Bundesstelle für
Flugunfalluntersuchung

German Federal Bureau of
Aircraft Accident Investigation

Investigation Report

Identification

Type of Occurrence:	Accident
Date:	24 January 2005
Location:	Düsseldorf
Aircraft:	Airplane
Manufacturer / Model:	Boeing / 747-212B
Injuries to Persons:	No injuries
Damage:	Aircraft severely damaged
Other Damage:	Aerodrome equipment
Information Source:	Investigation by BFU
State File Number:	BFU AX001-05

This investigation was conducted in accordance with the regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and the Federal German Law relating to the investigation of accidents and incidents associated with the operation of civil aircraft (*Flugunfall-Untersuchungs-Gesetz - FlUUG*) of 26 August 1998.

The sole objective of the investigation is to prevent future accidents and incidents. The investigation does not seek to ascertain blame or apportion legal liability for any claims that may arise.

This document is a translation of the German Investigation Report. Although every effort was made for the translation to be accurate, in the event of any discrepancies the original German document is the authentic version.

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Abbreviations

AIP	Aeronautical Information Publication
AMSL	Above Mean Sea Level
AOM	Airplane Operations Manual
ATIS	Automatic Terminal Information Service
BFU	German Federal Bureau of Aircraft Accident Investigation
CAS	Calibrated Air Speed
CVR	Cockpit Voice Recorder
FAA	Federal Aviation Administration
FCOM	Flight Crew Operations Manual
FDR	Flight Data Recorder
FL	Flight Level
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
LDA	Landing Distance Available
NM	Nautical Mile
PIC	Pilot in Command
RVR	Runway Visual Range
TAS	True Airspeed
UTC	Universal Time Coordinated
V_{REF}	Reference Landing Approach Speed (all engines operating)

Synopsis

On 24 January 2005 the German Federal Bureau of Aircraft Accident Investigation (BFU) was informed at 0615 hrs[1] that an air accident had occurred at Düsseldorf Airport involving a Boeing 747-212B cargo aircraft.

During the landing of a Boeing 747-212B at Düsseldorf Airport the end of the snow-covered runway was overshot. The airplane had been on a flight from Dubai, United Arab Emirates, to Düsseldorf, Germany.

The occupants remained uninjured; the airplane was severely damaged.

The air accident is due to the fact that the braking action values reported to the crew did not correspond with the runway conditions which had changed because of the heavy snowfall since the last measurement.

The following factors contributed to the air accident:

- The high dynamics of the weather changes
- The lack of a measurement method providing reliable braking coefficient values under all weather conditions.

1 All times local, unless otherwise stated.

1. Factual Information

1.1 History of the Flight

On 23 January 2005 the cargo aircraft Boeing 747-212B took off from Dubai Airport at 2234 UTC for a flight to Düsseldorf. The Pilot in Command (PIC), the co-pilot and a flight engineer were aboard. After more than six hours of flight time the aircraft was the first airplane approaching Düsseldorf Airport in the morning of 24 January 2005.

According to the radar data, at 0543:56 hrs the aircraft was in the area of Arnsberg in Flight Level (FL) 180 when the co-pilot established radio contact with Düsseldorf Radar. "Radar, good morning …, descending to flight level one two zero." The controller answered: "…good morning, information Kilo, runway two tree left." The co-pilot confirmed: "Roger, have Kilo, two tree left …". The recordings of the Cockpit Voice Recorder (CVR) show that the crew then selected the ATIS frequency and listened to Information Kilo.

At 0545 hrs the crew extended the airplane's flaps initially to position 5° and later to 10°.

At 0545:55 hrs the controller radioed the crew: "… I just talked to the tower and ah for the time being braking action on all parts of the runway is supposed to be good. They are measuring again right now because it started to snow again and I'll keep you advised." Approximately one minute later the controller issued the descent clearance to FL80. The crew discussed to select the wheel brakes to autobrake medium and to switch anti-ice on once the minimums were reached due to the snowfall. At 0547:18 hrs, after he had conducted a new landing data check for auto brakes minimum with the OPS computer, the flight engineer said: "Eight thousand four hundred fifty six feet to land." The PIC answered: "I will put ah medium on this … for the snow."

At 0548:40 hrs the controller informed: "… turn left heading two six zero, radar vectors to the ILS two tree left. And ah, vectors so to make sure you land till right at six o'clock local". At that time the airplane was south of Hagen in FL103. The co-pilot answered: "Oh, excellent, thank you. Two six zero on the heading then." Within the next minute the crew talked about that the landing should be delayed to six o'clock at the earliest.

During a radio message at 0550:31 hrs the controller said: "… latest update on the weather situation ahm the friction tester has reported braking action to be good for the moment however as its continuing to snow they are ah afraid that it might worsen, so they are going to do another friction test right before you land."

At 0551:35 hrs, as the aircraft was about in FL75, the controller instructed a right hand turn to a heading of 020° and the descent to 4,000 ft AMSL and gave the barometric air pressure (QNH) of 1,017 hPa. The CVR recorded the PIC's comment: "He is starting giving us a delay."

At 0552:33 hrs the controller informed the crew of their current distance to the touchdown point of about 25 Nautical Miles (NM).

At 0553:01 hrs the controller asked about the airspeed of the aircraft. The co-pilot answered: "one eighty Sir." Twenty seconds later the controller instructed the crew: "…turn left, heading tree two zero." This was acknowledged and the aircraft turned into the base leg of runway 23L.

The PIC instructed the crew at 0553:46 hrs to complete the approach checklist. Once this had been done he requested to extend the flaps to 20°.

As the airplane was on the base leg descending to 4,000 ft AMSL the controller said at 0554:50 hrs: "… weather update we now have a surface wind of three four zero degrees eleven knots, that's slight tail wind component by two knots. Visibility is down to one thousand five hundred meters, still in snow showers and ah cloud base is now five hundred feet only." The co-pilot acknowledged the message and the pilots then talked about the tail wind component of two knots.

At 0555:16 hrs the controller instructed to continue the descent to 3,000 ft AMSL which the co-pilot acknowledged and asked to have the wind information repeated. The controller answered: "… surface wind of three four zero degrees one one knots, that's a two knots tail wind component at the moment."

The controller instructed a left hand turn to 260° and issued the ILS approach clearance for runway 23L.

According to the CVR the landing gear was extended and the flaps were put in 25°. At 0557:42 hrs, as the aircraft was about 8.5 NM prior to the threshold in about 3,000 ft AMSL, the controller said: "… latest wind is now tree tree zero degrees, one two knots. And ah, you may pick, well let's say one seven zero knots or less will be good I think now, to make it. Because you are catching up slight tail wind there. And for further contact tower now one one eight decimal tree. Good bye."

The PIC requested to put the flaps in 30° and to complete the landing checklist. The co-pilot established radio communication with Düsseldorf Tower. At 0558:12 hrs, as the airplane was 6.6 NM away in 2,500 ft AMSL, the tower controller answered: "Good morning, … we are just waiting for the braking action values from the friction tester stand by a second. The surface wind is actually tree tree zero degrees one two knots." The crew subsequently completed the landing checklist. The speed of the airplane decreased to approximately 160 kt.

