray to a runway surface imposes a high risk if such a project is not properly managed and the task not properly performed. It should be emphasised that the surface texture (micro- and macro-texture) of such a runway surface should not be compromised in any way, nor should the runway's friction coefficient or water drainage characteristics be compromised by the fog-spray.

Prior to the application of fog spray on any runway belonging to an aerodrome licensed by the regulating authority, special written permission should be obtained from the authority. Clear field guidelines and considerations must accompany such an application. It is recommended that the Air Safety Department of the SACAA draft clear guidance material on the subject of fog spray and the requirements that should be complied with by the industry in this regard.

4.2.8 The Air Safety Infrastructure Division should compile a detailed checklist of the civil infrastructure for aerodrome audit inspections.

The form used by the inspector conducting an audit of FAGG on 1 November 2009 was found to lack critical content, especially on maintenance intervention. The "Runway" section in the current form requires extensive revision. Most importantly, it should include inspection points of the runway surface. This should include a detailed inspection of the runway surface texture (macro and micro), runway slope (both longitudinal and transverse), runway evenness (with special emphasis on water drainage and puddles), runway grooving (if applicable), and runway friction coefficient data evaluation. Should such an inspection require any practical tests, the audit team should conduct these and the results be recorded and analysed to ensure that the recommended standards and practices are met.

4.2.9 It is proposed to certifying authorities that the landing safety margin of 1.917 (1.92) during wet weather operations for aircraft above 5 700 kg not equipped with thrust reversers be amended following a feasibility study.

The absence of these devices was a significant contributory factor to the accident in question. Although not a primary braking system, thrust reversers have a significant slowing effect and offer added safety in that they do not depend on the condition of the runway.

4.2.10 It is recommended to the Director of Civil Aviation that the Air Safety Infrastructure Division should, in compliance with the recommendations of ICAO Annex 14, volume 1, attachment A (guidance material supplementary to Annex 14, volume 1) section 7: Determination of friction characteristics of wet paved runways, define the minimum friction levels and publish it in the AIP as a minimum standard. It is further recommended that proper guidance material be compiled by the SACAA in this regard and be made available to all stakeholders.

4.2.11 It is recommended to the Director of Civil Aviation that the Air Safety Infrastructure Division should, in compliance with the recommendations of ICAO Annex 14, volume 1, chapter 2: Water on a runway, develop guidance material that should be made available to all industry stakeholders. It is essential that the State provide clear guidelines on the inspection of wet runways.

4.2.12 It is recommended to the Director of Civil Aviation that the Air Safety Infrastructure Division should, in compliance with the recommendations of ICAO Annex 14, volume 1, attachment A, section 8, list the constant friction-measuring devices that are approved by the SACAA and set out the limitations of these.

Recommendations addressed to the Aircraft Operator:

4.2.13 The operator should place the emergency evacuation placard in the form of a placard on the ceiling of the cockpit, allowing for quick access should the situation require.

The pilots were unable to access the emergency evacuation checklist, which was located in the QRH (Quick Reference Handbook), due to the deformation of the cockpit structure.

4.2.14 The operator should implement a procedure in the operations manual (SOP) whereby cockpit crew are encouraged to request the water depth on the runway from ATC during wet weather operations.

It is believed that the availability of such information from ATC, updated regularly during rain and wet runway conditions, would enhance the pilots' decision-making process during the approach phase of the flight.

4.2.15 The operator should consider retro-fitting thrust-reverser systems on their fleet of Embraer 135 aircraft.

Although thrust reversers do not constitute a primary braking device, they have the potential to assist with deceleration, especially during landings on short, wet runways, as these devices do not depend on the condition of the runway.

4.2.16 It is recommended that the operator consider revising its operations manual – aircraft SOPs, as it lacks significant information. It does not designate who is to deal with certain important inspections and tasks, and fails to provide flight crew with clear guidelines on when a go-around should be performed.

4.2.17 It is recommended that the operator consider revising its technical log sheet to accommodate a signature, date, time-stamp and comment column, to filled in and signed off after each transit check (external safety inspection) is performed by a crew member and/or maintenance engineer.

4.2.18 It is recommended that the operator encourage flying crew to perform go-around's whenever there is any doubt that the approach and subsequent landing might jeopardise the safe operation of the flight. Detailed statistics should be kept of all go-around's to ensure that flying crew does not become complacent in their assessment and execution of the approach and subsequent landing.

5. APPENDICES

5.1	Annexure A	Airlink Red Tag 21
5.2	Annexure B	Transcript of communication between ATC and ZS-SJW
5.3	Annexure C	Description of some of the systems of the Embraer 135
5.4	Annexure D	Runway 11/29 fog spray application chart
5.5	Annexure E	Background to fog-spray
5.6	Annexure F	Runway 11/29 friction test graphs for FAGG (all four test dates)
5.7	Annexure G	Dunlop Tyre examination report

5.8	Annexure H	Hydroplaning
5.9	Annexure I	Auto-braking system
5.10	Annexure J	Product data sheet SS-60 stablemix bitumen emulsion
5.11	Annexure K	Glossary of abbreviations

ANNEXURE A

Airlink Red Tag 21

AIRLINK

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South Africa

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E-mail: info@flyairlink.com

MEMO

RED TAG 21

To: Embraer Pilots

From: Line Check Captain: Embraer

Cc: Jhb / Cape Town

Date: 01 February 2008

Re: AQUAPLANING

When approaching to land on a WET or CONTAMINATED runway the possibility of aquaplaning must be anticipated and the following procedures and guidelines applied:

1. A thorough briefing must be done and all possibilities must be considered. In order to ensure that there is enough time to prepare and plan the approach, the weather as well as the tendency of the weather must be obtained as soon as possible before the commencement of the decent. If there is at all a possibility of the landing being executed on a wet or contaminated runway, this must be included in the approach briefing as well as the procedures thereof.
2. Diversion or holding overhead must be considered.
3. Approach procedures and speeds are critical. A well planned and executed approach, flare and touchdown at the correct speed and touchdown zone will minimize the landing distance.
4. Consider a landing uphill, if possible, depending on the wind speed and direction.
5. The importance of the approach speed can not be emphasized enough. The V Ref (+ wind correction) speed must be maintained. If this speed can not be maintained, a go-around must executed.
6. Configure the aircraft early so that there will be enough time for the flying pilot to reduce to the required speed as soon as possible on final approach. Do not push the envelope.
7. All pre landing checks must be done well in advance so that in the last part of the approach, both pilots can monitor the progress of the approach.
8. Aim to land on the touch down zone. Do NOT allow the aircraft to float.
9. Allow for a positive touch down, do not attempt to do a soft landing, this waste precious runway.
10. Immediately after touchdown, check that the automatic ground spoiler deployment has activated when the thrust levers are reduced to idle.
11. Lower the nose wheel immediately onto the runway after touchdown, and keep forward pressure on the control column. It will decrease lift, increase main gear loading.
12. Directional control is achieved by applying forward pressure on the control column and the use of rudder pedals. Do not attempts to steer the aircraft with nose wheel steering until the aircraft has reached taxi speed as the nose wheel may still be hydroplaning.

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13. Apply brakes with moderate-to-firm pressure, smoothly and symmetrically and let the anti-skid to its job. By releasing and applying brakes (pumping) the antiskid has to recalculate wheel speeds. Therefore valuable time and distance is wasted.
14. During **Dynamic hydroplaning**, the antiskid does not activate. The critical speed for dynamic hydroplaning of the Embraer at maximum landing weight is 84 knts and the VRef about 140knts. This creates a window of 56knts. In other words during dynamic hydroplaning the aircraft will need to slow down to 84knts before the antiskid would activate.
15. If no braking is felt, hydroplaning is probably occurring. Do not apply **EMERGENCY / PARKING BRAKE.** This will cut out the anti-skid protection and may cause the spoilers to close. Maintain direction with rudders and keep brake pressure on until the aircraft is decelerated.
16. **Most importantly. WHENEVER IN DOUBT, DO NOT ATTEMP TO LAND.**

Apart from the above, it is of critical importance that during the pre-flight, were the forecast weather at destination may involve the risk of aquaplaning, that the tyre pressure and condition of the tyres are well within the limits

Attached are the basic principles of hydroplaning, issued by the Embraer Safety department.

Regards

Dave Sands
Line Check Captain E-135

Please sign the memo in the Red Tag file.

ANNEXURE B

Transcript of communication between ATC and ZS-SJW

ZS-SJW was flying under the call sign Regional Link 625 and was communicating on the George tower frequency 118.9 MHz.

Time	From	To	Message
08:46:34	Link 625	ATC	George, good day, Regional Link 625.
08:46:58	ATC	Link 625	Regional Link 625, good day to you, your position now?
08:47:03	Link 625	ATC	Good day, okay, we are inbound radial 298, at 40 DME, flight level 200 for level 160, estimate Golf Alpha Victor at 5 to.
08:47:13	ATC	Link 625	Link 625, George, clear Golf Romeo Victor flight level 100, report level 120, expect no delay ILS approach runway 11. Information Echo.
08:47:24	Link 625	ATC	Okay, Golf Romeo Victor level 100, calling passing level 120 for the ILS approach runway 11 and requesting the intermediate approach for Regional Link 625.
08:47:34	ATC	Link 625	Regional Link 625 copy, continue with the intermediate approach.
08:49:58	Link 625	ATC	George, Regional Link 625 is passing level 120 at 20 DME.
08:50:01	ATC	Link 625	Regional Link 625, descent Golf Romeo Victor 8 000 feet, QNH 1011, transition level 95, or Golf Romeo Victor.
08:50:09	Link 625	ATC	Descent Golf Romeo Victor, 8 000 feet, QNH 1011 report Golf Romeo Victor next, regional link 625.
08:50:16	ATC	Link 625	It looks like there is rain to the west but overhead the field it is overcast at about 10 000 feet.
08:50:24	Link 625	ATC	Okay thanks copy, call you overhead next.
08:52:07	Comair 910	ATC	Comair 910, request taxi.
08:52:11	ATC	Comair 910	Comair 910, taxi alpha holding point runway 11.
08:52:14	Comair 910	ATC	Alpha holding point 11, Comair 910.
08:52:34	Comair 31 Delta	ATC	George Tower, Comair 31 Delta, morning again.
08:52:38	ATC	Comair 31 Delta	Comair 31 Delta, good day to you.
08:52:41	Comair 31 Delta	ATC	Okay, we are Oscar Lima Alpha, we got 2 hours 40 endurance, level 230, request for Port Elizabeth, start please?
08:52:51	ATC	Comair 31 Delta	Comair 31 Delta, push start approved, runway 11, QNH 1011, Information Echo on the ATIS.
08:53:00	Comair 31 Delta	ATC	1011, push back start approved, runway 11, Comair 2 correction, 31 Delta.
08:53:03	ATC	Comair 31 Delta	Comair 31 Delta, are you requesting routing direct to Visa?
08:53:09	Comair 31 Delta	ATC	Affirm, Comair 2, correction 31 Delta.

08:53:12	ATC	Comair 31 Delta	Copy that, last reported weather for PE, cloud base is still 2 to 300 feet but the last arrival reported runway in sight at 400 feet.
08:53:21	Comair 31 Delta	ATC	Fantastic, thank you.
08:53:23	Link 625	ATC	Regional Link 625, overhead Golf Romeo Victor 8 000 feet, ready for the approach.
08:53:27	ATC	Link 625	Regional Link 625, report established on the outbound leg, maintain 8 000 feet. Would you like to do the descent as soon as you are on the outbound heading?
08:53:35	Link 625	ATC	We will call you turning outbound maintaining 8 000 feet, Regional Link 625.
08:53:47	Comair 910	ATC	Sir, the clearance for 910 please?
08:53:53	ATC	Comair 910	Comair 910, clear George to Johannesburg, climb to flight level 100, level change after takeoff 11, continue runway track to 8 000 feet and left turn onto track to Cato, squawk code of 3777.
08:54:12	Comair 910	ATC	Departure runway 11, we are cleared up to flight level 100, runway track 8 000, left-hand turn Cato, squawk 3777. Comair 910.
08:54:25	ATC	Comair 910	Comair 910, read-back correct.
08:55:00	Comair 910	ATC	Comair 910 ready.
08:55:03	ATC	Comair 910	Comair 910, line up runway 11, there will be a short delay for spacing for Johannesburg flow control.
08:55:10	Comair 910	ATC	Okay, we are lining up runway 11, Comair 910.
08:55:13	Link 625	ATC	Regional Link 625 is established outbound 8 000 feet.
08:55:22	ATC	Link 625	Thank you, Regional link 625, commit an intermediate approach at your own discretion and report next established localiser, clear for the ILS approach.
08:55:30	Link 625	ATC	Clear for the ILS approach and copy the intermediate at our own discretion, we call you localiser established next. Regional Link 625.
08:55:37	ATC	Express-way 502	Express 502 on passing 8 000 feet, turn left to Cato, climb to level 150.
08:55:44	Express-way 502	ATC	Passing 8 000, left Cato, climb level 150. Expressway 502.
08:55:50	ATC	Express-way 502	Expressway 502, early turnout available on request for rain avoidance.
08:55:55	Express-Way 502	ATC	Copy that, we will call you on the early turnout. Expressway 502.
08:55:59	ATC	Express-way 502	Thank you, your level passing now?
08:56:02	Express way 502	ATC	Passing 4 500 feet. Expressway 502.
08:56:06	ATC	Express-way 502	Thank you.
08:56:07	Comar 31 Delta	ATC	Comair 31 Delta, request taxi.
08:56:10	ATC	Comair 31 Delta	Comair 31 Delta, taxi Alpha, holding point runway 11.

08:56:13	Comair 31 delta	ATC	Alpha holding point runway 11. Comair 31 Delta.
08:56:40	Express-way 502	ATC	George, Expressway 502 passing 6 000 feet, request early left.
08:56:46	ATC	Express-way 502	Expressway 502, enter rain avoidance and turn left on track to Cato.
08:56:50	Express-way 502	ATC	Enter rain avoidance on left, left on track to Cato. Expressway 502.
08:57:34	ATC	Express-way 502	Expressway 502, your level passing and rate of climb?
08:57:38	Express-way 502	ATC	Passing 7 000 feet and we're 2 000 feet per minute. Expressway 502
08:57:43	ATC	Express-way 502	Expressway 502, rate of climb 1 500 feet per minute or better until passing flight level 130.
08:57:49	Express-way 502	ATC	1 500 feet per minute or greater until passing 130. Expressway 502.
08:57:56	ATC	Comair 910	Comair 910, rate of climb restriction from 7 000 feet 1 500 feet per minute or less, runway 11, you are clear takeoff, wind is 130 degrees 7 knots.
08:58:07	Comair 910	ATC	From 7 000 feet, rate of climb 1 500 feet or less, we are clear for takeoff runway 11. Comair 910.
08:58:32	Comair 31 Delta	ATC	Comair 31 Delta is ready.
08:58:39	ATC	Comair 31 Delta	Comair 31 Delta, clearance George to Port Elizabeth, climb to 8 000 feet, level change after departure, runway 11, right-hand turn on track to Eveso, squawk code 3204.
08:58:50	Comair 31 Delta	ATC	Departure runway 11, climbing to 8 000 feet, right-hand Eveso, squawk 3204. Comair 31 Delta.
08:58:57	ATC	Comair 31 Delta	Comair 31 Delta read-back correct, listen out for departure.
08:59:00	Comair 31 delta	ATC	Listen out. Comair 31 Delta.
08:59:05	Link 625	ATC	Regional Link 625 is clear, is established localiser runway 11 at 9 500 feet, field in sight.
08:59:15	ATC	Link 625	Thank you, Regional Link 625, runway 11, clear to land, surface wind 130 degrees 5 knots. Runway is wet.
08:59:22	Link 625	ATC	Clear to land, runway 11. Regional Link 625.
08:59:50	ATC	Express-way 502	Expressway 502, level passing and DME?
08:59:55	Express-way		Passing level 110 and we are 17 DME. Expressway 502.
09:00:03	ATC	Express-way 502	Expressway 502, contact Cape Town East now 124.7 and call me back passing level 150 please.
09:00:11	Express-way 502	ATC	Cape Town 124.7 and we will call you back passing 150. Expressway 502.
09:00:42	Comair 910	ATC	Comair 910, request early left turn due to rain and terrain clearance.
09:00:48	ATC	Comair 910	Comair 910 early left turn approved, left on track to Cato.
09:00:52	Comair 910	ATC	Thanks, left on track to Cato and terrain avoidance, clearance approved. Comair 910.
09:01:00	ATC	Link 625	Wind check, 090 degrees 5 knots.

09:01:04	Link 625	ATC	Thank you.
09:01:07	ATC	Comair 31 Delta	Comair 31 Delta, behind the landing Embraer line up 11 behind.
09:01:11	Comair 31 Delta	ATC	Behind the landing traffic line up and wait. Comair 31 Delta.
09:01:24	Express-way 502	ATC	George, Expressway 502 passing 150.
09:01:27	ATC	Express-way 502	Expressway 502, thank you, have a great day.
09:01:29	ATC	Comair 910	Break, Comair 910 climb to level 150.
09:01:33	Comair 910	ATC	Flight level 150. Comair 910.
09:02:23	ATC	Comair 910	Comair 910 report level.
09:02:28	Comair 910	ATC	Passing level eight five. Comair 910.
09:02:31	ATC	Comair 910	Thank you Comair 910, no further rate of climb restrictions, report level 110.
09:02:37	Comair 910	ATC	No further climb restrictions, level 110. Comair 910.
09:02:57	ATC	Comair 31 Delta	Comair 31 Delta, the other aircraft had just overrun the runway. I wouldn't be able to accommodate this departure for the time, would you like to taxi back to the apron?
09:03:07	Comair 31 Delta	ATC	Okay, ja, we will taxi back, thanks very much, Comair 31 Delta.
09:03:11	ATC	Comair 31 Delta	Comair 31 Delta, sorry for that, taxi and vacate left at the intersection 02, hold short of Alpha please.
09:03:17	Fire tenant	ATC	Tower, fire tenant, fire tenant, reason for the alarm?
09:03:20	ATC	Fire tenant	The Embraer has overrun the runway, the Embraer has overrun the runway past the threshold of runway 29 on the grass at the localisers' antennas.
09:03:28	Fire tenant	ATC	Okay copy and we will proceed onto 29 and copy about the aircraft.
09:03:34	Comair 910	ATC	Comair 910 passing level 127.
09:03:37	ATC	Comair 910	Comair 910, contact Cape Town 124.7, cheers now.
09:03:40	Comair 910	ATC	124.7, good day, Comair 910.
09:03:46	ATC	Foxtrot Victor 3	Foxtrot Victor 3 proceed delta to the Embraer at the threshold of 29.
09:03:51	Foxtrot Victor 3	ATC	Proceed to the threshold of 29, Foxtrot Victor 3.
09:04:03	Rescue 2	ATC	Tower, fire tenant rescue 2 may we proceed to the threshold of 29?
09:04:08	ATC	Rescue 2	Affirm sir, proceed Delta to the threshold 29, Embraer has overrun the runway.
09:04:12	Rescue 2	ATC	Thank you sir.

There was no further communication about the accident and the aerodrome was closed down for several hours.

ANNEXURE C

Description of some of the systems of the Embraer 135

Control system

The rudder of the Embraer 135 is split into two sections in tandem: forward and aft. The forward rudder is driven by the control system, while the aft rudder is mechanically linked to the forward rudder and is thus deflected as a function of forward rudder deflection. The forward rudder is driven by two actuators connected to a power control unit (PCU) in the rear fuselage. The PCU is commanded by the rudder pedals via control cables that run from the pedals in the flight deck to the PCU. The maximum rudder deflection is ± 15° on the ground and 10° in the air. The corresponding rudder pedal deflection is ± 9° on the ground and ± 6° in the air.

The nose-wheel steering system is electronically controlled and hydraulically operated. The steering position can be controlled by the rudder pedals or steering handle (also known as the tiller) on the pilot-in-command's left console. There is no steering handle on the co-pilot's side. The pedals can command up to ± 5° of nose-wheel steering angle and the steering handle can command up to ± 71°. If the pedals and steering handle are used in combination, the maximum of ± 76° of nose-wheel steering angle can be obtained. The steering handle is normally only used below a speed of 40 kt.

Brake system (overview)

The Embraer 135 has two main landing gears, with two wheels on each gear. Each wheel has a disc brake and an associated hydraulic brake control valve. Normal braking is controlled by two brakes on the rudder pedals. The aircraft is fitted with an anti-skid system designed to provide the maximum allowable braking effort for the runway surface in use, minimising tyre wear and optimising braking distance while preventing skidding. To perform this function, the BCU computes the wheel's speed signal from the four main transducers. If one wheel speed decreases below the aircraft's average wheel speeds, skidding is probably occurring, and the braking pressure is relieved. After the wheel speed has returned to the average speed, normal braking operation is restored. The wheels and corresponding brakes are numbered sequentially from one to four (left outboard is number one and right outboard is number four).

The anti-skid protection system does not apply pressure on the brakes, but only relieves the pilot-commanded pressure (the amount of hydraulic pressure applied by the pilot on the brakes) to avoid skidding. The differential braking technique may change in some limited situations, when the pilot may have to reduce the pressure on the side opposite to the turn, instead of applying pressure to the desired side.

The Embraer 135 does not have an auto-brake system and ZS-SJW was not fitted with the optional thrust-reverser system.

Main brake system operation

The Embraer 135 maintenance manual, chapter 32, page 40, states:

"The main brake system has two sub-circuits which operate independently:

- *An outboard wheel control*
- *An inboard wheel control*

The main brake components are:

- *Brake control unit*
- *Pedal transducer*
- *Pressure switch*
- *Brake shut-off valve*
- *Brake control valve*
- *Check valve*
- *Hydraulic fuse*
- *Brake assembly*

Hydraulic system 1 and 2 supply the main brake system with a pressure of 3 000 psi.

The main brake system is of the fully digital brake-by-wire type. The pilot and co-pilot's pedals control the main brake system. The brake system includes the following functions:

- *Metering*
- *Anti-skid*
- *In-flight brake*
- *Touch-down protection*
- *Cross-over protection*
- *Bit functions*

It also has differential braking capabilities. The Brake Control Unit (BCU) contains the necessary circuits to provide all these functions, in two cards:

- *One to control the inboard wheel brake*
- *One to control the outboard wheel brake*

The pedal transducers give the signals for brake control, to the brake control valve, via the BCU.

Four wheel speed transducers give speed signals to the BCU.
The hydraulic power supply system 1 supplies the outboard wheels and the system 2, the inboard wheels.

One pressure switch in the system 1 pressure inlet and other in the system 2 pressure inlet monitor the inlet pressure values to the BCU.

The brake shut-off valve opens (energises) the inlet pressure to the brake control unit.

The BCU controls the brake control valve to supply pressure to the brake assembly, in proportion to the operation of the pilot pedal transducers.

A hydraulic fuse, installed downstream of the brake control valve, isolates the brake control line, if too much leak occurs.

A pressure transducer, installed upstream of the brake assembly, monitors the brake pressure values to the BCU.

On the brake assembly, a shuttle valve isolates the normal brake lines from the emergency/parking brake lines.

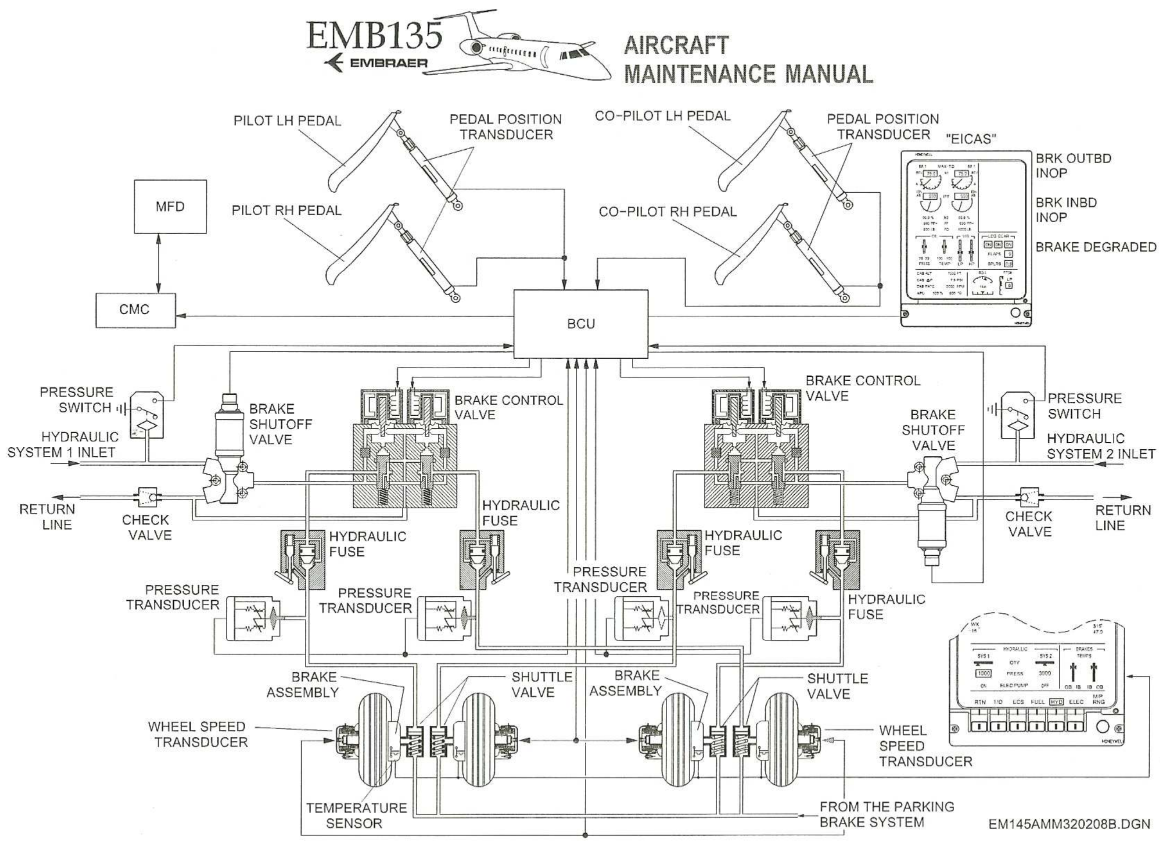
The malfunctioning display (MFD) hydraulic page shows indications of:

- *Fluid quantity*
- *Hydraulic pump pressure and electrical hydraulic pump operation*

The engine indication and crew alerting system (EICAS) status page shows alarms of:

- *'BRAKE OUTBD INOP'*
- *'BRAKE INBD INOP'*
- *'BRAKE DEGRADED'*

The figure below shows the normal brake system operation circuit."



NORMAL BRAKE SYSTEM OPERATION

<u>Emergency brake system</u>

The Embraer 135 aircraft operations manual, chapters 2-12, page 8, states:

"The emergency brake system is used when parking the airplane or when the normal braking system has failed. The emergency brake is mechanically commanded and hydraulically actuated. It is totally independent of the BCU, so it has none of the normal braking system protections.

The emergency brake is controlled through a handle located on the left side of the control pedestal. This modulates the Emergency/Parking Brake Valve. When the *emergency/parking brake valve is actuated, hydraulic pressure coming from a dedicated accumulator is equally applied to the four main landing gear brakes. Braking capacity is proportional to the handle displacement. A BRAKE ON indicating light illuminates to indicate that pressure is being applied to the wheel brakes. A locking device allows the handle to be held in the actuated position, for parking purposes.*

The accumulator is supplied by hydraulic system 2. A caution message is displayed on the EICAS in case of accumulator hydraulic low pressure. The accumulator allows 6 complete emergency actuation or at least 24 hours of parking brake actuation."

Anti-skid protection

The Embraer 135 aircraft operations manual, chapter 2, page 4, states:

"The anti-skid protection controls the amount of hydraulic pressure applied by the pilots on the brake. The anti-skid provides the maximum allowable braking effort for the runway surface in use. It minimises tyre wear, optimises braking distance, and prevents skidding. In the system each wheel has its speed compared against the average speed of all four main wheels.

To perform this function, the BCU computes the wheel speed signals from the four speed transducers. If one signal falls below the wheel speed average, a skid is probably occurring, and braking pressure is relieved on that side. After that wheel speed has returned to the average speed, normal braking operation is restored.

It is important to emphasise that the anti-skid protection does not apply pressure on the brakes, but only relieves it. So, to perform a differential braking technique, the pilot should reduce pressure on the side opposite to the turn, instead of applying pressure to the desired side. For wheel speeds below 10 knots, the anti-skid function is deactivated."

Locked wheel protection

The Embraer 135 maintenance manual, chapter 32, page 42, states:

"The main intention of a locked wheel protection is to keep a tyre from bursting when brakes are applied.

For wheel speed above 30 knots, the anti-skid system activates the locked wheel protection.

This system logic compares the speed of paired wheels (left inboard with right inboard, and left outboard with right outboard). If the slower wheel speed is less than or equal to 30% of the faster wheel's speed, the skid control circuitry sends a corrective signal to the associated brake valve. The brake valve commands a full brake pressure relief to the associated wheel, allowing speed recovery/equalisation. The 30% tolerance between the wheels is provided to permit an amount of differential braking, for steering and manoeuvring the aircraft at low speeds when needed.

For wheel speeds below 30 knots, the locked wheel protection is deactivated and the brake system actuates without the wheel speed comparator. For wheel speeds below 10 knots, the anti-skid function is deactivated, allowing the pilot to lock and pivot on a wheel."

Touchdown protection

The system is designed to prevent the pilot from accidently depressing the brake pedals before or during the touchdown, causing the aircraft to land with locked wheels.

The Embraer 135 maintenance manual, chapter 32, page 42, states:

"The touchdown protection is a feature that prevents brake actuation before the main wheels spin up, when the airplane is still airborne, during landing. This protection permits the brake actuation only after 3 seconds have elapsed since the latest touchdown or after the wheels have spun up to 50 knots.

To provide the touchdown protection, the brake system receives signals from both main landing gear air/ground switches. In the event one landing gear air/ground switch fails at the air position, the brake system will operate normally.

However, if both air/ground switches fail at the air position, thus generating a false signal to the brake system, braking capacity will be available only for wheel speeds above 10 knots. Below 10 knots, a loss of the main brake capacity will occur, but emergency brake will still be available.

In bouncing landings, the countdown is reset after each jump (with both main landing gear legs).

The BCU fully controls the anti-skid operation.

The figure 'BRAKE OPERATION WITH ANTI-SKID (TAXI AND TAKE-OFF)' shows the anti-skid operation during taxi and take-off.

The figure 'BRAKE OPERATION WITH ANTI-SKID (LANDING)' shows the anti-skid operation during the landing."

Spoilers

The Embraer 135 ,maintenance manual, chapter 27, page 2, states:

"Introduction

The function of the spoiler control subsystem is to provide the aircraft with aerodynamic brake in flight (speed brake function) and lift dumper on the ground (ground spoiler function).

There are four spoiler surfaces, two in each upper wing surface, installed in front of the inboard flap surfaces.

Description

There are two (inboard and outboard) surfaces in each wing. The outboard surfaces provide the speed brake and ground spoiler functions, while the inboard surfaces provide only the ground spoiler function. The spoiler surfaces are made of composite material and the subsystem is electrically controlled and hydraulically actuated.

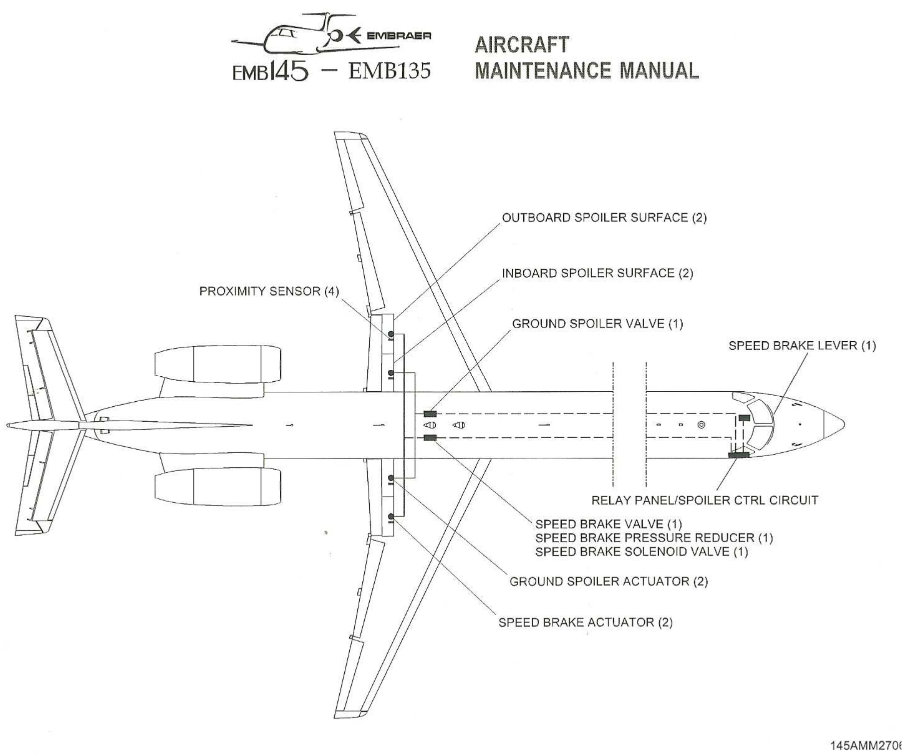
The control of the ground spoiler function is automatic during landing and rejected take-off. The pilot controls the speed brake function. The subsystem has indication on the EICAS *display and voice messages through the aural warning system.*

Operation

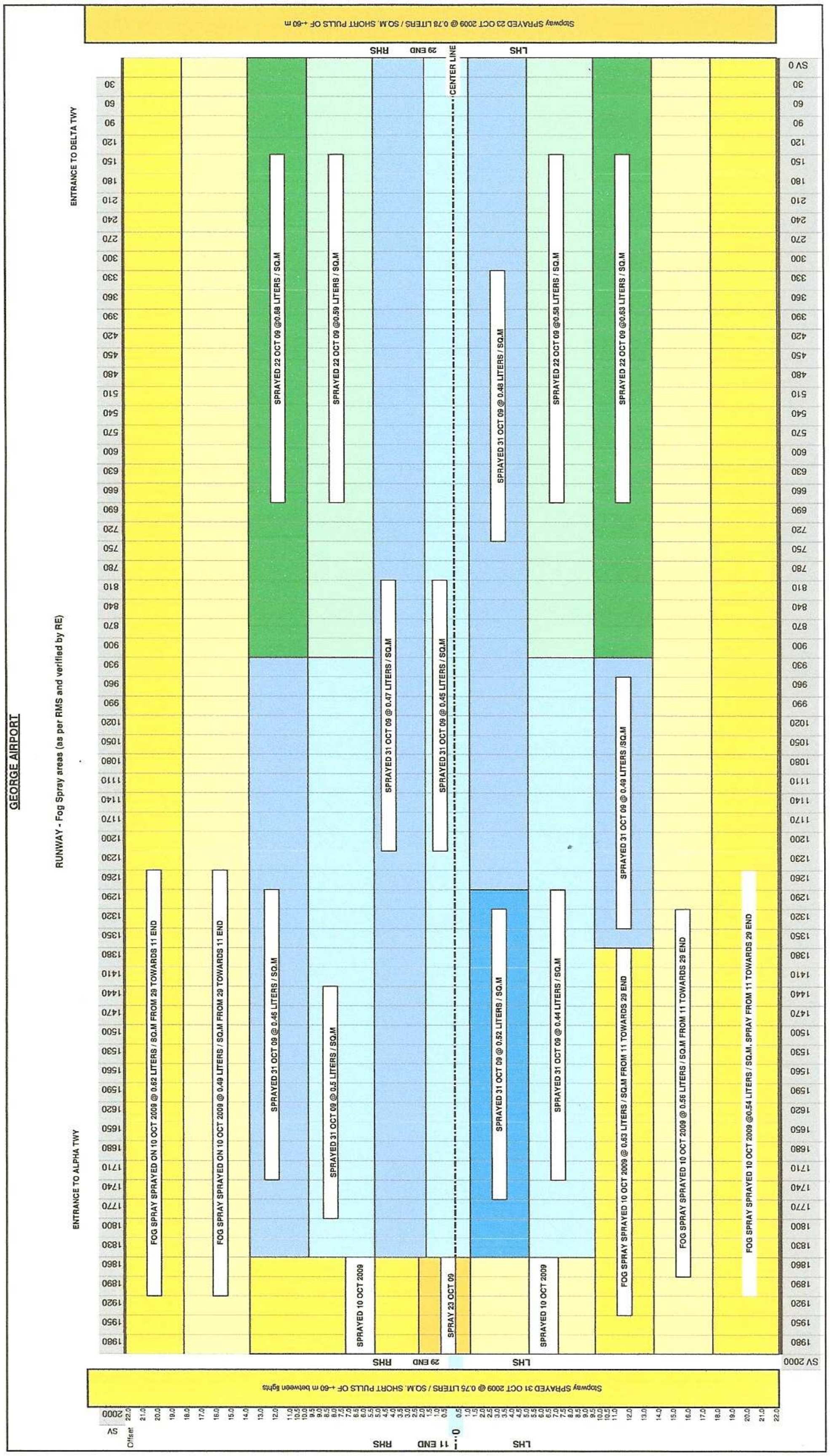
The SCU controls the spoiler without pilot input for the ground spoiler function.

The SCU operates the spoiler surfaces to open (ground spoiler function) when the following conditions occur:

- *Airplane on the ground.*
- *Main landing gear wheels turning above 25 knots.*
- *The two engines' thrust lever angles below 30° or N2 below 56%."*



ANNEXURE D – Runway 11/29 fog spray application chart


GEORGE AIRPORT
RUNWAY - Fog Spray areas (as per RMS and verified by RE)

ANNEXURE E

Quoted from:

Basic Asphalt Emulsion Manual, Fourth Edition (Asphalt Institute).

Pavement Work Tips No. 23, May 2003, Sprayed Sealing – Surface Enrichment, produced by Austroads in conjunction with the Australian Asphalt Pavement Association (AAPA).

Fog Seal Guidelines, Caltrans Division of Maintenance, State of California Department of Transportation, October 2003.