At 0559:26 hrs the tower controller said: "… the braking action was measured to be medium at all parts. And ah the visibility dropped right now due to the heavy snow showers at the field ah. The RVR value at the touch-down zone is presently nine hundred meters, at the mid-point one thousand one hundred meters and ah stop end one thousand one hundred meters." At that time the aircraft was in about 1,400 ft AMSL and approximately 3.5 NM from the threshold.

At 0559:47 hrs the tower controller said: "And, ah … you are cleared to land two tree left. The wind is currently tree tree zero degrees one one knots." At the time of the landing clearance the airplane was about 2.5 NM away in approximately 1,000 ft AMSL.

At 0600:09 hrs, at about 1.4 NM prior to the threshold, the co-pilot said: "Lights, there is lights." Twenty-three seconds later as the airplane was about 0.4 NM prior to the threshold in approximately 400 ft AMSL the tower controller gave the wind information: "Tree two zero, ten." Two seconds later the co-pilot said: "Minimums" and the PIC answered: "Land."

At 0600:49 hrs the co-pilot said: "Touch down." Two seconds later the CVR recorded increasing engine noise. At 0601:13 hrs the flight engineer said: "Ninety knots", two seconds later the co-pilot added: "Eighty knots" and a short time later "... manual braking." At 0601:22 hrs the PIC said: "Still fifty" and one of the crew members said "We are going off." In the ensuing 15 seconds or so the CVR recorded expletives of the crew and at 0601:52 hrs the PIC exclaimed: "We got fires" and requested nine seconds later to complete the fire checklist.

At 0601:55 hrs the co-pilot informed the tower: "… we have overrun the runway Sir…" Eighteen seconds later the co-pilot added: "We need the fire service, we got off the runway." The controller answered: "The fire brigade is on the way and ah yes can you give me any reports about your condition?" The answer was: "We are all right but have a fire on two engines two and three." Within the subsequent twenty seconds the tower controller enquired about the number of occupants and whether or not dangerous goods were aboard. At 0605:43 hrs the controller said: "The fire brigade is on the way, will reach you within the next minute, everything is fine with you." The co-pilot answered: "Yes Sir, we just go to evacuate the aircraft Sir … we still have number two its status on fire but we fired the bottles, it is still on." To the co-pilot's question at 0606:19 hrs: "Can you see any indications of fire on the left hand side?" the controller said: "No, I presently have no visual contact with you." Ten seconds later the controller confirmed that he could see fire on the engine. At 0607:28 hrs the controller informed the crew: "The fire brigade is now reaching the aircraft and are you, will you stay within the aircraft with all three persons or is anybody out already." The co-pilot stated that all occupants were still aboard and that they were in the process to open the front door. At 0609:15 hrs the controller said that he could still see fire on the left side of the airplane.

At 0620:44 hrs the controller informed the crew: "… the fire brigade is of course with the aircraft and they can see that your door is blocked from the outside. So, do you have any other ah chance to get out of the aircraft?" The co-pilot then said: "Yeah, we … come out through the E and E compartment which is just ah behind the nose … gear."

The three occupants left the airplane uninjured.

The reference speed (V_{REF}) the crew had calculated for the approach was 150 kt. The FDR data shows that the final approach was conducted with landing flaps in 30° and an average Calibrated Airspeed (CAS) of 160 kt.

The FDR data also shows that the airplane touched down with 58% N1 at a CAS of 155 kt with 1.2 g. The aircraft's bank angle during touch-down was 0° and the heading was 232°.

Two seconds after touch-down the thrust reversers of all four engines were deployed. The engine thrust N1 of engines 2 and 3 increased within the next six seconds to 96 - 100% and on engine 1 to about 85%. Seventeen seconds after the reversers had been deployed the engine thrust N1 on engine 1 had a value of 95%. At this time speed had decreased to 98 kt.

Twenty-seven seconds after touch-down the engine thrust N1 was reduced; the N1 for engines 3 and 4 to about 70% within five seconds and for engines 2 and 1 to 60%

and about 40%, respectively. After another five seconds N1 of all engines had increased to 100% again and remained there for the subsequent 17 seconds.

Fifty-four seconds after touch-down the vertical acceleration began to fluctuate between 0.4 and 1.6 g. At that time the N1 of the inboard engines 3 and 4 began to fluctuate while the N1 of the outboard engines 1 and 4 remained almost constant. Another eight seconds later the engine thrust N1 of all four engines decreased within four seconds to about 40% then the FDR recording ended.

Within three seconds after touch-down the deceleration of the aircraft changed from 0 to -0.17 g. Between 8 and 27 seconds after touch-down the deceleration decreased to -0.11 g. After another eight seconds about -0.09 g was reached which decreased to -0.05 g about 46 Seconds after touch-down. Between 46 and 54 seconds after touch-down the deceleration increased to -0.1 g. During the subsequent 12 seconds until the end of the FDR recording the deceleration fluctuated between -0.1 g and -0.33 g and finally decreased to 0 g.

The PIC stated the autopilot had been engaged when he received the landing clearance, the airplane had been in landing configuration, the autobrake system had been selected to medium, and the landing checklist had been completed. In about 1,200 ft he had seen the approach lighting and in 900 ft AMSL the runway lighting. The airplane had had the correct speed and was stabilised. In 500 ft AMSL he had had visual contact with the runway which was covered with snow. In about 150 ft above ground the PIC disengaged the autopilot and assumed control. He stated he had touched down the airplane about 1,700 ft (518 m) beyond the threshold. After touch-down he had used maximum thrust reverse. The ground spoilers had extended. The auto brake system worked and the airplane slowed down. The airplane approached the runway lighting of the 3,000 ft point. The flight engineer shouted "Ninety knots" as the pilot applied wheel brakes manually with maximum intensity. The thrust reversers remained in full use. In about 1,500 ft prior to the end of the runway he had had the impression the airplane was accelerating with active thrust reverse and wheel brakes. The airplane overshot the end of the runway including the runway safety area and collided with the installations of the Instrument Landing System (ILS) and the approach lighting of runway 05. Engines 2 and 3 caught fire.

Flight engineer and PIC completed the engine fire / severe damage checklist and activated the fire extinguishers of the two burning engines.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Third Party
Fatal			
Serious			
Minor / None	3		

1.3 Damage to Aircraft

The aircraft was severely damaged.

1.4 Other damage

The localizer antenna of runway 23L and parts of the approach lighting of runway 05 were damaged.

1.5 Personnel Information

1.5.1 Pilot in Command (PIC)

The 55-year-old PIC held a valid US American Air Transport Pilot's Licence (ATPL). The type ratings for B737 and B747 were listed.

His medical certificate carried the restriction to wear glasses.

The pilot had a total flying experience of about 20,000 hours, about 2,300 hours of which were on the type. In the previous 30 days he had flown about 25 hours.