"Fog spray/seals are a method of adding asphalt to an existing pavement surface to improve sealing or waterproofing, prevent further stone loss by holding aggregate in place, or simply improve the surface appearance. However, inappropriate use can result in slick pavements.

The Asphalt Emulsion Manufacturers Association (AEMA) defines a fog spray/seal as 'a light spray application of dilute asphalt emulsion used primarily to seal an existing asphalt surface to reduce ravelling and enrich dry and weathered surfaces'. (1). Others refer to fog spray/seals as enrichment treatments since they add fresh asphalt to an aged surface and lengthen the pavement surface life (2). Fog spray/seals are also useful in chip seal applications to hold chips in place in fresh seal coats. These are referred to as flush coats. This can help prevent damage arising from flying chips. The Asphalt Institute also adds that fog spray/seals can seal small cracks (3).

A fog spray/seal is a light application to an existing surface of a slow setting asphalt emulsion diluted with water. It can be diluted in varying proportions – up to 1 part emulsion to 5 parts water, but in most cases, a one-to-one dilution is used.

A fog spray can be a valuable maintenance aid when used for its intended purpose. It is not a substitute for an asphalt-aggregate surface treatment. It is used to renew old hot-mix asphalt (HMA) pavement surfaces that have become dry and brittle with age, to seal small cracks and surface voids, and to inhibit ravelling. The surface enrichment is generally only applicable to areas of low traffic.

The fairly low-viscosity diluted emulsion flows easily into the cracks and surfaces voids. It also coats aggregate particles on the surface.

This corrective action prolongs pavement life and may delay the need for major maintenance or rehabilitation for a period of 1 to 3 years.

The total quantity of fog spray used is approximately 0,45-0,70 litre/square metres (0,10-0,15 gallon/square yards) of diluted material. Exact quantities are determined by the surface texture, dryness, and degree of cracking or ravelling of the pavement on which the fog spray is to be sprayed. Over-application must be avoided because it will result in asphalt pickup by vehicles and possibly create a slippery surface.

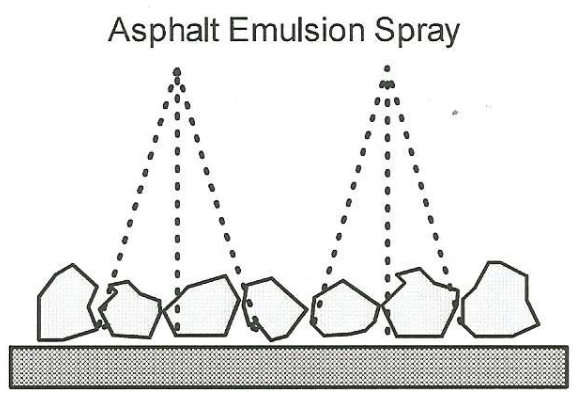
Traffic must be kept off the fog spray until the emulsion breaks and is substantially absorbed into the existing surface. This curing period may range from one hour in hot, dry conditions to as much as three hours or longer in cool, humid conditions.

Fog sprays/seals are primary applied to:

- *Renew and protect old oxidised asphalt surfaces.*
- *Seal small cracks and surface voids.*
- *Prevent damage to pavements placed in cold weather.*
- *Prevent ravelling of chip seals.*
- *Prevent snow plow damage to chip seals.*
- *Blacken new chip seals.*
- *Prevent ravelling of open-graded surfaces.*
- *Maintain and delineate shoulders in high-volume surfaces.*

Function of a Fog Spray/Seal:

A fog spray/seal is designed to coat, protect, and/or rejuvenate the existing asphalt binder. The addition of asphalt will also improve the waterproofing of the surface and reduce its aging susceptibility by lowering permeability to water and air. To achieve this, the fog spray/seal material (emulsion) must fill the voids in the surface of the pavement. Therefore, during its application it must have sufficiently low viscosity so as to not break before it penetrates the surface voids of the pavement. This is accomplished by using a slow-setting emulsion that is diluted with water. Emulsions that are not adequately diluted with water may not properly penetrate the surface voids resulting in excess asphalt on the surface of the pavement after the emulsion breaks, which can result in a slippery surface. The figure below conceptually shows a fog spray/seal application.



Schematic of Fog Spray Application

Surface enrichment treatment before (left) and after (right).

During application, the emulsion wets the surface of the aggregate and the existing binder film. Cationic (positively charged) emulsions can displace water from the surface of an aggregate or aged asphalt film. The emulsion then breaks by loss of water and chemical action, forming a film of new binder on the aggregate and existing binder film. The rate at which the emulsion breaks is dependent on several factors with weather conditions (e.g., wind, rain, temperature, etc.) being dominant factors. For anionic (negatively charged) emulsions, there is no surface-specific interaction with most aggregates. The emulsion breaks due to water loss by evaporation and absorption of water by the aggregates and surface voids of the pavement.

Fog Spray/Seal Performance – Benefits and Limitations:

Fog spray/seals are an inexpensive way of arresting ravelling and adding binder back into aged surfaces. They can also hold chips in place in fresh chip seals (or older chip seals beginning to loose rock), reducing the potential for vehicle/aircraft damage.

Fog spray/seals are not useful as seal coats on tight surfaces without the addition of aggregates as they will reduce surface texture and may create a slippery surface. Fog spray/seals should not be used on Rubberized Asphalt Concrete (RAC) or polymer modified mixes unless the pavements are over five years old as these binders age at a different rate.

The application of fog spray/seals is also limited by weather. A cut-off date in the autumn will ensure that rain will not be a factor and that the emulsion will fully cure before freezing conditions are encountered. In addition, seal coats applied in the winter have less time to penetrate the pavement and are more prone to cause slick surface conditions.

Don't Fog Spray if:

Fog sprays are not effective for long-term crack sealing. And fog sprays are not the answer when a pavement has low surface texture, large cracks, rutting, shoving, or other structural deficiency.

An excessive application rate may result in a thin asphalt layer on top of the original HMA pavement. This layer can be very smooth and cause a loss of skid resistance.

Enrichment is only effective if the pavement is sound and the amount of stone loss or cracking is minimal. There must be adequate texture to accommodate the additional binder without compromising surface friction properties. As a general rule, there should be at least 1 mm texture depth remaining after treatment. Surface enrichment may be repeated several times provided that sufficient texture remains after each treatment."

Federal Aviation Administration Advisory Circular No. 150/5320-12C, chapter 4: Maintaining High Skid-Resistance, states:

"Need for Maintenance:

As traffic mechanically wears down micro-texture and macro-texture and as contaminations build up on runway pavements, friction will decrease to a point where safety may be diminished. Where high numbers of aircraft operations occur, the venting of excess fuel can lead to serious loss of friction by either causing contaminant build-up or an oil film on the pavement surface. Also, fog spray (seal) treatment of HMA surfaces can substantially reduce the pavement's coefficient of friction during the first year after application. Surfaces which already have marginally acceptable friction can become unacceptable when given this type of surface treatment.

When the measured coefficient of friction values approach or drop below the Maintenance Planning Level (MPL) as shown in the table below extracted from ICAO Annex 14, Volume 1, Attachment A, Section 7, Table A-1, Aerodromes, as well as document FAA AC No. 150/5320-12C, timely maintenance for removal of contaminants and/or restoration of the runway surface to a good friction characteristics should be scheduled without delay."

Test equipment	Type	Test tyre pressure (kPa)	Test speed (km/h)	Test water depth (mm)	Design objective for new surface	Maintenance planning level (MPL)	Minimum friction level (MFL)
Mu Meter	A	70	65	1.0	0.72	0.52	0.42
	A	70	95	1.0	0.66	0.38	0.26
Skiddometer	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.47	0.34
Surface Friction Tester	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.47	0.34
Runway Friction Tester	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.54	0.41
TATRA Friction Tester	B	210	65	1.0	0.76	0.57	0.48
	B	210	95	1.0	0.67	0.52	0.42
GripTester	**C**	**140**	**65**	**1.0**	**0.74**	**0.53**	**0.43**
	C	**140**	**95**	**1.0**	**0.64**	**0.36**	**0.24**

This table, headed "*Friction levels for new and existing runway surfaces*", was developed by the National Aeronautics and Space Administration (NASA). The relationship of the friction/speed gradient was determined at NASA's Wallops Flight Facility in 1989 by conducting friction surveys at different speeds (20, 40, 60 and 80 mph) on several types of pavement surfaces that represented a wide range of friction values. The 20 mph test was regarded as being too slow and the 80 mph test would have precluded most touchdown zones. Therefore, a compromise was made and tests were conducted at only two speeds, 40 mph (65 kph) and 60 mph (95 kph), which was felt would provide an adequate representation of the friction/speed gradient for most pavement surfaces.

Fog seal on runway/road surfaces.

Unified Facilities Guide Specifications (UFGS) 32-01-13, August 2008 (Exterior Improvements, Bituminous Seal and Fog Coats), states:

"*Part 1 General (Fog spray)*

NOTE: Bituminous seal coat should not be used on primary roads or airfield areas. Fog spray/seals lower the frictional resistance of paved surfaces and will not be used on runways, high speed taxiway turnoffs, or moderate to high speed roads unless approval is obtained from NAVFACENGCOMHQ (Naval Facilities Engineering Command Headquarters), or AFCESA (Air Force Civil Engineering Support Agency) in the United States."

The Standard Practice Manual for Flexible Pavements, published in 2001 by the US Department of Defense, states:

"Fog seals and rejuvenators ***(Air Force bases should contact their MAJCOM pavement engineers prior to using these applications on airfield pavements, due to possible decrease in skid resistance).***

Fog seals.

a. General.

A fog seal is a very light spray application of a diluted emulsified asphalt to an existing asphalt pavement surface. The fog seal is used to maintain old pavements, reduce raveling, waterproof, and in general, extend the life of the existing pavement. Fog seals are especially good for treating pavements which carry little or no traffic. However, there are several considerations when using fog seals.

(1) The pavement skid resistance can be reduced.

(2) The pavement air voids or permeability can be reduced.

(3) The pavement should be closed to traffic for 12 to 24 hours to allow for proper cure of the seal material"

"Maintenance and repair of surface areas", a manual published in 1995 by the US Departments of the Army, the Navy, and the Air Force, limits the use of fog

sprays, and emphasises the need for dedicated pavement engineers to be involved in the process – due to the possible decrease in skid resistance

"Bituminous surface treatments are used for corrective or preventive maintenance of pavement surfaces or as a wearing surface for low volume roads. The use of these treatments is limited to pavements which are structurally adequate since these treatments add no significant strength to the pavement.

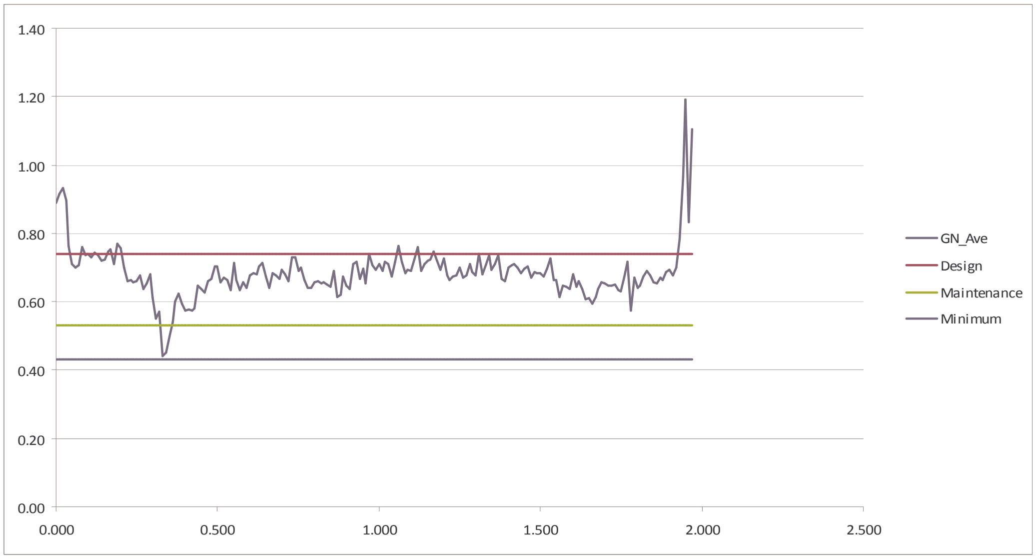
(1) Rejuvenator. Rejuvenators are especially developed products which can be used to extend the life of bituminous pavements. These products may be sprayed on the pavement surfaces by use of a conventional asphalt distributor. The rejuvenators penetrate into the bituminous pavement usually to a depth of 1/4-inch and soften the asphalt binder. The use of rejuvenators also help retain surface fines and reduce cracking in pavements. One disadvantage of rejuvenators is the lowering of the pavement's skid resistance. For this reason, the use of rejuvenators on runways or other high speed pavements must be carefully controlled. When an unacceptably slippery surface results from the application of a rejuvenator, an application of sand may be applied to increase the skid resistance of the pavement surface.

(2) Fog seal. *A fog seal is a light spray application of asphalt emulsion applied similarly as a rejuvenator. However, the fog seal is not intended to penetrate into the pavement. A fog seal can be used to seal a pavement surface to waterproof and prevent ravelling of surface aggregate. Sand may be applied to areas where the fog seal has lowered the pavement's skid resistance below an acceptable level."*

1 September 2009

Runway 29, left of the centreline. Friction measurements at 65 km/h,.

29-1MLC



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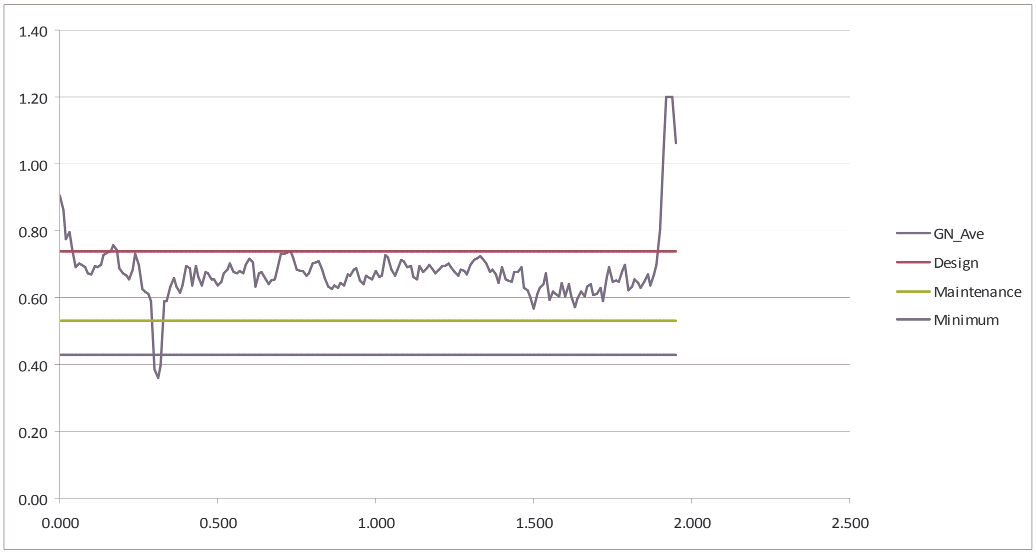
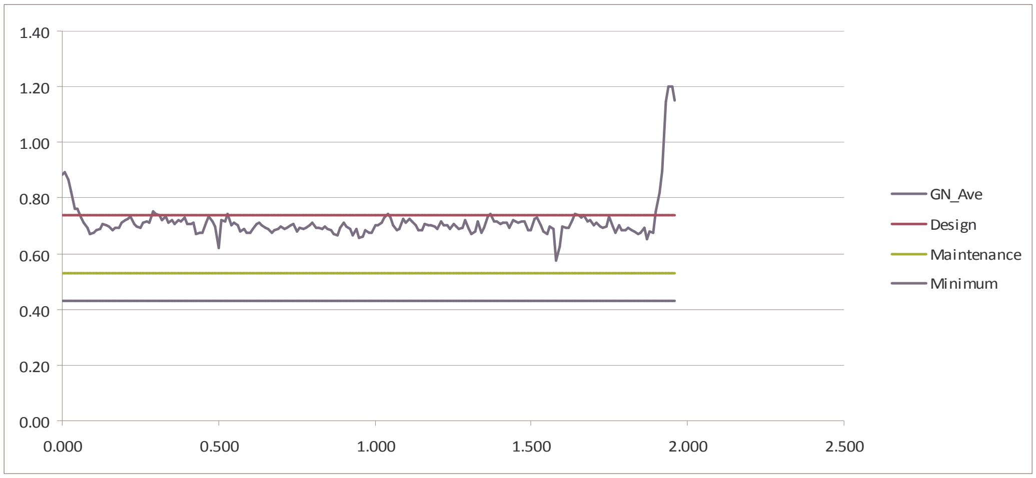
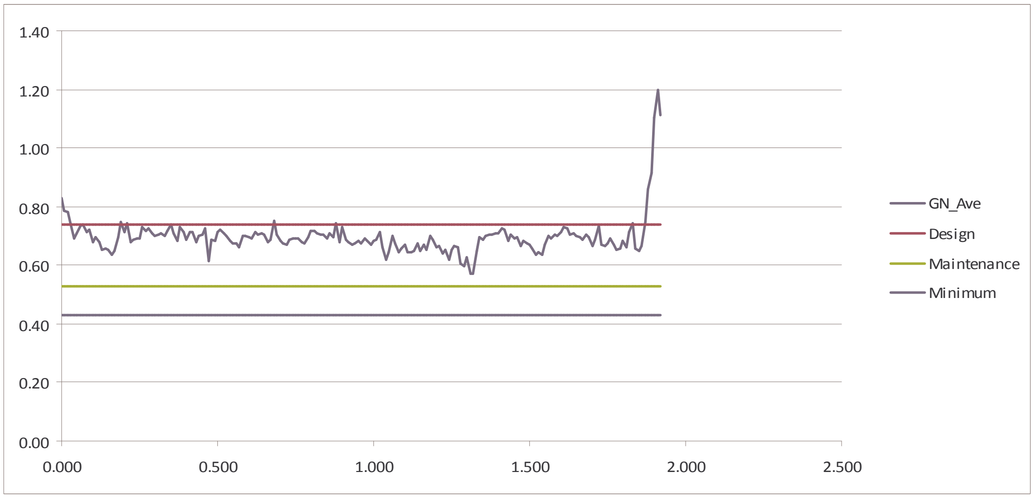


29-5MLC



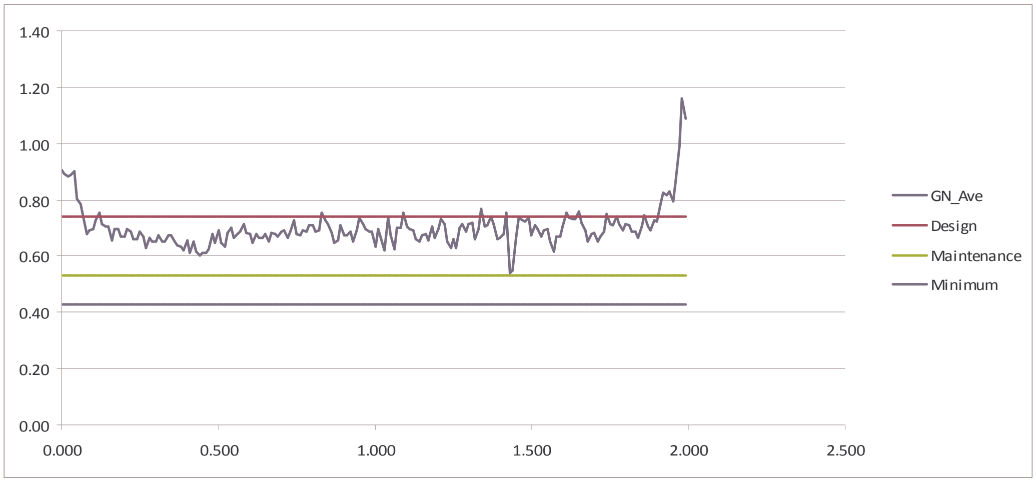
29-8MLC



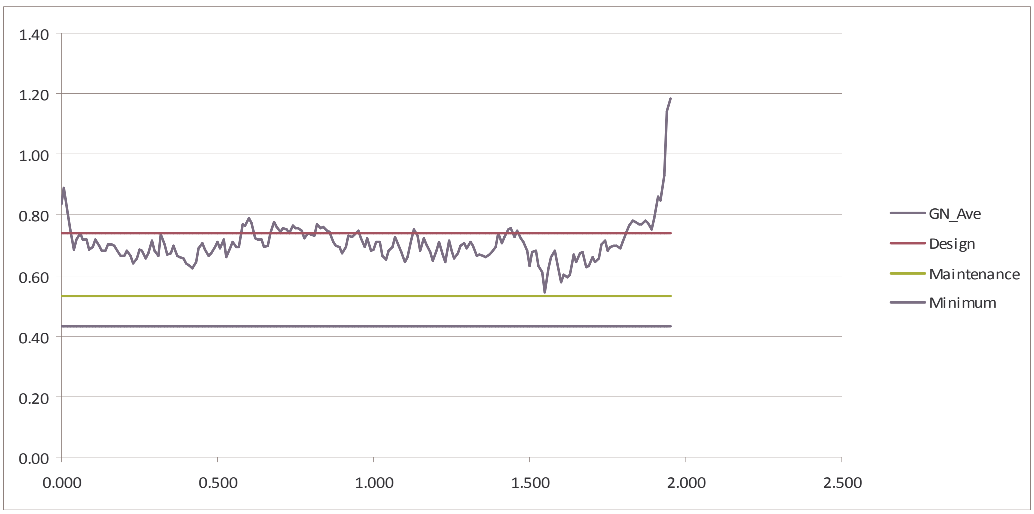
1 September 2009

Runway 11, left of the centreline. Friction measurements at 65 km/h.

11-1MLC



11-3MLC



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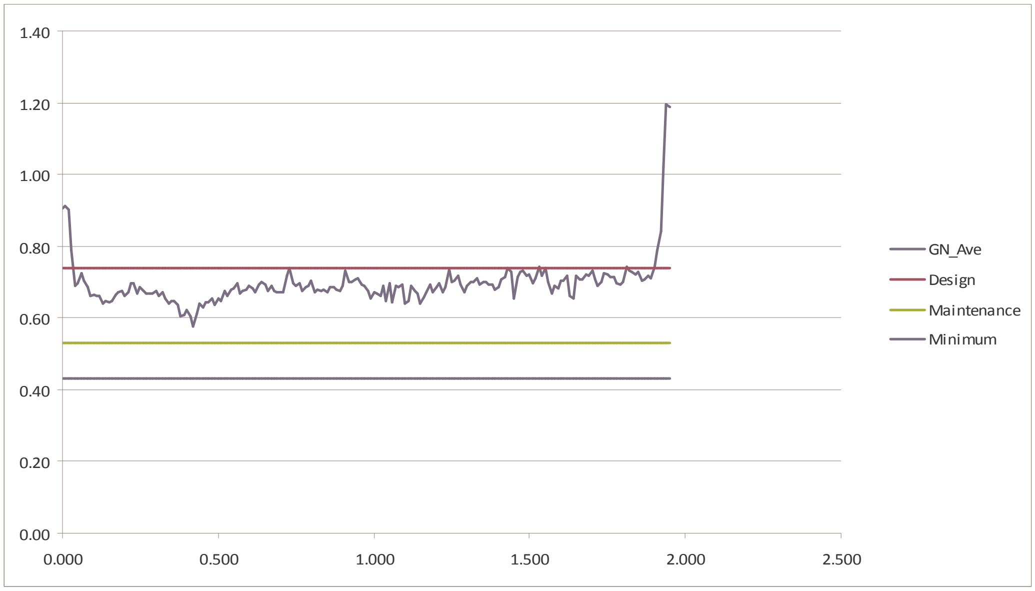
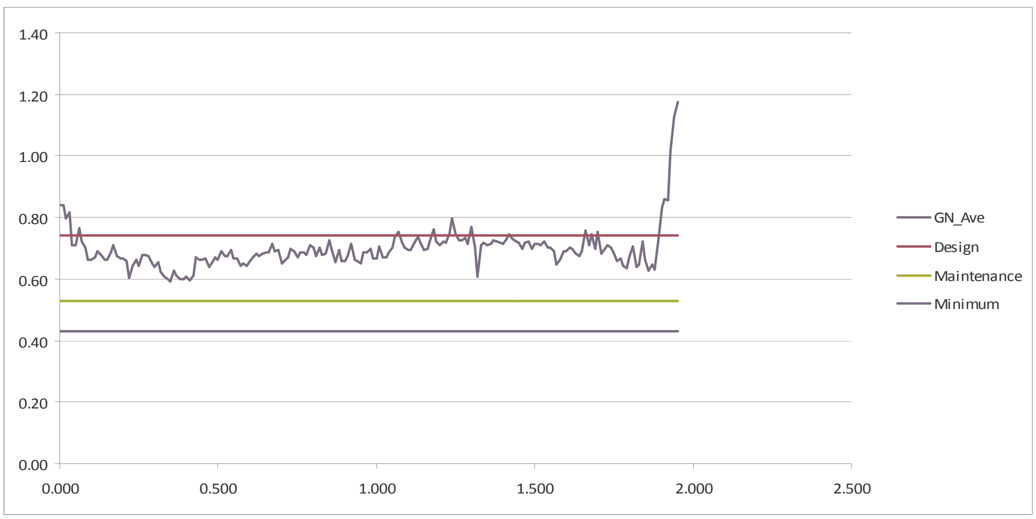
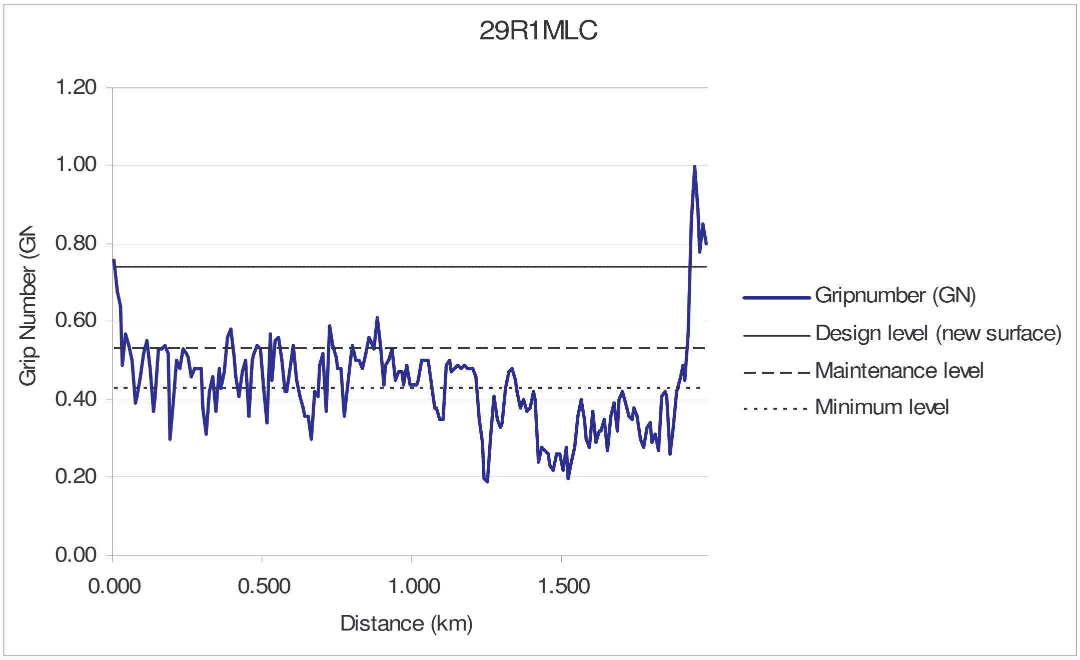


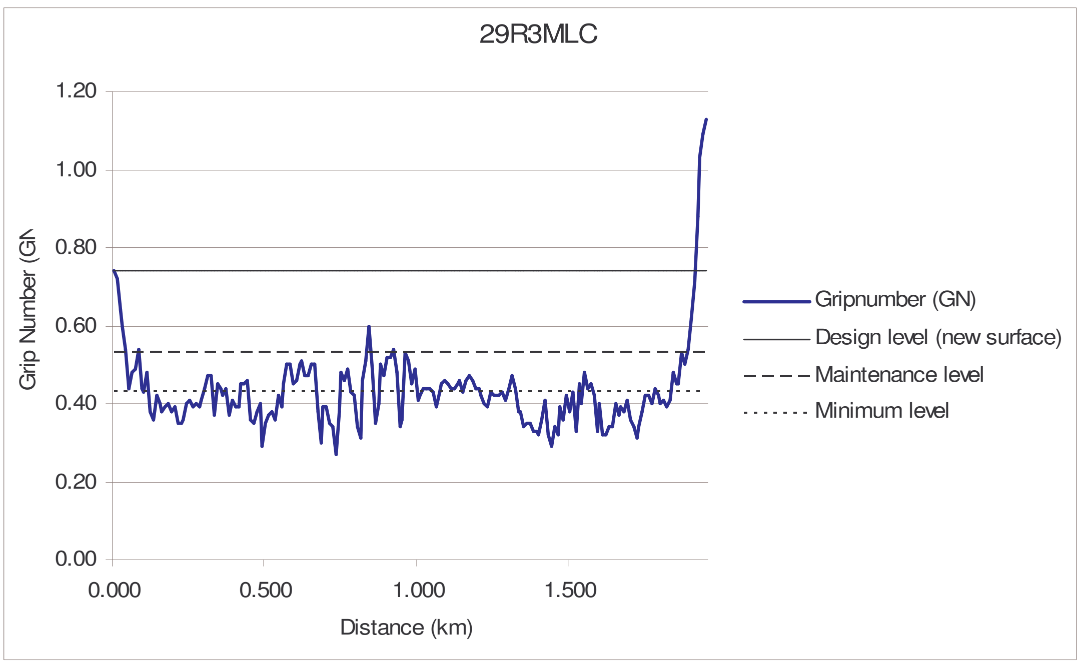
11-8MLC

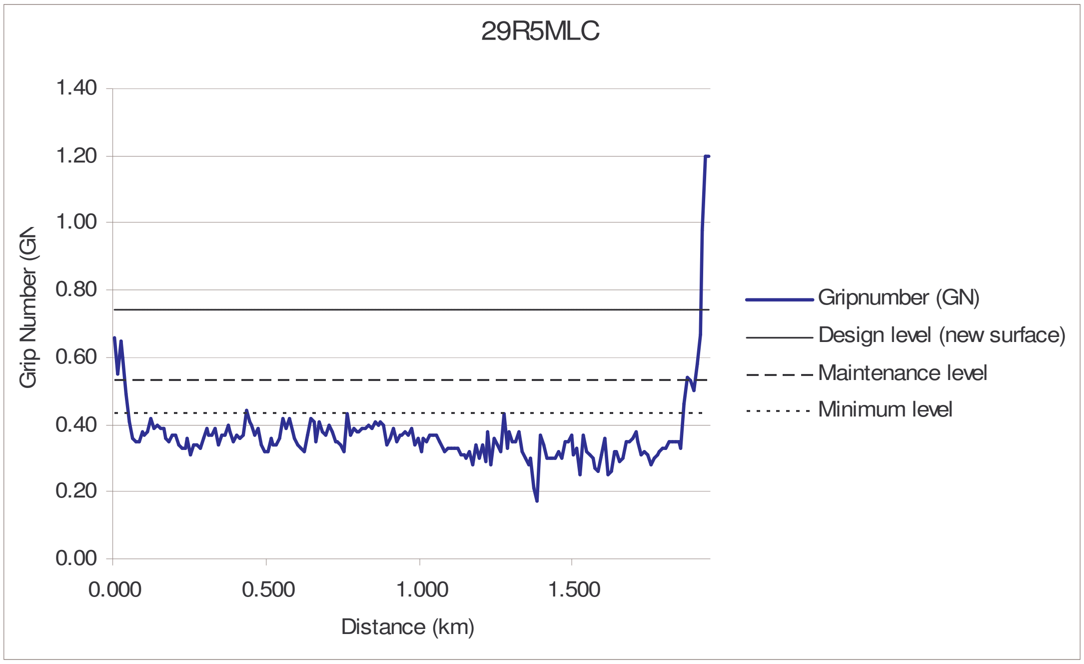


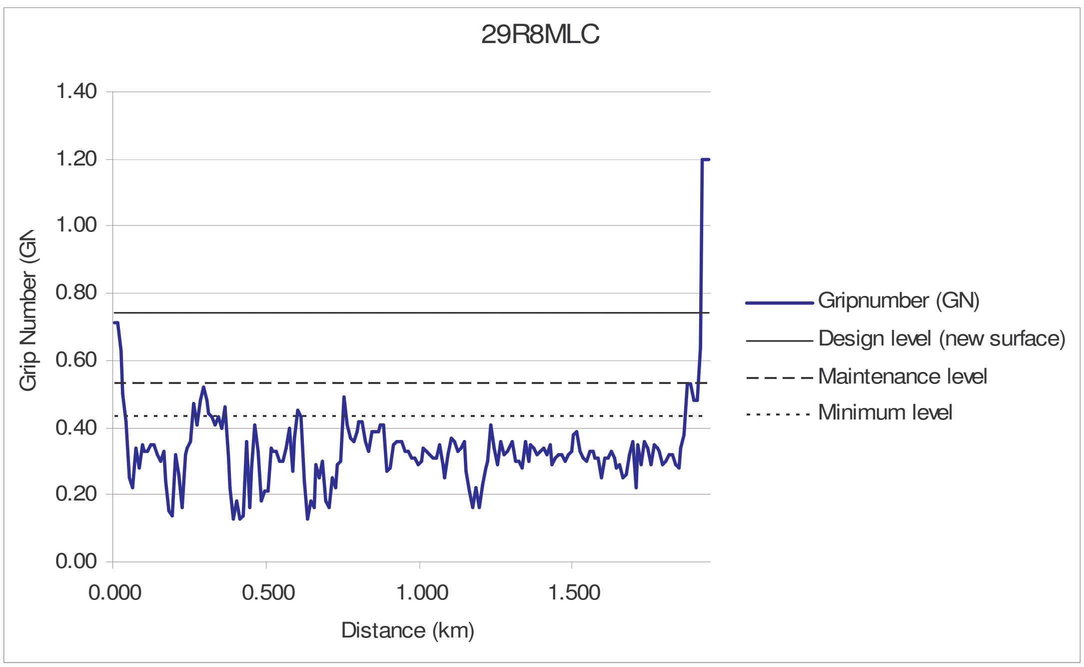
6 November 2009

Runway 29, left of the centreline. Friction measurements at 65 km/h.