He had a 24-hour rest period prior to the flight. On 23 January 2005 at 2000 UTC the pilot had left the Hotel in Dubai and drove to the airport.

1.5.2 Co-pilot

The 58-year-old co-pilot held a valid US American Air Transport Pilot's Licence (ATPL). The type rating for the B747 was listed.

He had a total flying experience of about 14,600 hours, about 3,000 hours of which were on the B747. In the previous 30 days he had flown about 30 hours.

His medical certificate carried the restriction to wear glasses.

He had an 18-hour rest period prior to the flight. He too had left the hotel in Dubai at 2000 UTC to drive to the airport.

1.5.3 Flight Engineer

The 60-year-old flight engineer held a valid US American licence for flight engineers on jet airplanes as well as an ATPL including the type rating for the B747.

His medical certificate carried the restriction to wear glasses.

1.6 Aircraft Information

In 1992, the airplane Boeing 747-212B was converted from a passenger to a cargo airplane. The aircraft had an US American certificate of registration and was operated by an US American air operator.

Manufacturer:	Boeing
Type:	747-212B
Manufacturer's Serial Number (MSN):	21048
Year of manufacture:	1975
MTOM:	368,317 kg
Engines:	General Electric CF-6-50E2

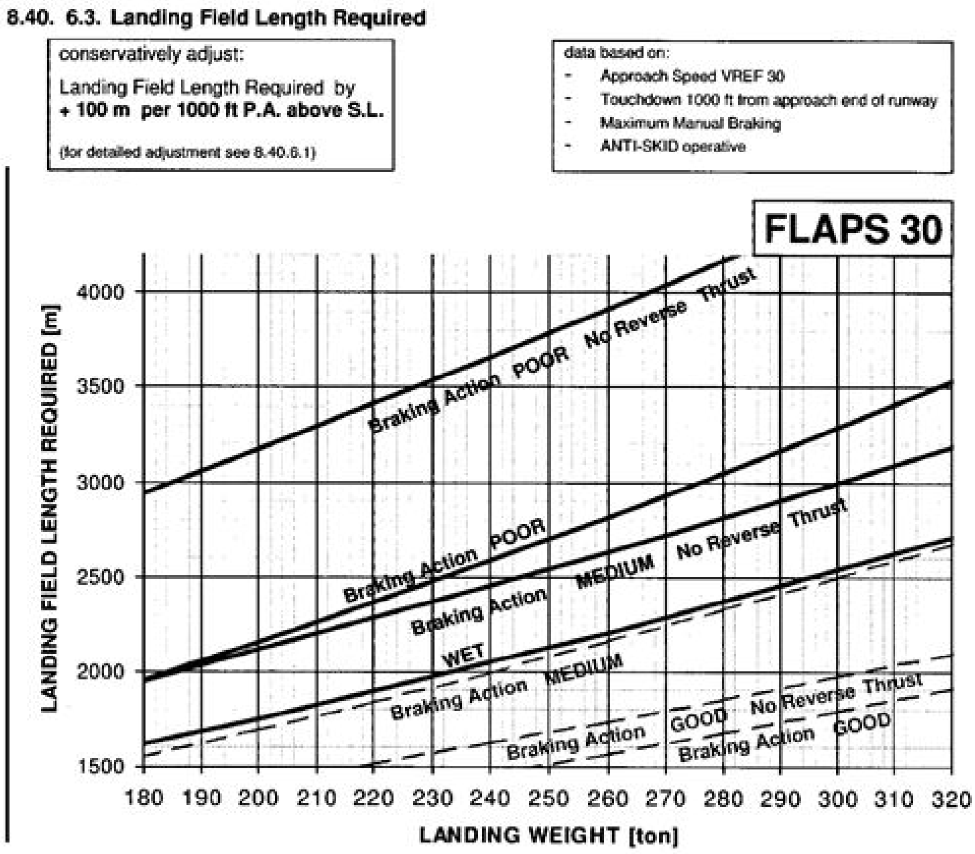
Total operating time of the aircraft was 92,024 hours and 22,782 flights. The airplane had a *Standard Airworthiness Certificate* issued on 29 June 2004 by the US American Federal Aviation Administration (FAA). The conduct of a D-check was confirmed with the same date.

The crew filled in the Weight & Balance Sheet prior to the flight and it stated a cargo mass of 99,897 kg. Therefore, the calculated Take-off Gross Weight (TOGW) of 368,316 kg was one kilogram less than the Maximum Take Off Mass (MTOM). The Minimum Landing Mass (MLM) was 285,762 kg. The centre of gravity was within limits. On this flight the freight consisted of textiles. There were no dangerous goods aboard. The weighing of the freight in Düsseldorf resulted in 100,470 kg and was therefore 573 kg higher than the value used for the calculations prior to departure.

1.6.1 Airplane Operations Manual (AOM)

The Airplane Operations Manual chapter Take Off and Landing on Contaminated Runway stated values for the maximum crosswind component. For the braking action good it was 30 kt, for medium to good 25 kt, for medium and medium to poor 15 kt, and for poor 10 kt.

The chapter also contained a graph for the determination of the Landing Field Length Required (LFLR) depending on the airplane mass.



Source: Boeing

1.7 Meteorological Information

Meteorological Aerodrome Routine Report (METAR)

A METAR report summarises the flying weather conditions existing at an aerodrome. This is followed by a TREND landing weather forecast of the likely weather development, whose validity is limited to two hours. METAR reports for international airports are updated every day around the clock on the hour + 20 minutes and on the hour + 50 minutes.

Selected Special Aviation Weather Report (SPECI)

Selected special aviation weather reports depend upon events that have been reported, which generally consist of coded current observations and values measured. The landing weather forecast is formed on the basis of the TREND forecast and SPECI observations.

Terminal Aerodrome Forecast (TAF)

Information about the expectable weather conditions at an airport during the forecast period for the purpose of pre-flight preparation.

1.7.1 Meteorological Pre-Flight Preparation

Prior to take-off in Dubai, the crew had weather information for the following airports available: Dubai (OMDB) as aerodrome of departure, Düsseldorf (EDDL) as arrival aerodrome and Copenhagen (EKCH) as alternate aerodrome. These weather reports were:

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ORIG      DXB/OMDB-DUBAI INTL          DEST        DUS/EDDL-DUSSELDORF
                                       DEST ALTN   CPH/EKCH-COPENHAGEN,KASTRUP

SURFACE OBSERVATIONS
OMDB METAR OMDB 231600Z 30011KT 9999 SCT040 BKN080 20/17 Q1015 NOSIG
EDDL METAR EDDL 231550Z 29011KT 9999 FEW025 SCT040 BKN070 05/M01
       Q1018 NOSIG
EKCH SPECI EKCH 231609Z 33010KT 290V360 3000 SHSN SCT008 BKN020CB
       M00/M01 Q1001 04750158 54710163 12720169 TEMPO 0800 VV005