6 November 2009

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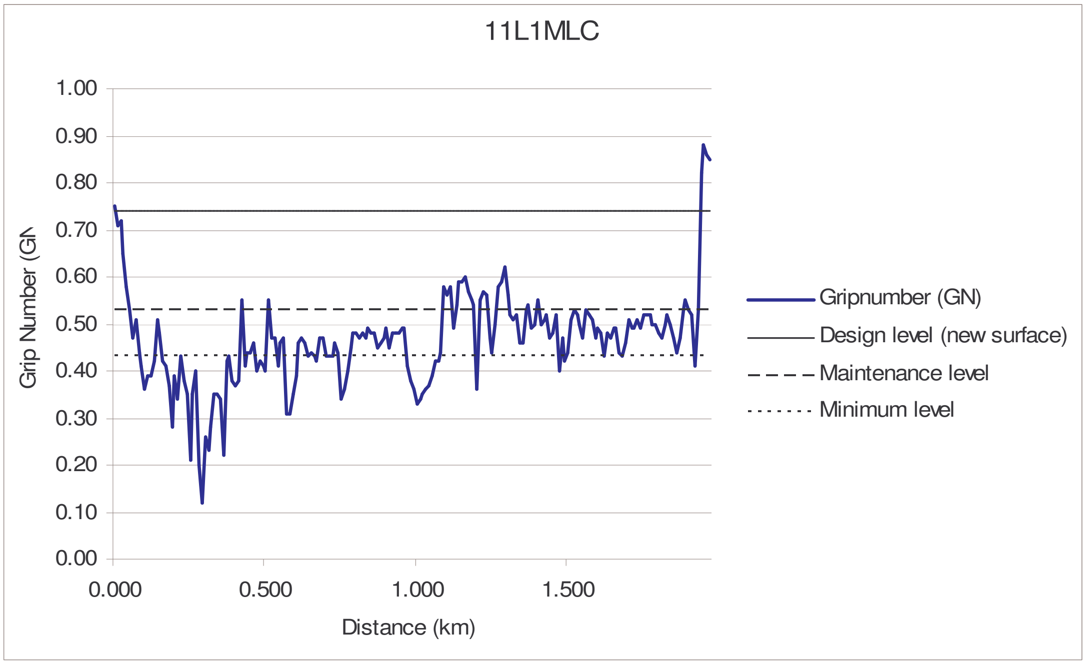
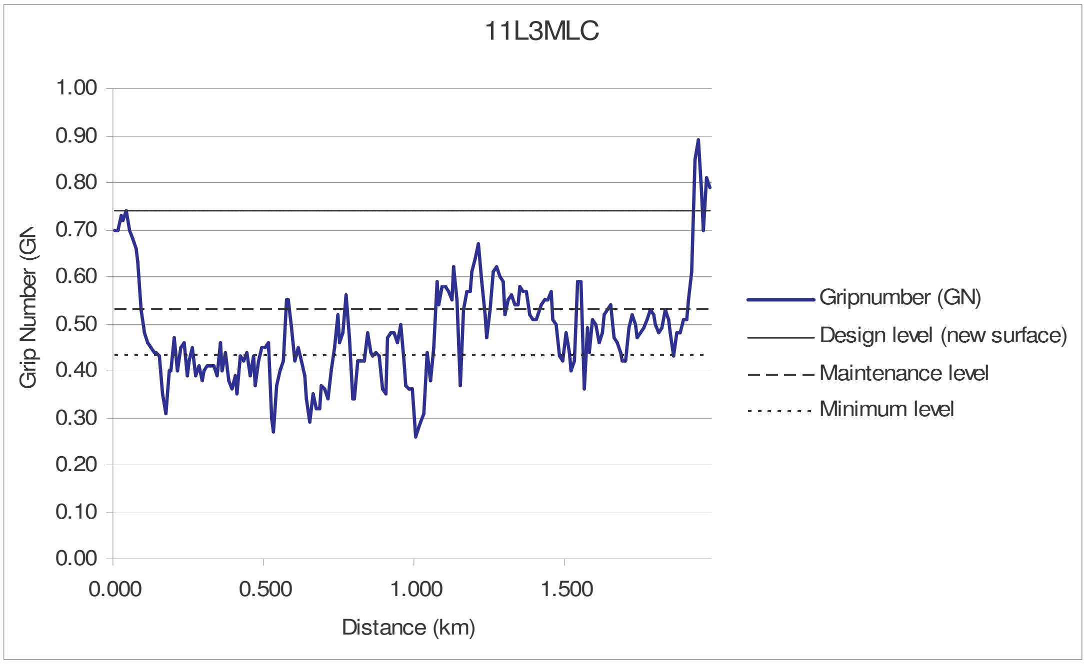
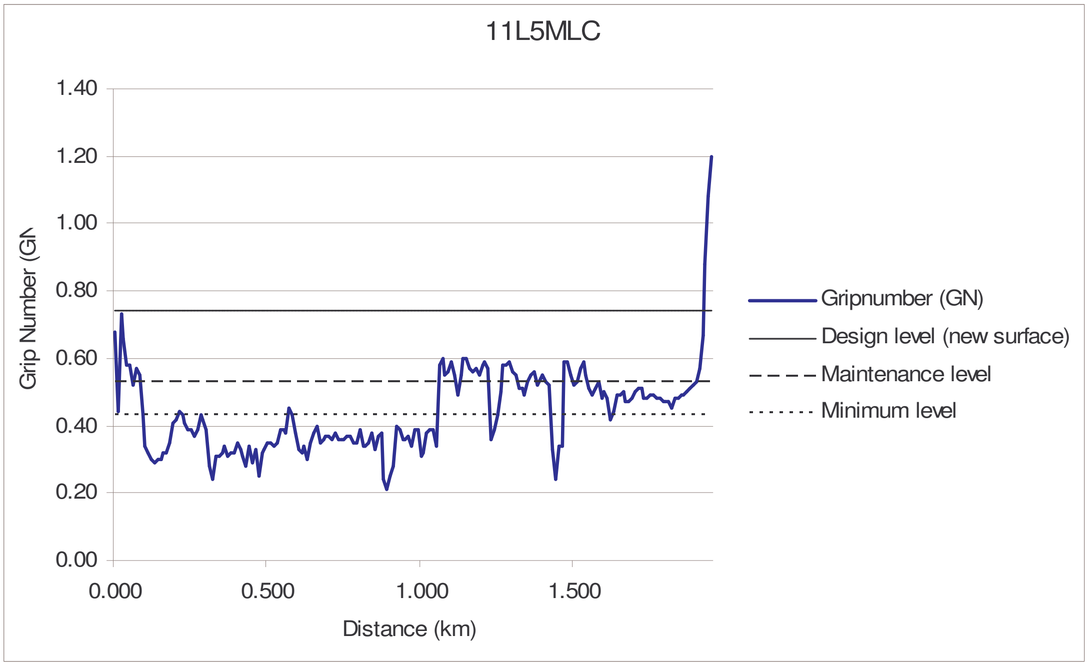
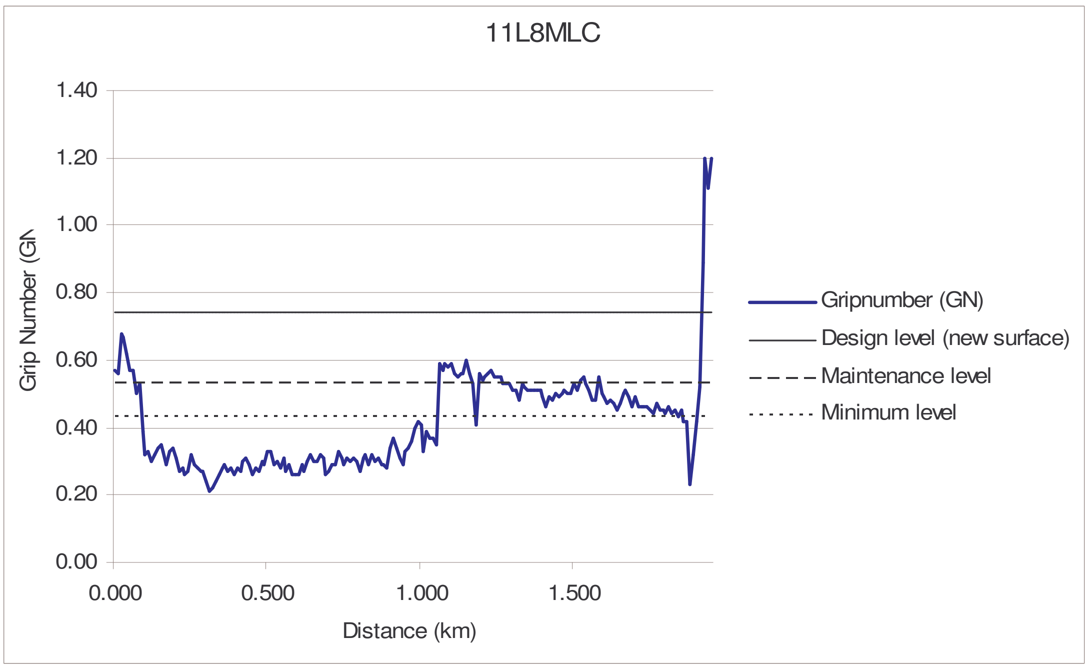


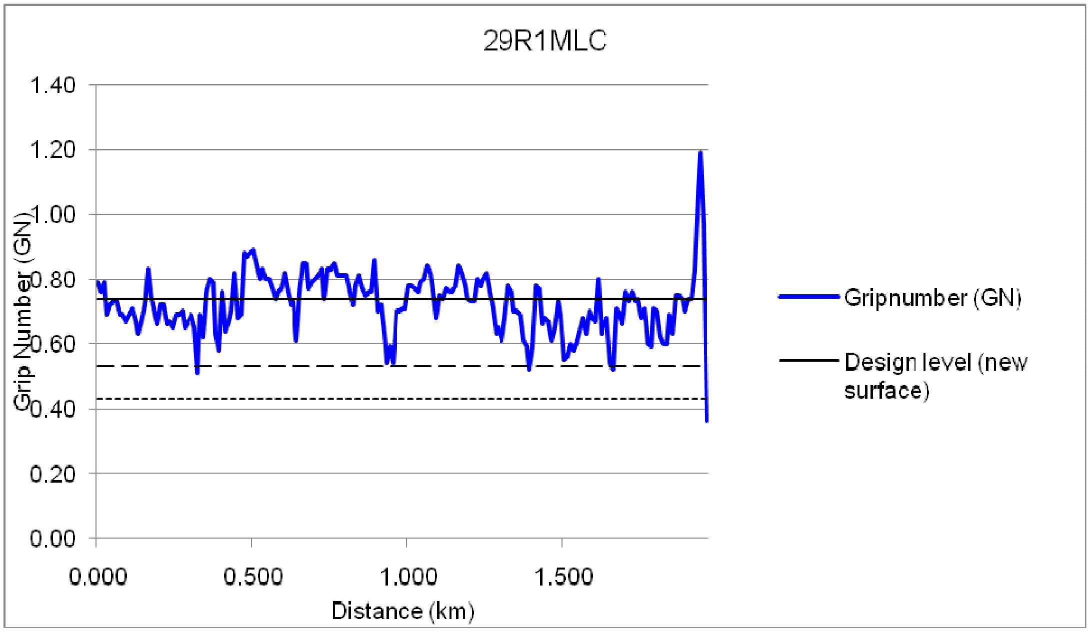






9 December 2009

Runway 29, left of the centreline. Friction measurements at 65 km/h.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1.20
1.00
0.80
0.60
0.40
0.20
0.00
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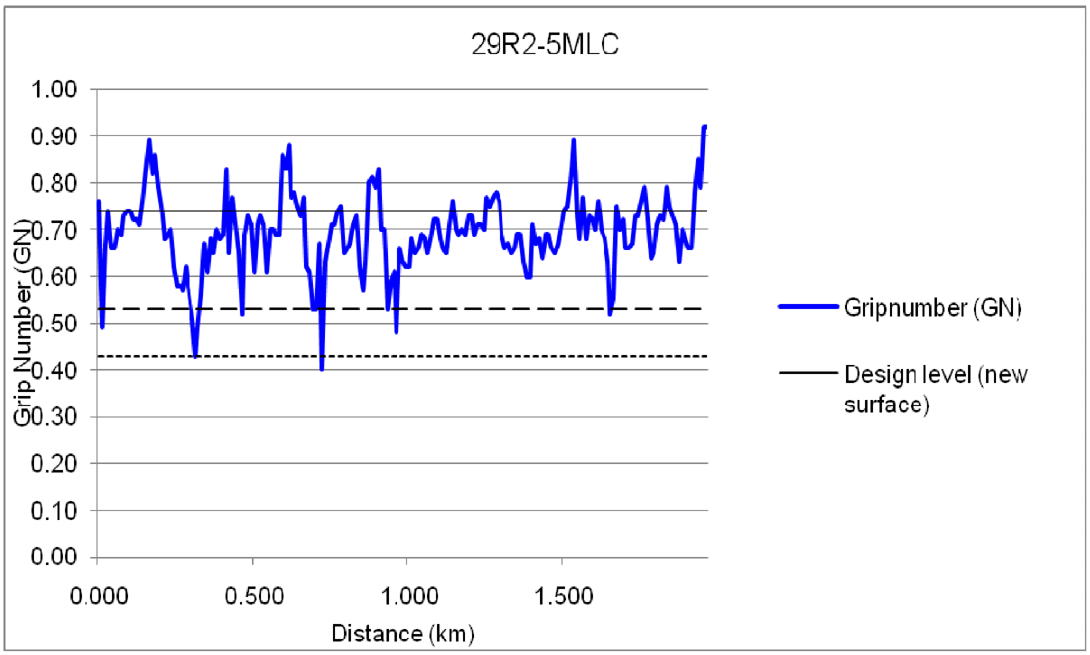
1.000
1.500
Distance (km)
Gripnumber (GN)
Design level (new surface)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0.40
0.30
0.20
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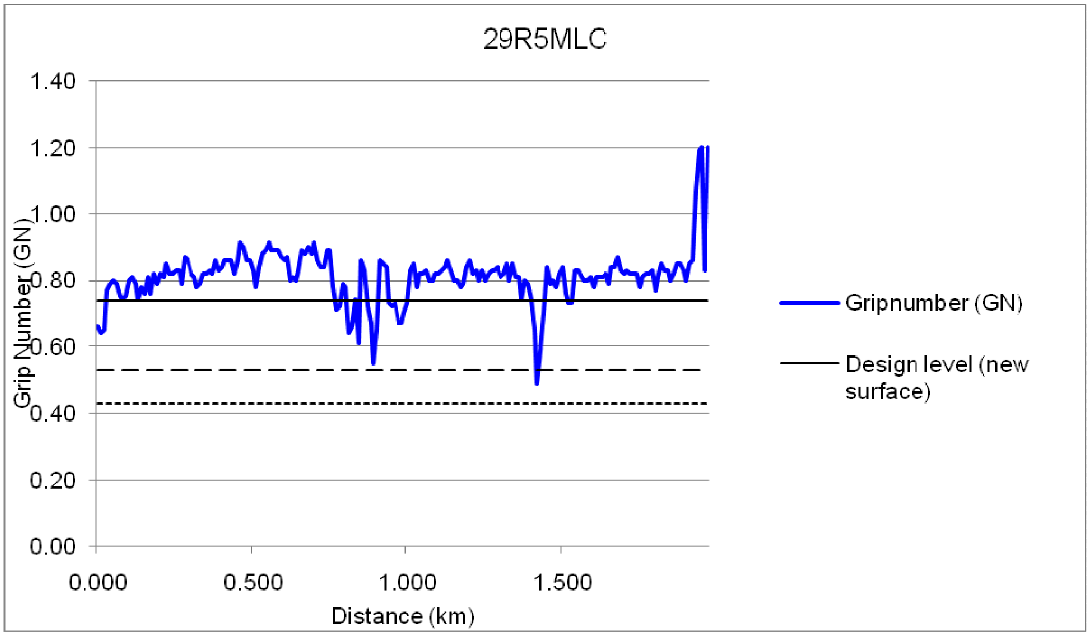
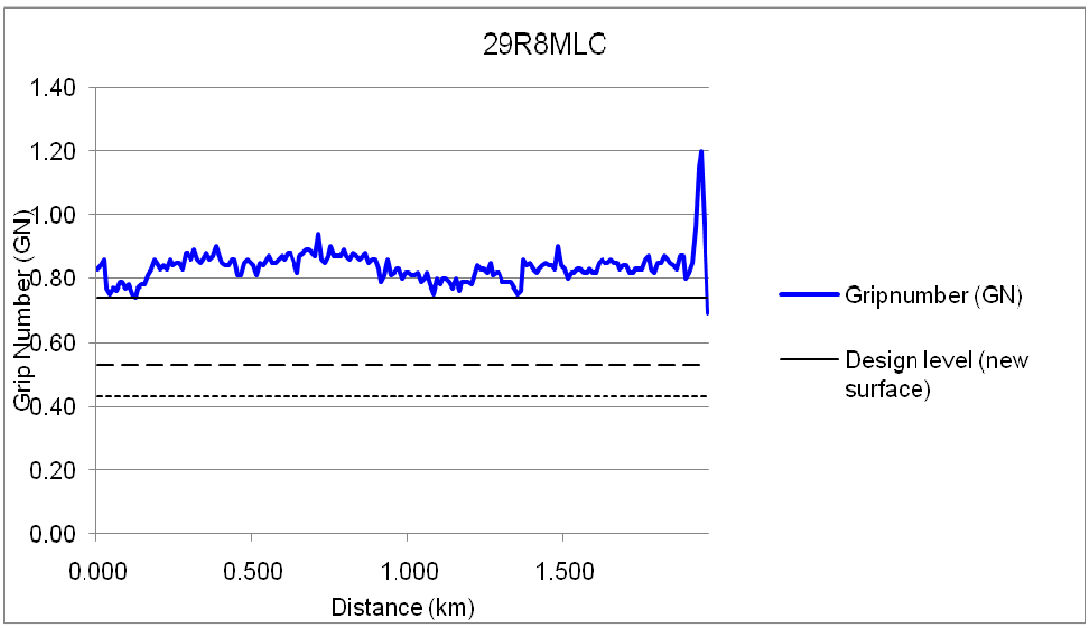
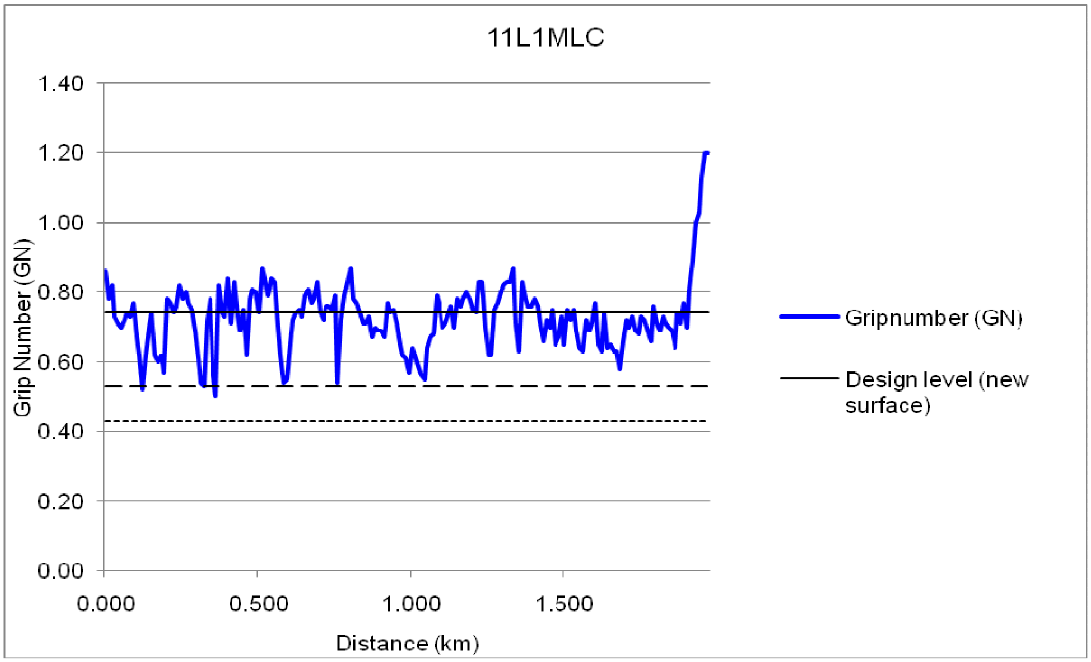
0.500
1.000
1.500
Distance (km)
Gripnumber (GN)
Design level (new surface)





9 December 2009

Runway 11, left of the centreline. Friction measurements at 65 km/h.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0.60
0.40
0.20
0.00
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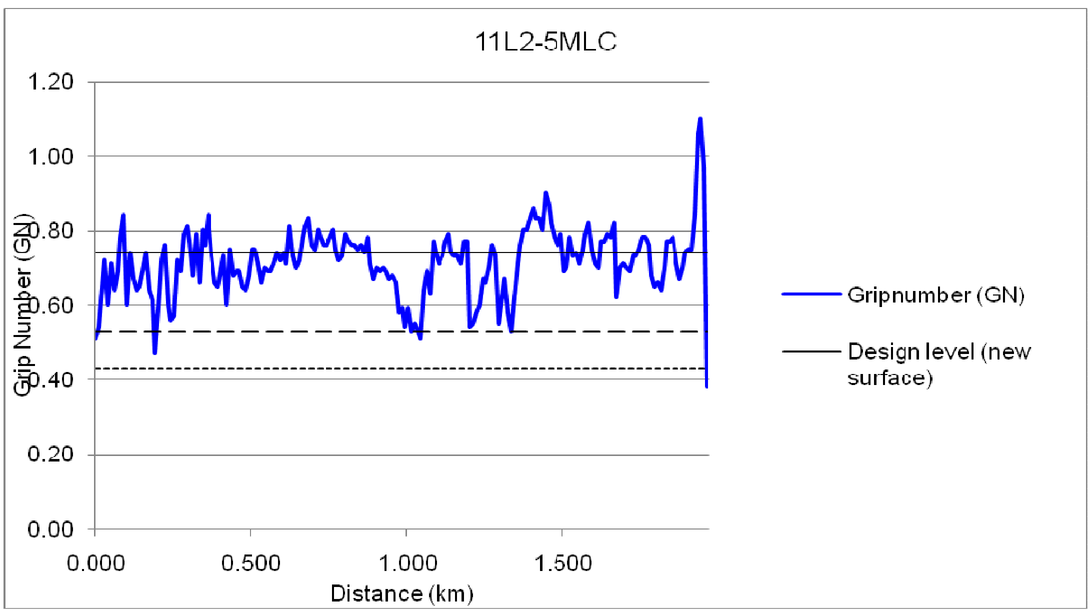
0.500
1.000
1.500
Distance (km)
Gripnumber (GN)
Design level (new surface)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0.40
0.20
0.00
Grip Number (GN)
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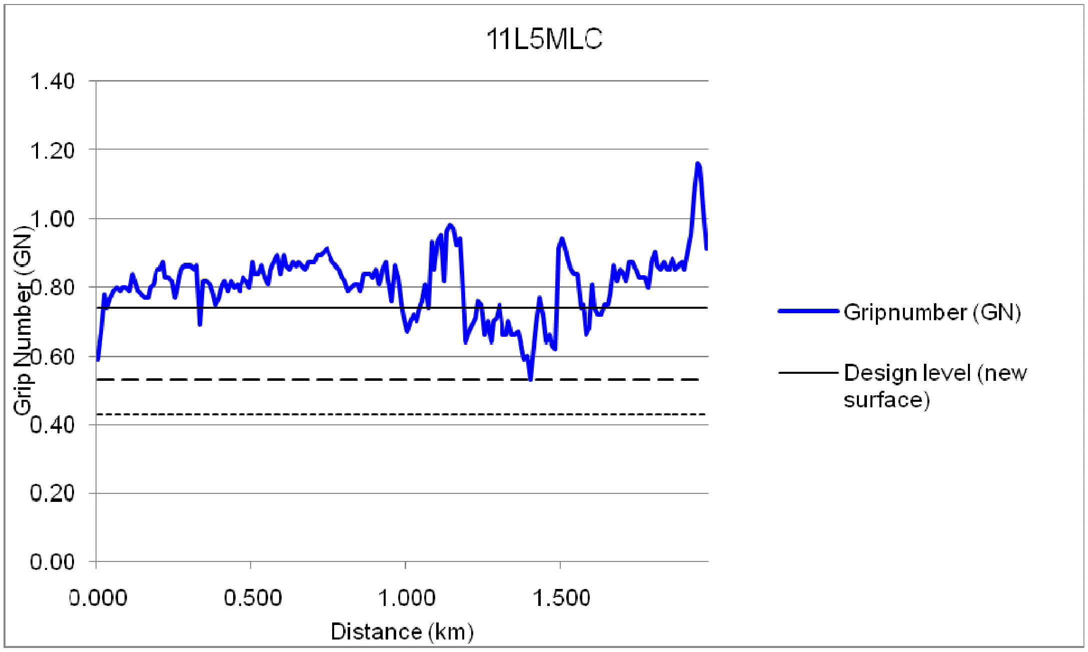
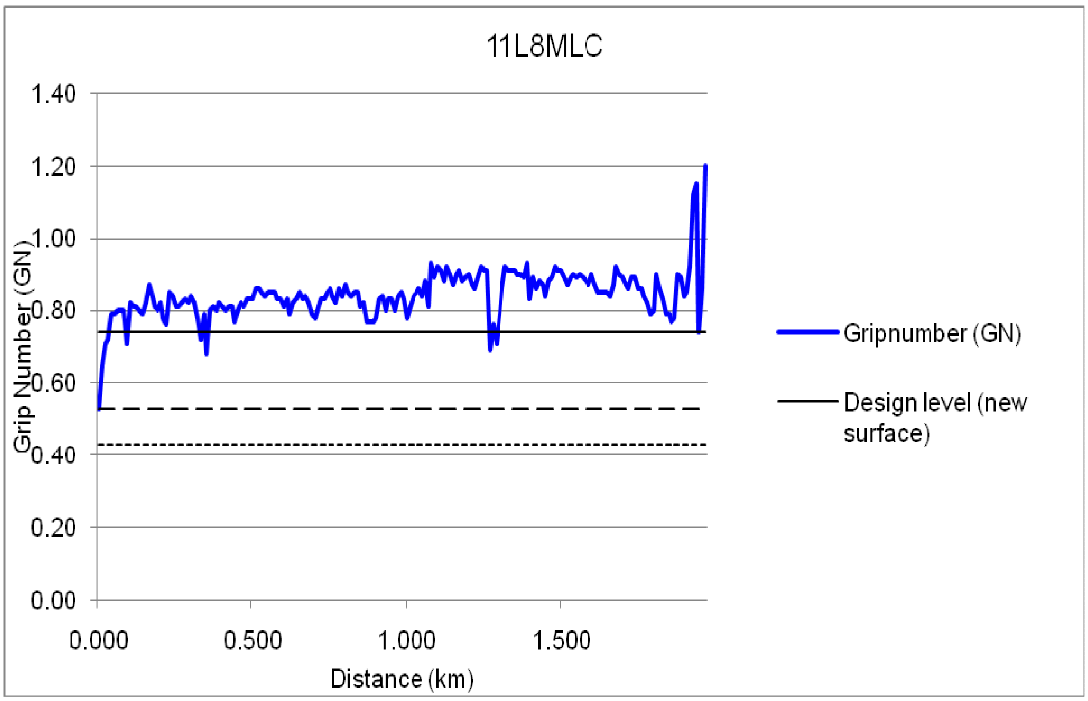
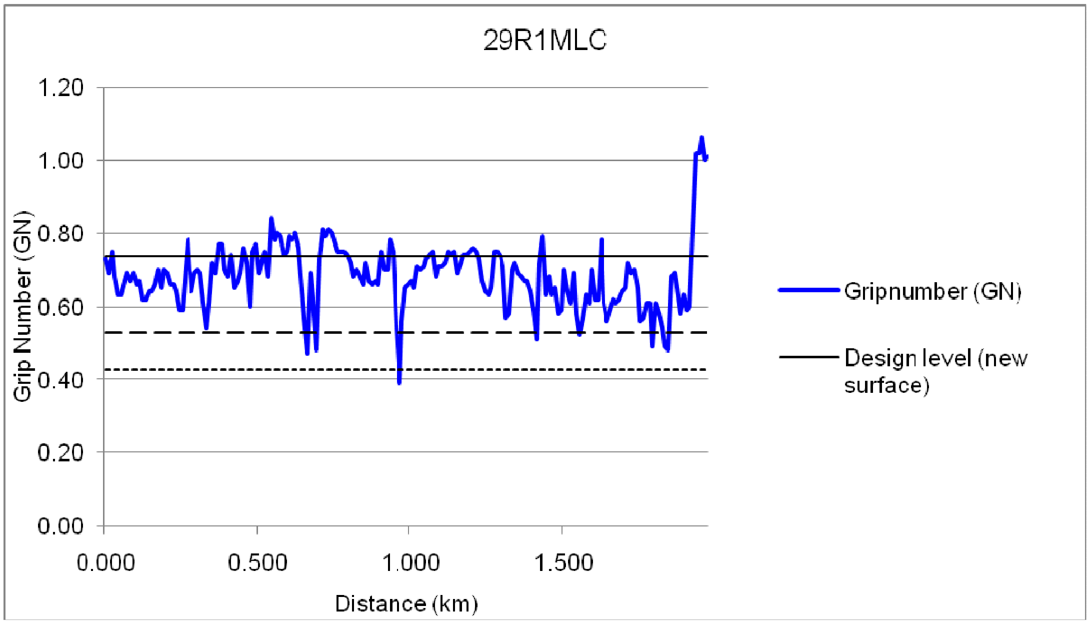
0.500
1.000
1.500
Distance (km)
Gripnumber (GN)
Design level (new surface)





15 February 2010

Runway 29, left of the centreline. Friction measurements at 65 km/h.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Grip Number (GN)
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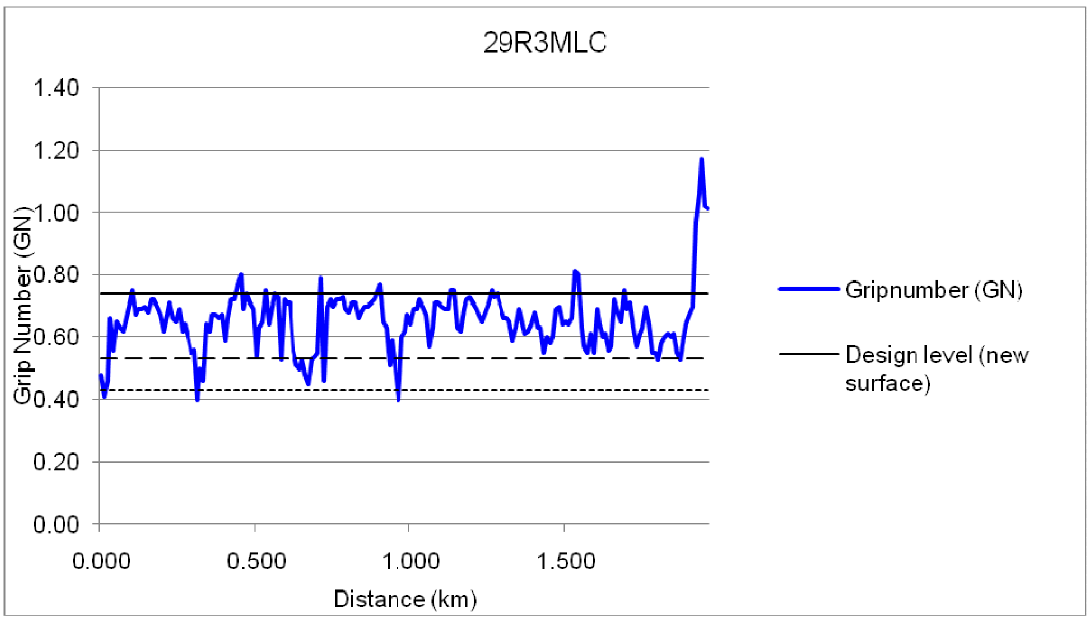
1.000
1.500
Distance (km)
Gripnumber (GN)
Design level (new surface)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1.000
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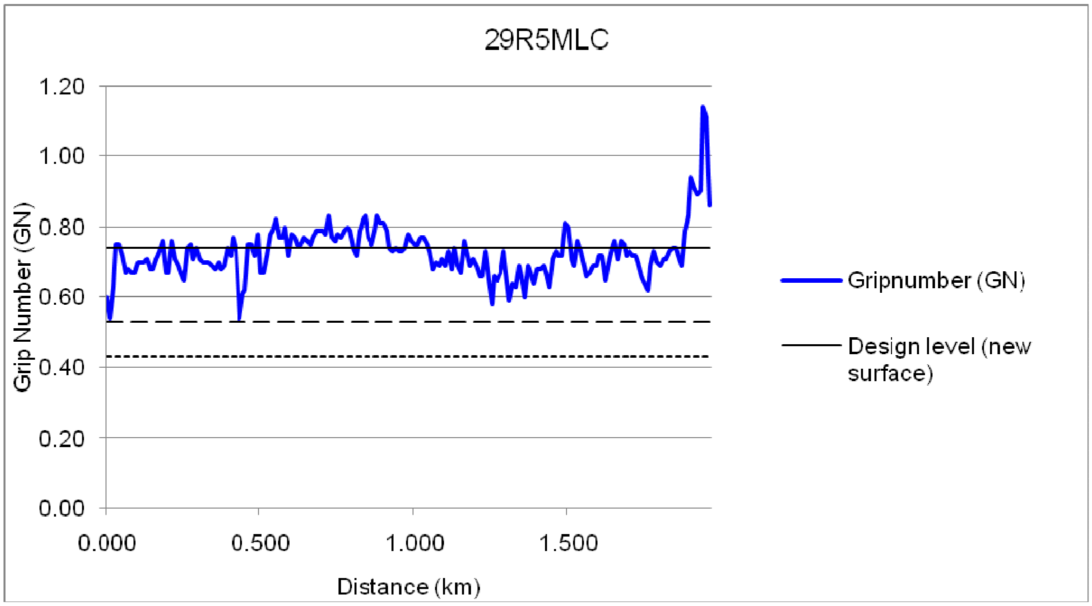
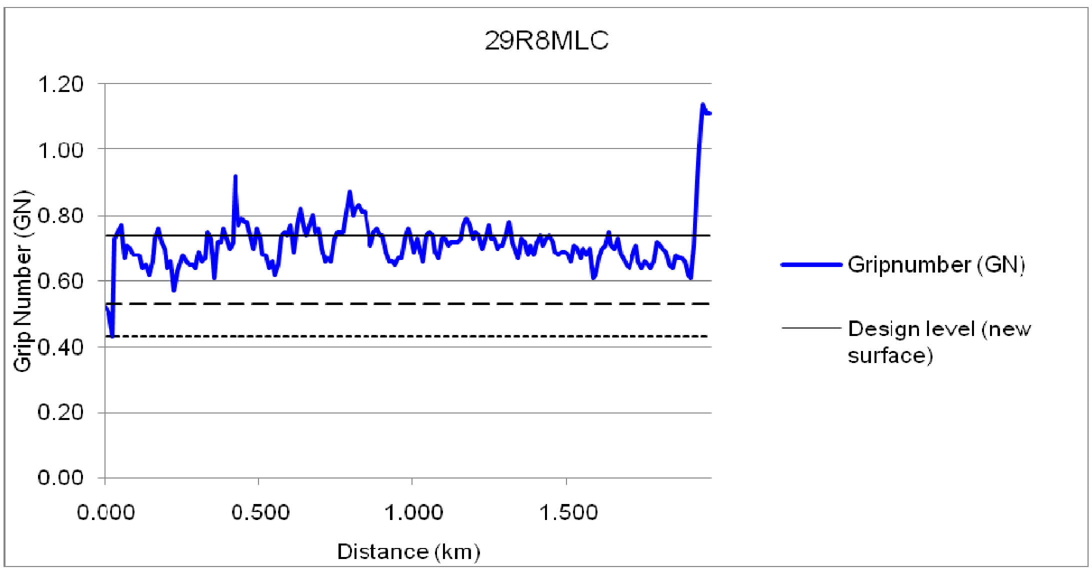
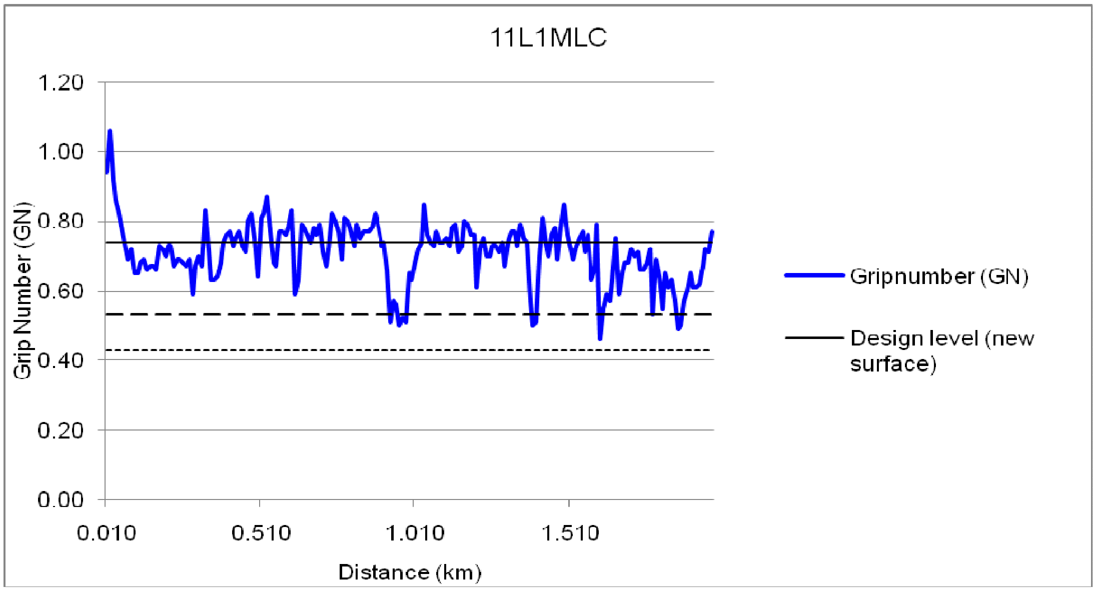
Distance (km)
Gripnumber (GN)
Design level (new surface)





15 February 2010

Runway 11, left of the centreline. Friction measurements at 65 km/h.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0.80
0.60
0.40
0.20
0.00
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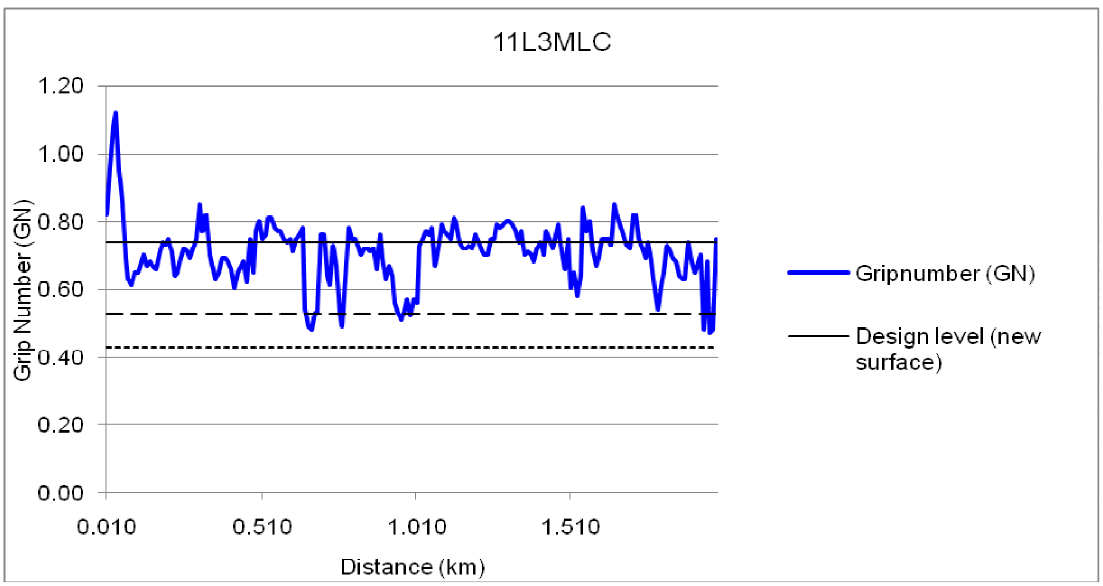
1.010
1.510
Distance (km)
Gripnumber (GN)
Design level (new surface)