FORECASTS
OMDB TAF OMDB 231818 31010KT CAVOK BECMG 2124 24005KT BECMG 0507
       31015KT
     TAF COR OMDB 231212 31015KT 7000 FEW030 BKN100 PROB30 1221
       31015G25KT 3000 TSRA FEW008 SCT025CB BKN030 OVC080
EDDL TAF EDDL 231000Z 231812 31010KT 8000 BKN15 TEMPO 1806 2000
       SHSN BKN005 SCT010CB
     TAF EDDL 230400Z 231206 30010KT 9999 SCT015 BKN030 BECMG 1518
       4000 -RASN BKN010 TEMPO 1806 31015G25KT 2000 SHSN BKN005
       SCT010CB
     TAF EDDL 231500Z 231601 30013KT 9999 BKN020 TEMPO 2001 3500
       -SNRA BKN010
     TAF EDDL 231200Z 231322 30010KT 9999 BKN030 TEMPO 1622 4000
       -RASN BKN013 PROB30 TEMPO 1922 2000 SN BKN006
EKCH TAF EKCH 231040Z 231812 01018KT 9999 SCT030
     TAF EKCH 230440Z 231206 28012KT 9999 SCT020 TEMPO 1218 0800
       SHSN VV005 BECMG 1517 02015KT
     TAF EKCH 231440Z 231524 31015KT 9999 SCT020CB BKN040 TEMPO
       1518 33016G30KT 0800 SHSN VV005 BECMG 1820 01018KT SCT030
     TAF EKCH 231230Z 231221 26010KT 9999 SCT020CB BKN040 TEMPO
       1218 0800 SHSN VV005 BECMG 1416 33016KT BECMG 1820 02018KT
       SCT030
```

Excerpt documentation Source: Operator

Until 2200 UTC, i.e. half an hour prior to departure in Dubai, additional TAFs for Düsseldorf Airport were issued:

TAF EDDL 231600Z 240018 33012KT 9999 BKN025 TEMPO 0012 2000 SHSN BKN005 SCT010CB=

TAF EDDL 232100Z 232207 32010KT 9999 SCT012 BKN030 TEMPO 2207 33015G25KT 3000 –SHSNRA BKN008 SCT015CB=

TAF EDDL 232200Z 240624 34010KT 9999 SCT010 BKN040 TEMPO 0624 36015G25KT 3000 -SHSN BKN008=

1.7.2 Weather Conditions at the Arrival Aerodrome

At the day of the accident sunrise in Düsseldorf was at 0821 hrs (0721 UTC).

The aviation routine weather reports (Appendix 1) make clear that from 0420 hrs until 0520 hrs (0320 until 0420 UTC) the weather was good with visibilities of more than 10 km. The three aviation routine weather reports contained the landing weather forecast (TREND) (NOSIG) (no significant change) valid for the next two hours. At 0537 hrs, and therefore 17 minutes later than the previous METAR, a selected special aviation weather report (SPECI) was published in which visibility had decreased to 7,000 m and the lowest cloud base had dropped from 1,200 ft to 800 ft above ground and it had begun to snow (-SHSN; showers of light intensity). The TREND published a visibility of 4,000 m, snow showers of medium intensity (SHSN) and a cloud cover of 5 - 7 oktas in 800 ft (BKN). At 0540 hrs (0440 UTC) visibility had decreased to 2,500 m due to snow showers of medium intensity. The TREND published NOSIG. Ten minutes later, which means about 10 minutes prior to the landing, the published METAR reported a visibility of 1,500 m and a cloud base of 500 ft above ground. The TREND published weather improvement with visibilities of more than 10 km. At 0556 hrs, i.e. four minutes prior to the landing, a selected special aviation weather report (SPECI) was issued, which showed a decrease in visibility to 800 m and an RVR value for runway 23L of 1,400 m and heavy snowfall.

From 0544:45 hrs on ATIS Information Kilo with the following content was broadcast:

> *This is Düsseldorf information Kilo special met report time 0440, expect ILS approach, runway in use 23, transition level 60, all departures contact radar on frequency 128.55 after take-off, wind 330 degrees 9 knots, visibility 2 500 meters, snow showers, clouds broken 800 ft, temperature zero, dew point minus zero, QNH 1 017 hectopascal, trend no significant change, information Kilo out.*

From 0554:45 hrs on ATIS Information Lima with the following content was broadcast:

> *This is Düsseldorf information Lima met report time 0450, expect ILS approach, runway in use 23, transition level 60, all departures contact radar on frequency 128.55 after take-off, wind 330 degrees 8 knots, visibility 1 500 meters, snow showers, clouds broken 500 ft, temperature minus zero, dew point minus one, QNH 1 017 hectopascal, trend visibility becoming more than 10 km, no significant weather, clouds scattered 500 ft, broken 1 500 ft, information Lima out.*

1.7.3 Weather after the Accident

Appendix 1 shows the weather reports issued after the accident.

At 0502 UTC, one minute after the accident, the SPECI reported an improved visibility to a RVR of 1,500 m and the SPECI issued another two minutes later reported an increased visibility of 1,800 m and medium snowfall. The subsequent METAR reported a visibility of 4,000 m and in the reports of 0526 UTC and 0550 UTC visibility had increased to more than 10 km; the cloud cover had changed from 3 - 4 oktas in 500 ft above ground to 3 - 4 oktas in 1,200 ft above ground.

1.8 Aids to Navigation

Radar vectoring was used for the approach to Düsseldorf. Runway 23L was equipped with an Instrument Landing System (ILS) with a 3° glideslope. All electronic equipment such as ILS with separate Distance Measuring Equipment (DME) and the approach and runway lighting were fully functional.

1.9 Radio Communications

Radio communications were recorded and the recording was made available to the BFU for evaluation.

1.10 Aerodrome Information

The aerodrome elevation of Düsseldorf Airport is 147 ft AMSL. It has two parallel concrete runways oriented 053°/233°. Runway 05R/23L was 3,000 m long and 45 m wide. Runway 05L/23R was 2,700 m long and 45 m wide. Another runway, oriented 153°/333°, was 1,630 m long and 50 m wide. In general, runway 15/33 was certified for landings with aircraft with a maximum mass of up to 8 t but not for jet aircraft.

The Landing Distance Available (LDA) of runway 23L was 2,700 m. There was a 185 m long asphalt clearway with a width of 60 m connected to the end of the runway. At the western end of the clearway the localizer antenna for the ILS of runway 23L was located. The array of antennas consists of a series of dipole antennas which are arranged at right angles to the landing direction. The array is approximately as long as the runway width. The glideslope antenna for runway 23L is located 1,200 ft beyond the displaced threshold to the north of the runway.

Düsseldorf Airport had stipulated local flight limitations. This included limitations in regard to night flying operations. Scheduled landings were therefore not permitted between 2300 hrs (i.e. 2200 UTC in the winter months) and 0600 hrs (0500 UTC in the winter months).

Düsseldorf Airport had the ICAO Fire Fighting Category 9. The airport fire brigade headquarters was located south of the runways and about 200 m east of Terminal A and an additional fire station north of the runways.