11L3MLC
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1.00
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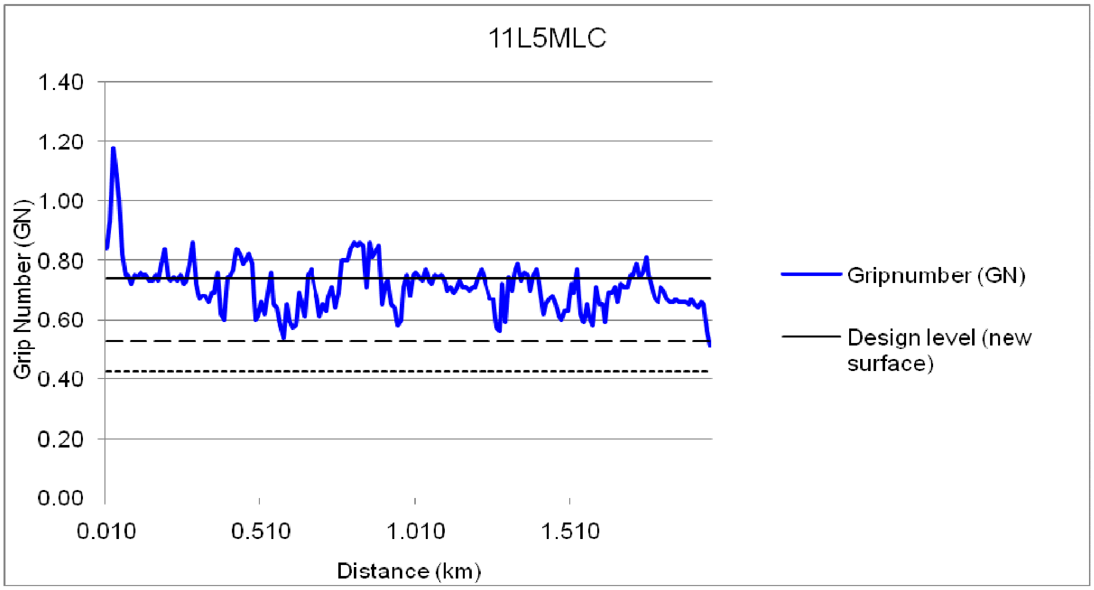
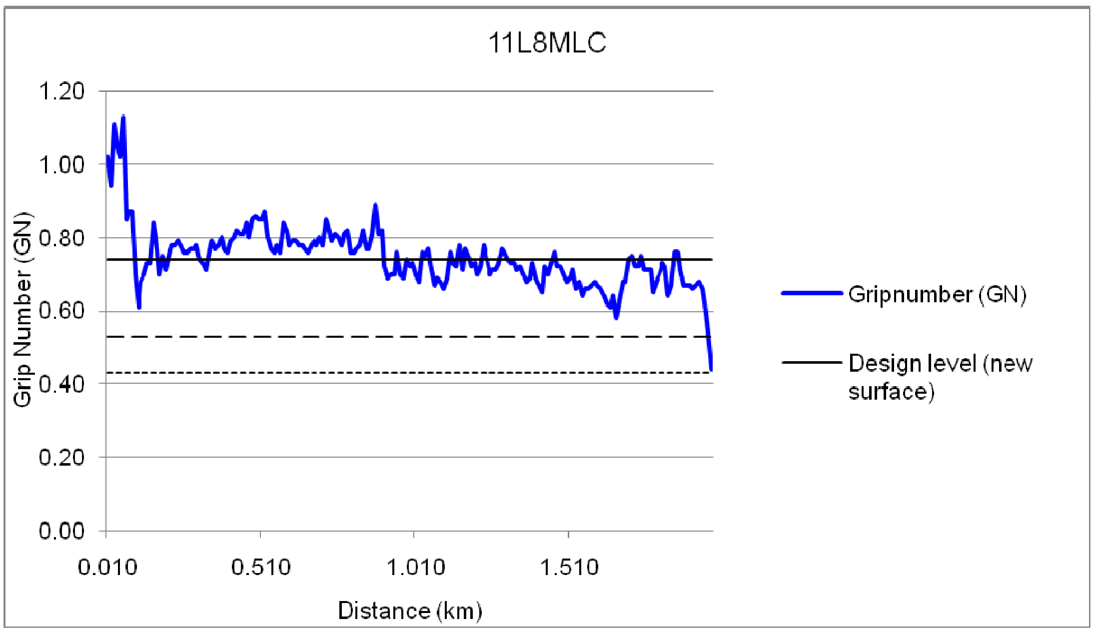
1.010
1.510
Distance (km)
Gripnumber (GN)
Design level (new surface)





ANNEXURE G

Dunlop Tyre examination report

DUNLOP AIRCRAFT TYRES LIMITED

TYRE INVESTIGATION REPORT T9993

CUSTOMER:	SA Airlink	AIRCRAFT:	ERJ-145 ZS-SJW
POSITION:	Main	DUNLOP REF:	T9993
SIZE:	30X9.5-14	PART NO:	DR31116T
MANUFACTURE:	Dunlop	RETREADER:	N/A
RETREAD STAGE:	R0	RETREAD DATE:	N/A
PLY RATING:	16	SPEED RATING:	210MPH
SERIAL NO:	09014331 08284318	DATE:	05/11/09

REASON FOR CUSTOMER REJECTION: Runway over-shoot following landing.
CUSTOMER REF.

*1. **EXAMINATION FINDINGS***

TREAD:

Both tyres were returned in a part worn condition and exhibited evidence of flat scald roughly the area equal to the tread footprint. Detailed examination of the tread on each tyre revealed the following:

Tyre serial number 08284318 exhibited an oval shaped flat spot approximately 18 cm in width and approximately 21 cm in length, typically formed under forward motion and load with a non-rotating wheel. The appearance of such flats varies with the conditions under which formation takes place and in this instance, the surface tread rubber has a " partly melted" appearance around the periphery of the flat, which indicates that the flat spot has been formed under wet conditions, i.e. the tyre has aquaplaned, (refer to photo 1 page 4).

TYRE INVESTIGATION REPORT T9993

The flat spot is shallow in depth, extending only to the top Inter Tread Fabric (ITF) layer. The ITF is a tread reinforcing layer of fabric cord approximately 2.0 mm beneath the tyre tread. The depth of the flat spot would indicate that aquaplaning was either for a short distance or more likely from the appearance and degree of lower heat generation exhibited by this tyre that it was at relatively low speeds.

Over the rest of the tread, the tyre is approximately 95% worn, with 0.5mm of tread remaining in the central grooves where the wear was at its most advanced, the unused skid depth of this tread pattern is 10.16mm (0.40").
The tyre shows some tears and lateral striations in the tread surface, due to lateral movement of the aircraft, probably coming into contact with some structure immediately following aquaplaning and leaving the runway, (refer to photo 2 page 4)

Tyre serial number 09014331 exhibited a similar oval shaped flat spot of a approximately the same dimensions: 18 cm in width and 21 cm in length, again typically formed under forward motion and load with a non-rotating wheel and having the same appearance as tyre serial number 08284318 in that it had a "Partly melted" appearance around the periphery of the flat, which indicates that the flat has been formed under wet conditions, i.e. the tyre has aquaplaned, (refer to photo 3 page 5). The remaining tread on this tyre had an average of 3.5mm approximately 65% worn.

The original manufacturing records were extracted from the Quality System, these confirmed that the right materials, including the specified tread compound, had been used for the construction of the two tyres and that they had been assembled in accordance with the manufacturing specifications.

2. *CONCLUSION*

Both tyres exhibit the appearance of aquaplaning as there is a partly scalding effect to the tread rubber, the surface of the tread rubber has some evidence of reversion and peeling of the compound (refer to photo # 4 page). This happens where there is sufficient standing water on the runway and the conditions of a landing are such that the tread fails to displace that standing water and results in spin-down of the tyre and either dynamic or viscous aquaplaning occurs.

TYRE INVESTIGATION REPORT T9993

As the tyre moves along the runway in a non-rotating condition heat is generated due to friction between the water film and tread rubber leading to the appearance of melted rubber. Whilst tyre serial number 08284318 was in an advanced state of tread wear, with just 1.5mm of centre groove remaining the same cannot be said for tyre serial number 09014331 as this tyre still had 3.5mm of centre groove depth remaining, which should have been sufficiently deep enough to channel the standing water away from the tread.

The degree of melted rubber and shallowness of the flat spot would indicate a loss of tyre contact with the runway surface at relatively low speeds and that viscous aquaplaning may have occurred. Viscous aquaplaning occurs at lower speeds than dynamic aquaplaning and is primarily due to some form of contamination such as oil present within any standing water on the runway. Further to the above, a low friction coefficient of the runway surface under wet conditions could also have been a contributory factor.

The writer however, does not have any full details of the incident or any pictorial evidence of the runway at the time of the incident and the above conclusions are based on appearance of the tyres only. Any laboratory analysis on the area of the flat spot would be corrupted by the fact that the aircraft appeared to overshoot the runway onto none paved areas such grass, mud etc.

3. *ACTION/RECOMMENDATIONS*

Both tyres will be held for a period of 1 month following issue of this report. After this time if no disposal instructions are received from the customer they will be disposed of by Dunlop.

Compiled by

Steve Fitzmaurice Digitally signed by Steve Fitzmaurice DN: cn=Steve Fitzmaurice, c=GB Reason: I am the author of this document Date: 2010.03.24 16:52:20 Z

Technical Support Manager

Approved by

David Baker-2010 Digitally signed by David Baker-2010 DN: cn=David Baker-2010, o, ou, email=david.baker@dunlopatl.co.uk, c=GB Reason: I have reviewed this document Date: 2010.03.24 16:47:53 Z

Chief Designer & Head of Airworthiness

TYRE INVESTIGATION REPORT T9993

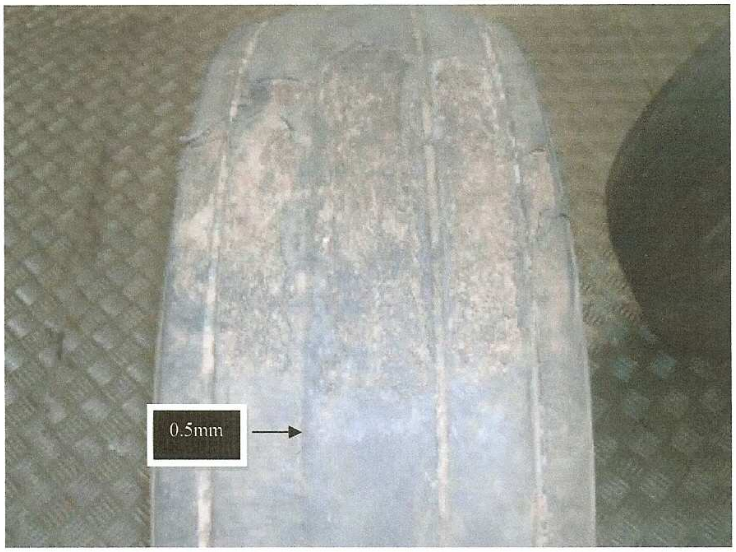


Photo # 1
Tyre serial number 08284318 exhibiting an area of tread with partial melting of tread rubber approximately the area of the tread footprint.

Depth of tread wear at the most advance point was 0.5mm of groove remaining.

Photo # 2 tyre serial number 08284318 shows gouges and cuts to the tyres sidewall. This damage is considered to have occurred as a result of the tyre aquaplaning

TYRE INVESTIGATION REPORT T9993

Tyre serial number 09014331 with a similar appearance of partly melted tread rubber as exhibited by tyre serial number 08284318.

Depth of tread wear at the most advanced point was 3.5mm groove depth remaining.

ANNEXURE H

Hydroplaning

This annexure is based on excerpts, taken in their entirety and adapted, from the following sources:

1. http://www.crashforensics.com/papers.cfm?
2. http://www.aaib.gov.uk/sites/aaib/cms_resources
3. http://www.atsb.gov.au
4. http://en wikipedia.org/wiki/Hydroplaning_(tires)
5. Airplane Flying Handbook, FAA Publication FAA-H-8083-3A (http://av-info.faa.gov)
6. ICAO doc 9137.

1. Definition

Hydroplaning or aquaplaning by the tyres of an aircraft occurs when a layer of water builds up between the tyres and the runway surface, leading to a loss of traction and preventing the aircraft from responding to control inputs such as steering, braking or accelerating. If it occurs on all the main wheels, the aircraft becomes, in effect, an uncontrolled sled.

2. Effect of hydroplaning

Hydroplaning may reduce the effectiveness of wheel braking in aircraft on landing or aborting takeoff, when it can cause the aircraft to run off the end of the runway. Hydroplaning was a factor in a 1999 accident when Qantas Flight 1 ran off the end of the runway in Bangkok during heavy rain as well as an Air France accident in Toronto, Canada, on 2 August 2005. Aircraft which can employ reverse-thrust braking have an advantage in such situations, as this type of braking is not affected by hydroplaning, but it does require a considerable distance to operate as it is not as effective as wheel braking on a dry runway.

Hydroplaning can occur when an aircraft is landed on a runway surface contaminated with standing water, slush, and/or wet snow. The three basic types of hydroplaning: viscous, dynamic and reverted rubber (vapour), each bearing its own characteristics but all resulting in impaired or totally absent aeroplane braking. Any of these can render an aircraft partially or totally uncontrollable at any stage during the landing roll.

The danger of hydroplaning can be substantially diminished through grooves cut into the runway that allow rainwater to flow away. The method was initially developed by NASA for space shuttles landing in heavy rain, and has since been adopted by most major airports around the world.

3. Types of Hydroplaning

3.1 Viscous

A tyre has to be in contact with the runway surface in order to accomplish its function of providing traction, either “positive” (accelerating the aircraft), or “negative” (stopping it). In order to do that, the tyre should remove most of the standing water or other “contaminant” (such as oil) between itself and the runway.

Viscous hydroplaning takes place due to the viscous properties of water, and can occur with a film of water no more than 0,025 mm in depth. The tyre, unable to penetrate the fluid, rolls on top of the film. This can occur at a much lower speed than dynamic hydroplaning, but requires a smooth or smooth-acting surface such as asphalt or a touchdown area coated with the accumulated rubber of past landings. Such a surface can have the same friction coefficient as wet ice.

3.2 Dynamic

This is a relatively high-speed phenomenon that occurs when there is a film of water on the runway at least 0,25 mm deep. As the speed of the aircraft and the depth of the water increase, the water layer builds up an increasing resistance to displacement, resulting in the formation of a wedge of water beneath the tyre. At a certain speed, termed the hydroplaning speed (Vp), the upward force generated by water pressure equals the weight of the aircraft and the tyre is lifted off the runway surface. In this condition, the tyre no longer contributes to directional control, and braking action is nil.

Dynamic hydroplaning is generally related to tyre inflation pressure. Tests have shown that for tyres with significant loads and enough water depth for the amount of tread so that the dynamic head pressure from the speed is applied to the whole contact patch, the minimum speed for dynamic hydroplaning (Vp) in knots is about nine times the square root of the tyre pressure in pounds per square inch (PSI). For an aircraft tyre pressure of 64 PSI, the calculated hydroplaning speed would be approximately 72 kt. This speed is for a rolling, non-slipping wheel; a locked wheel reduces the Vp to 7,7 times the square root of the pressure. Therefore, once a locked tyre starts hydroplaning it will continue until the speed reduces by other means (air drag or reverse thrust).

3.3 Reverted rubber

Reverted rubber (steam/vapour) hydroplaning occurs during heavy braking that results in a prolonged locked-wheel skid (the wheel “locks up”). Only a thin film of water on the runway is required to facilitate this type of hydroplaning. The tyre skidding generates enough heat to vaporise the underlying water film into a cushion of steam that eliminates tyre to surface contact. A side-effect of the heat is that it causes the rubber in contact with the runway to revert to its original uncured state. Indications of reverted rubber hydroplaning are distinctive “steam-cleaned” marks on the runway surface and patch of reverted rubber on the tyre.

Reverted rubber hydroplaning frequently follows dynamic hydroplaning, during which time the pilot may have the brakes locked in an attempt to slow the aircraft. Eventually the aircraft slows enough to where the tyres make contact with the runway surface and the aircraft begins to skid. The remedy for this type of hydroplaning is for the pilot to release the brakes and allow the wheels to spin up and then apply moderate braking. Reverted rubber hydroplaning is insidious in that the pilot may not know when it begins, and it can persist until very slow groundspeeds (20 knots or less) are reached – in fact, virtually until the aircraft comes to rest.

Reverted rubber skidding is a complex phenomenon, which over the years has been the subject of a variety of explanations. Reverted rubber skidding is akin to viscous skidding in that it occurs within a thin film of water and a smooth runway surface.

4. Pre-requisites for various hydroplaning types:

MODE	PREREQUISITE	SOLUTIONS
Viscous hydroplaning	- Thin water film - Smooth surface - Wheel free to roll	- Drainage (camber) - Runway grooving - Auto-braking / early lift-spoilers and reverse
Dynamic hydroplaning	- Flooded runway - High speed	- Drainage (camber) - Good tyre tread - On-speed landings closer to threshold / early lift-spoilers and reverse
Reverted rubber skidding	Thin water film Smooth surface Locked wheel Rubber deposits will exacerbate problem	- Drainage (camber) - Runway grooving - Avoid manual braking (use anti-skid / maxarets) - Remove rubber regularly over entire runway length

5. Reduction of risk

Any hydroplaning tyre reduces both braking effectiveness and directional control.

The FAA Airplane Flying Handbook offers the following advice to reduce the risk of hydroplaning if this appears to be a danger: When confronted with the possibility of hydroplaning, it is best to land on grooved runway (if available). Touchdown speed should be as slow as possible consistent with safety. After the nose-wheel is lowered to the runway, moderate braking should be applied. If deceleration is not detected and hydroplaning is suspected, the nose should be raised and aerodynamic drag utilized to decelerate to a point where the brakes so become effective.

Proper braking technique is essential. The brakes should be applied firmly until reaching a point just short of a skid. At the first sign of skid, the pilot should release brake pressure and allow the wheels to spin up. Directional control should be maintained as far as possible with the rudder. Remember that in a crosswind, if hydroplaning should occur, the crosswind will cause the aircraft to simultaneously weathervane into the wind as well as downwind.

Avoiding Hydroplaning/Aquaplaning

- Land on a grooved runway if available.
- Touch down as slow as is safely possible.
- Apply moderate braking after the nose-wheel is lowered to the runway.

- If hydroplaning is suspected, raise the aircraft's nose and use aerodynamic drag to decelerate to a point where the brakes become effective.
- Apply the brakes firmly until reaching a point just short of a skid. At the first sign of skid, release brake pressure and allow the wheels to spin up.
- Maintain directional control as far as possible with the rudder.

It also warns that if hydroplaning occurs in a crosswind, the aircraft is likely to weathervane into the wind as well as slide downwind.

Factors Affecting Aeroplane Hydroplaning

Among the factors affecting hydroplaning, we must highlight the following;

Thickness of water film (dept of water contamination)
Aeroplane speed
Tire pressure
Tire threat quality
Tire footprint
Runway friction
Runway construction

6. Factors affecting hydroplaning

Thickness of water film (depth of water contamination)

ICAO Annex 14, volume 1, chapter 2, Aerodrome Data, states:

"*Water on a runway*

2.9.4 Recommendation – Whenever water is present on a runway, a description of the runway surface conditions on the centre half of the width of the runway, including the possible assessment of water depth, where applicable, should be made available using the following terms:

DAMP – the surface shows a change of colour due to moisture.

WET – the surface is soaked but there is no standing water.

WATER PATCHES – significant patches of standing water are visible.

FLOODED – extensive standing water is visible.

2.9.5 Information that a runway or portion thereof may be slippery when wet shall be made available."

The terms tabled below are obtained from the South African Civil Aviation Regulations). The explanations are more detailed that those provided by the ICAO, but the terms "water patches" and "flooded" are not defined.

Reporting Term	***Surface Conditions***
Dry	*Means a dry runway which is neither wet nor contaminated, and includes those paved runways which have been specially prepared with grooves or porous*

	pavement and maintained to retain "effectively dry" braking action even when moisture is present.
Damp	*Means a runway of which the surface is not dry and on which the moisture does not give the runway a shiny appearance.*
Wet	*Means a runway of which less than 25% of the surface is covered with water, slush or loose snow or when there is sufficient moisture on the runway surface to cause it to appear reflective, but without significant areas of standing water.*

NASA studies since the 1960 indicate that a film of water as thin as one-tenth of an inch is sufficient to cause dynamic hydroplaning, and a runway covered with this depth of water should therefore be regarded as contaminated.

6.2 Aircraft speed

Research by NASA since the 1960s has resulted in formulae that determine the speeds above which hydroplaning may occur – the so-called NASA critical speeds. The formulae depend on tyre pressure and help to explain the mechanisms behind hydroplaning.

The first NASA Critical Speed is expressed as 8,6 x √P, where "P" is the tyre pressure in psi. (For practical purposes, the figure 8,6 is sometimes rounded off to 9.) This formula applies to when the aircraft is rolling on the runway and encounters water contamination. However, if contamination is encountered on touchdown, before the wheels are spinning, the equation changes to 7,7 x √P (where "P" is the tyre pressure in psi).

These equations are used to determine the speed above which hydroplaning may occur. However, it should be noted that dynamic friction requires speeds lower than static friction. Thus, once a tyre starts skidding over a water film, this condition will persist to speeds well below the critical speeds determined by the formula.

In the case of SA8625, assuming the worst-case scenario (aircraft at maximum landing weight, flaps 45°), the aircraft would touch down at about 130 kt and tyre pressure would be 145 psi.

Critical Speed 1 = 8,6 x √145
= 103 kt

Critical Speed 2 = 7,7 x √145
= 93 kt

Aircraft	Tyre pressure psi	Landing speed (A) kt	Critical speed (B) kt	**Window (A-B) kt**
EMB 135	145	140	103 (1)	**37**
EMB 135	145	140	93 (2)	**47**
EMB 135	145	140	98	**42**

The above table shows the "window value" for dynamic hydroplaning for the Embraer 135. The final critical speed figure – 98 kt – is an average of the values of column 1 and 2. Both critical speed formulae were used as the aircraft manufacturer does not clearly indicate that one has preference over the other or is more pertinent to the aircraft type. There might be variation from one aircraft model to another as tyre sizes and pressures vary, depending on loads

Studies into the critical hydroplaning speed by the National Aerospace Laboratory in the Netherlands have updated these calculations to account for new designs of tyre. According to the NLR's website, (www.nlr.nl):

Quoted from website: http://www.nlr.nl/id~4384/ln~en.pdf

Hydroplaning of modern aircraft tyres.

"Recent studies into the critical hydroplaning speed were conducted by the National Aerospace Laboratory (NLR) in the Netherlands. "These studies were considered necessary as the data that was compiled by NASA was ageing and need to be revised to conform to modern new tyre types that were introduced for civil aircraft. The following three tyre types were considered;

bias-ply;
radial belted tyre, and;
the type-H tyres.

It was concluded from the analysis that the radial-belted and type-H tyres had a significant lower hydroplaning speed than the bias-ply tyre. This was caused by the difference in tyre footprint characteristics of these tyres."

According to the tyre manufacturer, the accident aircraft was fitted with bias-ply tyres.

Following consultation with the author of the NLR study into hydroplaning of modern aircraft tyres, the IIC was informed that the critical hydroplaning speed is highly influenced by the type of tyres fitted to the aircraft. Their study showed that the critical hydroplaning speed for the bias-type tyre that was fitted to the accident aircraft could have been as low as 6,8 x $\sqrt{P}$ (where "P" is the tyre pressure in psi).

Critical speed = 6,8 x $\sqrt{145}$
= 82 kt

Conclusion:

Tyre damage indicated that hydroplaning had indeed occurred, but at what speed could not be determined with certainty. Taking into account the 20-kt disparity between the two sets of results, the critical hydroplaning speed for the tyres fitted to the accident aircraft was between 82 and 103 kt.

6.3 Tyre pressure

As seen above, tyre pressure plays a crucial role in determining hydroplaning speeds. The lower the tyre pressure, the lower the speed at which hydroplaning occurs.

Tyre pressure loss is considered acceptable up to a certain level. Today, most commercial aircraft tyres are inflated with nitrogen, which, with its relatively large molecules, is less likely to escape than pure air. But tyres nonetheless have a certain amount of permeability. In order to avoid damage to the tyre structure due to the nitrogen trapped inside the tyre carcass expanding and contracting, modern aeroplane tyres are provided with sidewall vent holes that allow the nitrogen to escape to the atmosphere.

Adequate tyre monitoring is essential, and lowers the chances of hydroplaning due to under-inflation.

6.4 Tyre tread quality

The main function of the treads is to make it easier for water to escape from below the tyre footprint (see below), thus releasing pressure that could lead to hydroplaning. The treads rob a certain amount of friction area from the tyre but are essential. Manufacturers design the treads taking into consideration the characteristics of a specific tyre and the amount of water that needs to be released. The lower the volume of water that the treads can handle, the higher the pressure below the tyre footprint, therefore tyres should always be replaced before they become excessively worn.
The grooves will rob some friction area from the tyre, but are a necessary.
Therefore, maintenance care should be taken not to allow excessively worn tyres to be kept in operation. The airplane tyre manufacturer instructions should be followed and emphasis should be place on the replacement of worn tyres.

6.5 Tyre footprint

The footprint is the measure of the area of the tyre that makes contact with the runway surface. Tyres are designed to meet certain aeroplane criteria, such as dimensions, weight and expected performance. These determine tyre size, composition, construction and other features.

One of these criteria is the traction needed for accelerating and braking, and this determines a tyre's footprint. If a tyre were absolutely rigid, its footprint would be limited to an extremely narrow line along its width (i.e. from side to side). Tyres, however, are flexible and deform slightly where they make contact with the surface, and this creates the footprint. This deformation is called tyre deflection.

The deflection is expressed as a percentage of tyre height and should vary as little as possible so that the footprint stays within its "best performance" margins. To achieve this, it is essential to maintain optimum tyre pressure at all times.

When the tyre is over-inflated, the deflection is *lower* and the footprint is *smaller*.
When the tyre is under-inflated, the deflection is *higher* and the footprint is *larger*.

As mentioned earlier, the hydroplaning critical speed is mainly a function of tyre pressure, and under-inflated tyres will hydroplane at speeds lower than those of properly inflated tyres. Over-inflating the tyre will thus help to avoid hydroplaning, but introduces its own problems. . The smaller footprint will mean less traction and thus less effective braking, and it will also cause abnormal wear. There is no substitute for proper inflation pressures.
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6.6 Runway friction

There are specific construction techniques involved in the building of runways that improve friction coefficients, providing better braking action, and help to avoid hydroplaning. Two important techniques to improve friction on a runway are micro- and macro-texturing.

The FAA's Advisory Circular no. 150/5320-12C, Measurement, Construction and Maintenance of Skid-Resistant Airport Pavement Surfaces, states:

"*Micro-texture refers to the fine scale roughness contributed by small individual aggregate particles on pavement surfaces which are not readily discernible to the eye but are apparent to the touch, i.e., the feel of fine sandpaper. Macro-texture refers to visible roughness of the pavement surface as a whole. Micro-texture provides frictional properties for aircraft operating at low speeds and macro-texture provides frictional properties for aircraft operating at high speeds. Together they provide adequate frictional properties for aircraft throughout their landing/takeoff speed range.*"

Macro-texture (and runway grooving, described in the following section) normally provides good water draining. However, all runways suffer to a certain extent from contamination such as rubber deposits from previous landings, which tends to make the surface smoother. (It is up to each civil aviation authority to provide its own guidance on when and how to remove rubber contamination.) In addition, macro-texture and grooving may simply be unable to cope with heavy rains, and water build-up may occur, increasing the threat of hydroplaning.

The visual texture of a runway, though, may be deceiving. Quoting again from the FAA's AC 150/5320-12C: *"A rough looking surface could provide adequate drainage channels for the water to escape, but the fine aggregate in the pavement may consist of rounded or uncrushed mineral grains that are subject to polishing by traffic, thereby causing the pavement surface to become slippery when wet. Likewise, a less rough looking surface, that may even have a shiny appearance when wet, will not necessarily be slippery if it has good micro-textural properties.*"

6.7 Runway construction

Three runway construction characteristics play a direct role in helping to prevent hydroplaning. The first is optimal runway friction, which determines the materials used in the construction process and the resulting micro- and macro-textures, as described above. Each CAA establishes its own rules. In the US, for example, the FAA guidelines are provided in the already-mentioned AC 150/5320-12C.

The second factor is runway cambering – the creation of a downward slope from the centreline of the runway. This helps to prevent pooling on the runway by allowing the water to drain away to the side. A rare problem can occur in a crosswind, when water is pushed up to forms pools on the upwind side. This may cause asymmetrical hydroplaning, where only the wheels on the left or right main landing gears skid, resulting in the threat of a runway side-excursion. This is a serious situation that requires quick reaction from the cockpit crew.

The third factor is runway grooving, which works together with cambering to remove water from the surface. Although it reduces runway friction to a certain extent by diminishing the area of contact available to the tyres, its advantages by far overcome this drawback. The specifications for runway grooving are the responsibility of each CAA. For example, the FAA's AC 150/5320-12C stipulates a groove width of 1/4in +1/16in -0in, a depth of 1/4in ±1/16in, and spacing of 1,1/2in +0in -1/8in, centre to centre. It also specifies that the grooves should run the length of entire runway and lie transverse to the direction of aircraft landing and takeoff.

ANNEXURE I

Auto-braking system

Edited excerpt from http://en.wikipedia.org/wiki/Autobrake:

"*An auto-brake is a type of automatic wheel-based hydraulic brake system for advanced aeroplanes. The auto-brake is normally enabled during takeoff and* *landing procedures, when the aircraft's longitudinal deceleration system can be handled by the automated systems of the aircraft itself in order to keep the pilot free to perform other tasks.*

Landing

While landing, the auto-brake can aid in freeing up the pilot to allow him or her to monitor other systems (such as the execution of the landing flare). There are usually several settings for the "intensity" or hydraulic pressure of the brake mechanism. The selection of these settings is normally done on the aircraft instrument panel before landing. These are often numbered or labelled, with "1" or "LO" referring to braking for a light speed reduction, and subsequent numbers or designations up to "MAX" referring to more abrupt speed reductions.

When the landing feature of the auto-brake is engaged, the aircraft automatically engages pressurised wheel braking upon touchdown to the landing surface. During the roll-out, application of the brake pedals transfers control back to the pilot.

One of the main advantages of engaging the auto-brake as opposed to manually pressing on brake pedals is the uniform deceleration mechanism of the auto-brake. The aircraft automatically decelerates at the selected level regardless of other factors, such as aircraft drag and other deceleration methods, e.g. deployment of thrust reversers or spoilers.

Rejected takeoff

While taking off, the aircraft's auto-brake can be set to the rejected takeoff mode, commonly indicated on an aircraft instrument panel as RTO. In the case of certain aircraft manufacturers, "MAX" mode is set. In the RTO setting, the aircraft monitors certain variables, depending on the auto-brake model. Most auto-brakes engage RTO braking if the pilot returns the throttle to the "idle" position, or if reverse thrust is engaged. Other auto-brake systems may monitor critical flight controls for failures."

ANNEXURE J – Product Data Sheet SS 60

SS 60

Stablemix Bitumen Emulsion

Product Data Sheet
2008/1

The road forward

DESCRIPTION

SS 60 is a low viscosity anionic slow-set bitumen emulsion.

USES

SS 60 is used mainly as a cold applied binder for the manufacture of *slow-set slurry mixtures* which can be batch mixed and applied by hand or with a continuous mix and lay machine.

Colas also manufactures special **SS 60** emulsion which can also be:

- Used for mixing with natural gravels or crushed aggregates for *stabilisation* of bases.
- Diluted with water and applied onto aged seals as an *enrichment spray* or as a *tack coat for* an asphalt overlay.

PROPERTIES

The slow setting nature of **SS 60** makes it ideal for mixing and applying slurries by hand. Slurry mixtures prepared by batch mixing can be kept workable in transit mixes up to 2 hours before setting.

SS 60 relies on the evaporation of the water component for breaking of the mix.

SPECIFICATIONS

SS 60 conforms to SABS 309 specification for anionic bitumen road emulsions.

EMULSION PROPERTIES	REQUIREMENT		TEST METHOD
	Min	Max	
Binder content, % m/m	60	62	ASTM D244
Residue on sieving, g/100 ml	–	0.25	SABS 309
Sedimentation after 60 rotations	Nil		SABS 309
Coagulation value when mixed with cement, % m/m	–	2	SABS 309

DIRECTIONS FOR USE

1. **SS 60** can be stored and mixed with aggregates at ambient temperature.
2. Can be stored for six months at ambient temperature without risk of settlement.
3. The binder should be heated to 60 °C for spray application.
4. If diluting with water, check the compatibility of the water with the emulsion.

Tel +27 (0) 21 531 6406 Fax +27 (0) 21 531 5514
PO Box 82 Eppindust 7475 E-mail: marketing@colas.co.za

Supplier: Colas South Africa (Pty) Ltd.
Emergency Telephone Number: 021 531 6406

1. Product Identification

Chemical Names and Synonyms: **SS 60; Bitumen Emulsion**

Use or Description: Dispersion of bitumen in a water phase containing anionic emulsifiers.

2. Typical Chemical and Physical Properties

Appearance	Brown Liquid
Odour	Mild
Viscosity @ 40 ºC	< 80 cSt
Viscosity @ 100 ºC	NA
Relative Density (g/cm³)	1,01-1,02
Solubility in Water @ 20 ºC	Water-dispersible
pH	10 - 12
Melting Point ºC	NA
Pour Point ºC	NA
Boiling Point ºC	100
Flash Point ºC	NA
Vapour pressure @ 20 ºC	< 0,1
Solids content % m/m	60 - 62

3. Hazards Identification and First-aid Measures

Effects of over exposure: Moderate eye irritation and slight skin irritation.

4. First-aid Measures

Eye contact: Flush thoroughly with water and obtain medical assistance.
Skin contact: Wash contact areas with soap and water before emulsion cures. Remove cured emulsion (bitumen) with minimum quantity petroleum solvent, e.g. white spirits followed by washing with soap and water.
Inhalation: Not expected to be a problem.
Ingestion: Not expected to occur in normal industrial use.

5. Fire-fighting Measures

The product is non-flammable.
Extinguishing Media: NA.
Special Fire-fighting Procedures: NA.
Unusual Fire and Explosion Hazards: None.

6. Accidental Release Measures

Procedures if material is released or spilled:
For large spills: Contain material and pump back to holding tank for later disposal.
Waste disposal methods: Dispose of waste at an appropriate waste disposal facility in accordance with applicable laws and regulations.

Supplier: Colas South Africa (Pty) Ltd.
Emergency Telephone Number: 021 531 6406

The road forward

7. Exposure Control/Personal Protection

Respiratory protection: No special precautions under ordinary conditions of use and with adequate ventilation.
Ventilation: No special precautions under ordinary conditions of use and with adequate ventilation.
Eye protection: Chemical type goggles and face shield should be worn when contact may occur.
Skin protection: Use chemical-resistant apron and/or other clothing to avoid skin contact.

8. Stability and Reactivity Data

Stability: (thermal, light, etc.) Stable.
Conditions to avoid: Extreme heat.
Incompatibility: Strong Oxidisers.
Hazardous Decomposition Products: Steam, bitumen fumes.

9. Handling and Storage

Do not heat above 60 ºC. Agitate from time to time if stored for prolonged periods.

Glossary of abbreviations

AAL	Above aerodrome level
AC	Advisory circular
ACSA	Airports Company of South Africa
ADF	Automatic direction-finder
AFIS	Aerodrome flight information service
AFM	Aircraft flight manual
AGL	Above ground level
AIID	Accident and Incident Investigation Division
ALAR	Approach and landing accident reduction
AME	Aircraft maintenance engineer
AMO	Aircraft maintenance organisation
AMSL	Above mean sea level
AOC	Air operating certificate
APU	Auxiliary power unit
ARFF	Aerodrome rescue and fire-fighting
ATC	Air traffic control
ATIS	Automatic terminal information service
ATSB	Australian Transportation Safety Bureau
BCU	Brake control unit
CAA	Civil aviation authority
CCA	Commissioner for civil aviation
CFME	Continuous friction-measuring equipment
CRM	Cockpit resources management
CVR	Cockpit voice recorder
DFDR	Digital flight data recorder
DH	Decision height
DME	Distance-measuring equipment
ELT	Emergency locator transmitter
EICAS	Engine indication and crew alerting system
EMAS	Engineering materials arresting system
FAA	Federal Aviation Administration
FAR	Federal aviation regulation
FO	First officer
FOD	Foreign object debris
ft	feet
FSF	Flight Safety Foundation
g	normal acceleration
GN	Grip number
GPS	Global positioning system
HMA	Hot-mix asphalt
hPa	Hectopascal
IAC	Instrument approach chart
ICAO	International Civil Aviation Organisation
IIC	Investigator-in-charge
ILS	Instrument landing system
JAR	Joint aviation requirements
kg	kilogram(s)
KIAS	knots indicated airspeed
km/h	kilometres per hour
kt	knot(s)
ℓ	Litre(s)

LLZ	Localiser (instrument landing system)
m	metre(s)
MAX	Maximum
MDA	Minimum decision altitude
MEA	Minimum en-route altitude
METAR	A timed aerodrome meteorological report
MFD	Multifunction flight display
MHz	Megahertz
mm	millimetre(s)
MORA	Minimum off-route altitude
MSA	Minimum safe altitude
MSA	Minimum sector altitude
MTOW	Maximum take-off weight
NASA	National Aeronautics and Space Administration
NDB	Non-directional radio beacon
NDoT	National Department of Transport
NRL	Nationaal Lucht- en Ruimtevaartlaboratorium (Netherlands)
NOTAM	Notice to airmen
nm	Nautical mile(s)
NVM	Non-volatile memory
OCH	Obstacle clearance height
OCL	Occlude
P	Tyre pressure measured in psi
PA	Passenger address system
PAPI	Precision-approach path indicator
PF	Pilot flying
PIC	Pilot-in-command
PNF	Pilot not flying
psi	Pounds per square inch
QRH	Quick reference handbook
RESA	Runway end safety area
RTO	Rejected take-off
SACAA	South African Civil Aviation Authority
SA-CATS-AH	South African Civil Aviation Technical Standards Aerodromes and Heliports
SAWS	South African Weather Services
SB	Service Bulletin
SOP	Standard operating procedures
SRA	Special rules airspace/area
TC	Transport Canada
TAF	Terminal aerodrome forecast
UTC	Co-ordinated Universal Time
UTFC	Ultra-thin friction course
VASI	Visual approach slope indicator
VDF	VHF direction finding station
VMC	Visual meteorological conditions
VOR	VHF omni-directional radio range
V_{MCL}	Minimum control speed during landing approach all engines operating
V_{REF}	Reference landing approach speed, all engines operating
V_{APP}	Reference landing approach speed + ½ headwind + wind gust
V_{FS}	Final segment speed
V_{S1}	Stalling speed (“clean configuration”)
V_{so}	Stalling speed in landing configuration with flaps down and no power applied.