1.10.1 Measurement of the Braking Coefficient at the Airport

The Aeronautical Information Publication (AIP) of the Federal Republic of Germany listed all German airports, including Düsseldorf Airport, which had to apply the procedures published by ICAO for the clearance and treatment of the movement areas from deposits as well as measuring and reporting surface conditions during the winter months. The airport operators were responsible for the clearance of the movement and parking areas as well as for the measurements involved, improvements, and reports on the condition of the hard surface areas to the local air traffic service provider.

The snowplan valid at the time of the accident stipulated that all braking coefficients have to be measured and transmitted in accordance with ICAO Annex 14 (measured coefficient, estimated braking action and code).

The Airport Ground Operations Manager on duty stated that from 0515 hrs on de-icing vehicles treated runways and taxiways as precautionary action against icing. From 0530 hrs on snow began to fall which initially did not form deposits. Around 0536 hrs the snowfall increased and then formed visible deposits. A SAAB Surface Friction Tester was deployed to determine the runway condition in regard to the prevailing brake coefficient.

The BFU had the radio communications recordings between the ground controller and the driver of the Friction Tester available for evaluation. According to which, the driver had radioed at 0539:08 hrs: "… wie Sie wahrscheinlich sehen, schneits im Moment ziemlich dolle und das bleibt jetzt auch ein bisschen auf der Bahn liegen, ah ich hab den Sprüher jetzt erst mal wieder zum Vorfeld gebracht und würd gern noch mal ne Messfahrt machen" (... as you can probably see it is sowing pretty heavily right now and some of it covers the runway, ah I took the de-icing vehicle back to the apron and would like to make another survey). The ground controller then issued the clearance "auf alle Bahnen" (for all runways).

According to the measurement plot the following values were measured for the sectors A, B, and C: For runway 23L 68, 59 and 52; for runway 05R 76, 69 and 61.

At 0549:08 hrs the driver radioed the controller: "… Nord- und Südbahn Braking Action ist Good ah es ist nur leichter Puderzucker drauf, aber es schneit natürlich weiter, ahm ich weiß nicht wann der erste Start raus will oder die erste Landung rein, ich bin jederzeit bereit, noch mal schnell ne Messfahrt zu machen" (... north and south runway braking action is good ah there is only slight "powdered sugar" on them but of course it continues to snow ahm I do not know when the first take-off will be or the first landing I am ready at any time to make another survey). The controller answered: "Wir ham ziemlich genau um 06:00 die erste Landung ne 747 auf der Südbahn, wenn Sie die kurz vorher noch mal messen können, das wär vielleicht nicht schlecht" (We will have the first landing at around 0600 a 747 on the south runway if you could measure again a short time before that probably would not be too bad). The driver answered: "Ja, überhaupt kein Problem, da stelle ich mich schon mal direkt an die Startschwelle 23L oder besser vorne ahm an den Kopf und ahm wie sieht's aus, ham Sie Landungen geplant auf der Nordbahn? (Yes, no problem I will position myself at the threshold of 23L or even better ahm at the head ahm how about have you planed landings on the north runway?). Sonst würden wir da mal anfangen schon mal prophylaktisch ne bisschen mal sauber zu machen, damit wir nachher nicht beide Bahnen zu haben" (Otherwise we would start there to clean a little then we would not have two runways at the same time). The controller said he would contact Langen Radar and enquire about the planed approaches.

At 0552:27 hrs the controller requested the driver of the friction tester to conduct another survey of the south runway. This was acknowledged and at 0552:33 hrs the driver received the clearance to enter the runway. About two minutes later at 0554:36 hrs the driver requested the clearance for the survey of runway 05R/23L (opposite direction). The survey was permitted.

At 0556:47 hrs the driver of the friction tester reported: "Frei von der Südbahn und ja, auf der Rückfahrt hat mein Drucker hier so'n bisschen gehangen aber auf der Hinfahrt ahm na ja ich geb Ihnen mal ahm ein Medium weil Teile, stellenweise ist es doch relativ glatt" (free of the south runway and yes on the drive back the printer got stuck a little but on the drive there ahm I will give you a Medium because parts are still relatively slippery). The ground controller asked: "Können Sie vielleicht einfach mal die genauen Werte geben für die drei verschiedenen Teile der Bahn?" (Could you please just give me the exact values for the three different sections of the runway?). At 0557:04 hrs the driver of the friction tester answered: "Ja kann ich machen. (Yes I can do that.) Für die Hinfahrt ist es, ahm warten se mal kurz ja, leider hat mein Drucker das so'n bisschen versaubeutelt (For the drive there it is, ahm wait , yes the printer has made a little mess of it). Ich hatte total jetzt auf der Rückfahrt 36 und warten se mal kurz, ich muss das nämlich noch mal kurz ausdrucken lassen, aber der frisst jetzt im Moment das Papier (I had a total of 36 now on the drive back and wait I will have to print it again out it is eating the paper). Das ist nämlich das Problem (That is the problem). Ich hatte so ziemlich genau dreißiger Werte (I have had pretty exactly 30 values). In der Mitte war's ein bisschen besser auf der Hinfahrt" (In the middle a little better on the drive there). The ground controller answered: "Also alles aber nur dreißiger Werte, ja?" (So all but only 30 values?). The driver answered: "Ja, stellenweise mal mit fünfundzwanziger dabei, aber prinzipiell so um die dreißig" (Yes, in places it was 25 but in principle around 30). The controller said: "Je versuchen Sie mal, die richtigen Werte uns zu geben, weil die Flieger die gern wissen möchten" (Try to give me the correct values because the flights want to know them) and the driver answered: "Ja, sobald mein Drucker wieder funktioniert, melde ich mich" (Yes as soon as the printer is working again I will call).

The BFU had the printed measurement plot available. During the friction survey in landing direction 23L (according to the radio communications recording between 0552:33 and 0554:36 hrs) the values 43, 31, and 36 were measured for the sectors A, B, and C; in landing direction 05R (between 0554:37 and 0556:47 hrs) the values were 51, 34, and 23. The mean values resulting from both friction surveys were 47 - 32 - 29 and resulted in a mean braking coefficient of 0.36 (braking action medium to good).

About fifteen minutes after the accident, another friction survey was conducted; between 0616 and 0620 hrs. The values for the sectors A, B, and C were: 15, 16, and 11; the opposite direction resulted in 15, 11, and 13. The resulting mean friction coefficient was 0.13, i.e. braking action poor.

1.11 Flight Recorders

The aircraft was equipped with a Flight Data Recorder (FDR) and a Cockpit Voice Recorder (CVR). Both recorders were analysed by the BFU.

The FDR recorded 22 parameters.

1.12 Wreckage and Impact Information

The airplane had come to rest beyond the end of runway 23L, about 580 m away from the threshold of runway 05R and 75 m south-west of the clearway in the grass. The airplane fuselage pointed in the direction of 240°.

The localizer antenna of the ILS of runway 23L was destroyed on a width of about 30 m in the area of the extended runway centre line.

Three stanchions of the approach lighting of runway 05R were severed. A fourth stanchion of the approach lighting had been turned by about 60° around the yaw axis and blocked the airplane's door 1L.

The airplane had opened and pushed aside the concrete lid of a cable manhole with its nose landing gear. One wheel of the nose landing gear was destroyed.

Blocked door L1 Photo: BFU

The cockpit indications for the inner and outer trailing edge flaps were in position 30°, as were the flaps. The leading edge slats were extended. On the autothrottle speed selector at the autopilot mode control panel a speed of 156 was selected; the command speed bugs on the airspeed indicators also showed 156. Both autopilots were disengaged. The navigation mode selector was in position ILS, the course transfer selector in dual; course 233° was selected. The altitude selector showed 4,000 ft. On both VHF navigation units the ILS frequency was selected. The radio altimeter on the left instrument panel showed a Decision Height (DH) of 200 ft.

In the cockpit among the pre-flight preparation and flight execution documentation a filled-in landing data card was found. It listed in writing the expected landing mass of 283,300 kg, the recorded weather data of the ATIS Information India and the calculated reference speed for the approach. The operational flight plan listed in writing a take-off mass of 368,316 kg, a take-off fuel of 110,800 kg and fuel remaining of 25.2 t.

The indicators on the work station of the flight engineer for the mass of fuel used of all four engines resulted in 86,910 kg.

The crew service door of the right fuselage side was open.

Open crew service door Photo: BFU

The air intake of engine 1 showed damages in the 5 o'clock position. The entire air intake of engine 2 up to the fan was severed and was lying in front of the engine. Fire had destroyed the left engine fairing in the area of the fan and the low pressure compressor. The thrust reverser doors were in the open position. The air intake of engine 3 was damaged in the 7 o'clock position; the thrust reverser doors were in the open position. The engine air intake of engine 4 showed damages in the 5 o'clock position. The fan blades of the engines 2, 3, and 4 were also damaged.

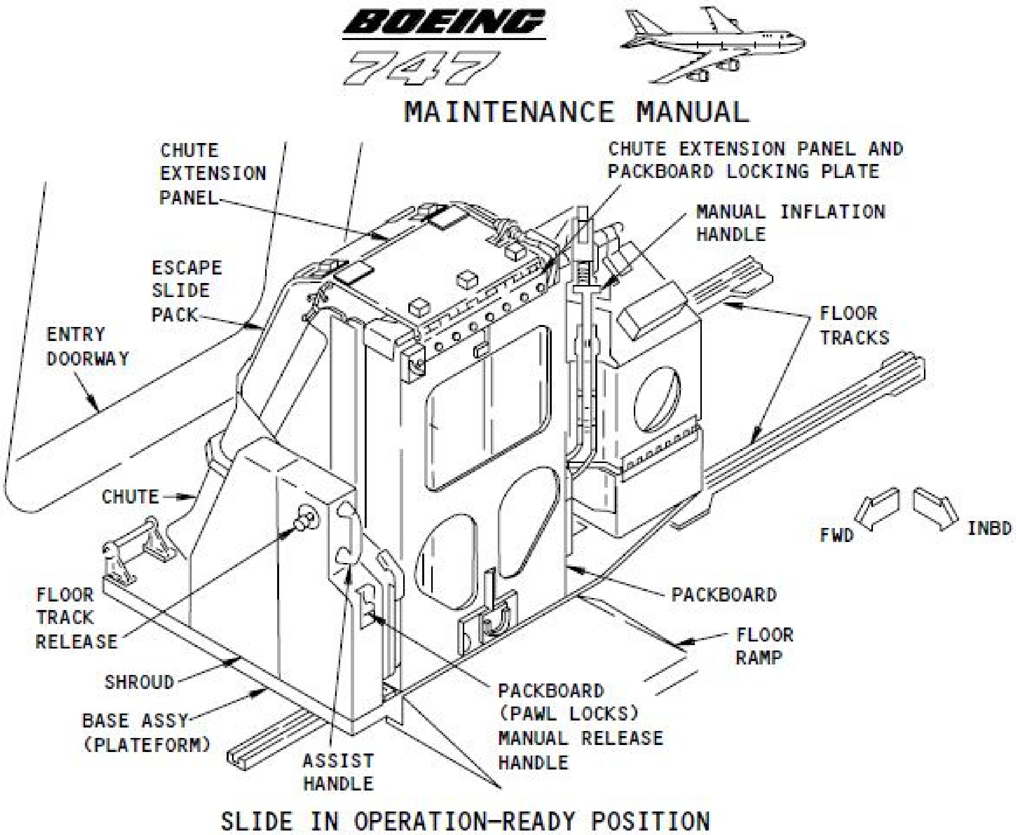
Parts of the ILS antennas were found in the engines. Fuselage and wings showed damages which were also a result of collisions with the antenna array.

The cargo aboard the airplane was salvaged and weight. The weighing determined a mass of 100,470 kg.

The mission report of the fire brigade showed that the removal of the remaining fuel was finished at 2057 hrs. About 29,000 l of fuel were removed.

1.12.1 Determinations on the Escape Slide

The crew service door on the upper floor of the right fuselage was open and pushed aside (opposite the flight direction). The platform including the escape slide mounted on top was in the position operation ready and directly in front of the doorway.



Excerpt Aircraft Maintenance Manual Source: Boeing

The escape slide was examined by an expert by order of the BFU.

It was determined that the packboard manual release handle on the escape slide was in the position unlocked. The escape slide assembly was not in the stowed position. It was tipped toward the doorway by about 30°. The still packed escape slide had burst open.

The manual inflation handle was in the triggered position.

The front deployment cable was fixed to the slider. The aft deployment cable was missing.

During deployment the fitted escape slide should be fixed to the fuselage by a suspension point. This should be accomplished by a lock which hooks into the packboard retainer latch bayonet located outside on the fuselage. Such a packboard retainer latch bayonet was not found on the fuselage.

The escape slide was examined at the manufacturer in the presence of the US American National Transportation Safety Board (NTSB).

It was determined that the packboard release was functional.

The forward slider connecting cable did not release from the slider during the attempted deployment of the escape slide. The forward side footing was bent upward by about 45°. The aft slider connecting cable had released from the slider.

The examination further determined that in 2004 during an aircraft maintenance D-check new bottle firing cable assemblies were installed. One end of the cable assembly had a clevis (P/N 69B55884-1) instead of the correct clevis (P/N 69B52257-6). The auto firing cable was not replaced during the aircraft maintenance but rigged incompletely.

Normal travel of the manual firing handle is 1.2 inch (30.5 mm) to initiate inflation but was found to be 0.7 inch (17.8 mm).

1.13 Medical and Pathological Information

Not relevant.

1.14 Fire

The two tower controllers stated that they could neither see the runway nor the accident site due to the heavy snowfall. They did see, however, the overshooting of the runway end on their aerodrome surface movement radar display and alerted the airport fire brigade.

The recordings of the phone calls between Düsseldorf Tower and fire brigade show that the controller had informed the fire brigade at 0601:55 hrs that the Boeing 747 had surely overrun runway 23 L ("mit Sicherheit in den Over Run Piste 23L"). At 0602:33 hrs the controller added: "… gut also Boeing 747 … steht im Over Run von der 23L also am Westende und es brennen wohl die Triebwerke 2 und 3 …" (... good Boeing 747 ... stands in the over run of runway 23L at the west end and the engines 2 and 3 are probably burning ...). The fire brigade acknowledged the information.

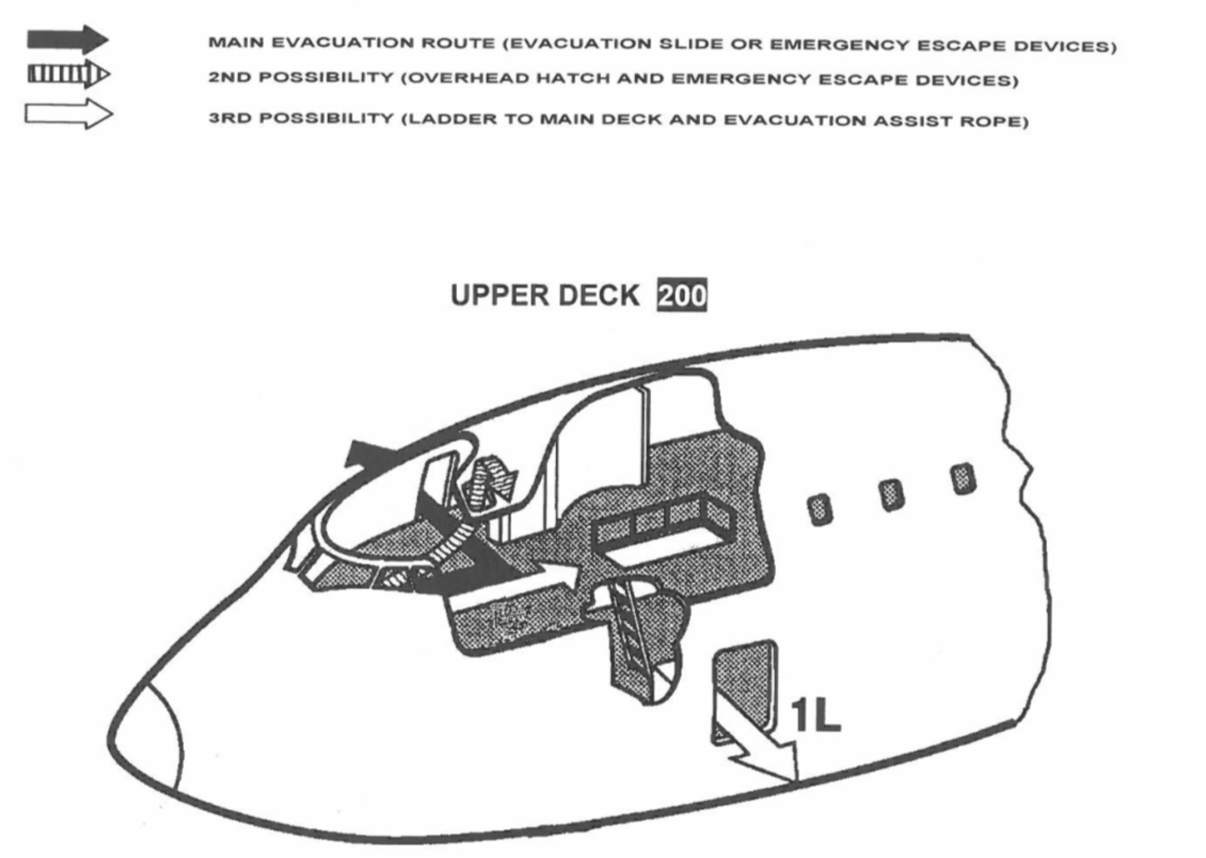
The mission report of the fire brigade states that at 0603 hrs the fire trucks were alerted and had left one minute later. The fire brigade stated that vehicles left from the main fire station as well as from the fire station north. The distance between main fire station and accident site via apron and taxiway M was 1,900 m; between the fire station north and the accident site via the north runway was about 2,600 m. According to the mission report visibility was poor due to snowfall. Apron and taxiway M had a snow cover of about 3 cm.

During the drive to the accident site the tower reported that three persons were aboard and the PIC would initiate evacuation. According to the mission report the fire brigade arrived at the airplane at 0607 hrs. The fire on engines 2 and 3 were initially fought with water guns and later with fire hoses. According to the mission report, within one minute the fire was under control and at 0626 hrs extinguished.

Damages on engines 2 an 3 Photo: BFU

1.15 Survival Aspects

The airplane had several emergency exit options. The crew service door on the upper deck on the right fuselage side was intended as main evacuation route.



Upper deck emergency escape routes Source: Boeing

According to the flight manual the crew service door on the upper deck on the right fuselage side behind the cockpit was the primary emergency escape route. The exit was fitted with an escape slide mounted to the cabin door.

The overhead escape hatch in the left cockpit roof was closed and locked. The steel cables for roping down through the escape hatch or the crew service door were in their mountings.

The PIC stated that after the engine fire / severe damage checklist had been completed he had gone to the main deck to door 1L to get his own impression of the fire. He had realised that the door had been blocked by a stanchion of the approach lighting and could not be opened. He saw that engine 2 was still burning and went back to the upper deck to the two other crew members. He saw that the flight engineer tried to activate the escape slide although in vain. He then tried together with the flight engineer to push the escape slide pack out the door but they did not succeed. Then the co-pilot could activate the escape slide. The escape slide inflated, but jammed between escape slide assembly and door frame, and burst. The arriving fire brigade told them to remain in the airplane until the fires on engines 2 and 3 were under control. After the fires were extinguished the fire brigade allowed the crew to leave the airplane. This was only possible through the escape hatch by roping down or via the E/E compartment. Since the fire had been extinguished the crew opted for the E/E compartment. Therefore the three occupants left the airplane through the hatch of the E/E compartment in the lower fuselage behind the nose landing gear.

1.16 Tests and Research

Not relevant.

1.17 Organisational and Management Information

1.17.1 Flight Operations Manual of the Operator

The US American operator conducted flight operations in accordance with *Code of Federal Regulations (CFR), Title 14, Part 121.* The Flight Operations Manual (FOM), chapter Approach and Landing, heading Surface Wind for Landing stipulated:

> *There is no limiting head wind component specified for landing.*
>
> *Tailwind component for all airplanes, the maximum steady-wind tailwind component for landing is 10 kt. A lower tailwind value may be limiting (reference runway length and condition) as indicated in the Performance chapter 4 of the Flight Handbook …*
>
> *Crosswind component*
> *the maximum crosswind component recommended for landing on a slippery runway is 15 kt.*
> *The maximum demonstrated crosswind component recommended for landing on a dry runway is 29 kt.*
> *The maximum crosswind component recommended for Catergory II or III, or for an autolanding is 10 kt.*

The chapter Meteorology of the operations manual included definitions and stipulations regarding the handling of estimated braking action and runway friction reports, respectively.

It stipulated, among other things:

- *There is no exact relationship between the coefficient of friction and actual stopping capability. Reports of braking action are used as advisory* *information only, since such reports are qualitative at best and can be transitory in nature.*

- *Takeoff from, landing at, or dispatch to an airport with an official Braking Action report of "NIL" or "Unreliable" is prohibited.*
- *Category II approaches are prohibited with braking action reported as nil.*
- *Category III approaches are prohibited with braking action reported as poor or nil.*

In case visibility or RVR is less than 1,200 m it was stipulated:

For initiation of an instrument approach at the destination airport when the RVR or visibility is less than 3/4 –mile, 4 000 ft (1 200 m) respectively, the following applies:

- *A fifteen percent increase in the minimum landing runway length is required. To determine this limitation, use the appropriate Landing Gross Weight Limited by Runway chart in the Performance chapter of the Flight Handbook.*
- *Precision instrument runway markings or runway centerline lights are required.*

The operations manual contained stipulations for a stabilised approach:

A stabilized approach must be established before descending below the following minimum stabilized approach heights:

- *500 ft above the airport elevation during VFR or visual approaches and during straight-in instrument approaches in VFR weather conditions*
- *MDA or 500 ft above airport elevation whichever is lower, if a circling maneuver is to be conducted after completing an instrument approach*
- *1,000 ft above the airport or TDZ elevation during any straight-in instrument approach in instrument flight conditions*
- *1,000 ft above the airport during contact approaches*

A stabilized approach means that the aircraft must be in an approved landing configuration, must maintain the proper approach speed with the engines spooled up, and must be established on the proper flight path before descend-

ing below the minimum stabilized approach height. These conditions must be maintained throughout the rest of the approach for it to be considered a stabilized approach.

The chapter Descent below Minimums stipulated:

If the following requirements are not met at decision height DA(H) or on a non-precision approach at the missed approach point (MAP) or in either case at any time thereafter, the pilot must execute a missed approach immediately.

Category I

- *The airplane is continually in a position from which a descent to a landing within the touchdown zone on the intended runway can be made at a normal rate of descent using normal maneuvers.*
- *The flight visibility is not less than the visibility required in the instrument approach procedure being used.*
- *At least one of the following visual references for the intended runway is distinctly visible and identifiable to the pilot:*

  I. *The approach light system except that the pilot may not descend below 100 ft above the touchdown zone elevation using the approach lights as a reference unless the red terminating bars or the red side row bars are also distinctly visible and identifiable.*

  II. *Runway threshold*

  III. *Threshold markings*

  IV. *Threshold lights*

  V. *Runway end identifier lights*

  VI. *Visual approach slope indicator*

  VII. *Touchdown zone or touchdown zone markings*

  VIII. *Touchdown zone lights*

  IX. *Runway or runway markings*

  X. *Runway lights*

1.18 Additional Information

1.18.1 ICAO Requirements Regarding Civil Operation of Aerodromes

At the time of the accident ICAO Annex 14 Aerodromes stipulated standards and recommendations regarding the operation of civil aerodromes. Annex A Guidance material supplementary to Annex 14 Volume I included stipulations regarding *Determining and expressing the friction characteristics of snow- and ice-covered paved surfaces.*

> *6.1 There is an operational need for reliable and uniform information concerning the friction characteristics of ice- and snow-covered runways. Accurate and reliable indications of surface friction characteristics can be obtained by friction measuring devices; however, further experience is required to correlate the results obtained by such equipment with aircraft performance, owing to the many variables involved, such as: aircraft mass, speed, braking mechanism, tire and undercarriage characteristics.*
>
> *6.2 The friction coefficient should be measured if a runway is covered wholly or partly by snow or ice and repeated as conditions change. Friction measurements and/or braking action assessments on surfaces other than runways should be made when an unsatisfactory friction condition can be expected on such surfaces.*
>
> *6.6 The table below with associated descriptive terms was developed from friction data collected only in compacted snow and ice and should not therefore be taken to be absolute values applicable in all conditions. If the surface is affected by snow or ice and the braking action is reported as "good", pilots should not expect to find conditions as good as on a clean dry runway (where the available friction may well be greater than that needed in any case). The value "good" is a comparative value and is intended to mean that aeroplanes should not experience directional control or braking difficulties, especially when landing.*

Measured Coefficient	*Estimated braking action*	*Code*
0.40 and above	*good*	*5*
0.39 to 0.36	*medium to good*	*4*
0.35 to 0.30	*medium*	*3*

Measured Coefficient	*Estimated braking action*	*Code*
0.29 to 0.26	*medium to poor*	*2*
0.25 and below	*poor*	*1*

The ICAO Doc 9137-AN898 *Airport Services Manual Part 2 Pavement Surface Conditions* included comments on the reliability of friction surveys. Chapter 4.2, subheading 4.2.3 states:

> *The reliability of conducting tests using friction-measuring devices in conditions other than compacted snow and/or ice may be compromised due to non-uniform conditions. This will apply in particular when there is a thin layer of slush, water film over ice, or uncompacted dry or wet snow on a runway. In such cases, the wheels of the friction-measuring device or of an aeroplane may penetrate the runway contaminant layer differently which would result in a significant difference in the friction performance indication. The results of friction tests obtained with different friction-measuring devices in such cases may be at great variance because of differences in test methods and, for a particular method, because of different characteristics of the vehicle and different individual techniques in performing the test. Care is also essential in providing runway friction information to pilots under conditions when a water film is observed on top of ice.*

The ICAO Doc 9137-AN/898 *Airport Services Manual Part 1 Rescue and Fire Fighting* stipulated, among other things:

> *2.7 Response Time*
>
> *2.7.1 The operational objective of the rescue and fire fighting service should be to achieve response times of two minutes and not exceeding three minutes to the end of each runway, as well as to any other part of the movement area, in optimum conditions of visibility and surface conditions. 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 per cent of the discharge rate specified in Table 2-2. …*

1.18.2 Documents Published After the Accident

The snowplan published in the AIP Germany was changed in regard to the transmission of measured braking coefficients so that the values can be reported by taking the runway surface conditions into consideration.

In 2012, ICAO published the *ICAO Circular 329 AN/191 –Assessment, Measurement and Reporting of Runway Surface Conditions*. The ICAO Friction Task Force issued the circular in preparation for intended changes in Annex 14 Aerodromes and Annex 15 Aeronautical Information Services. It included information on different friction measuring devices used worldwide, the characteristics of different deposits on runways and the reporting of runway conditions.

The circular described the friction coefficient as follows:

> *COEFFICIENT OF FRICTION*
>
> *4.1 It is erroneous to believe that the coefficient of friction is a property belonging to the pavement surface and is therefore part of its inherent friction characteristics. As described in Chapter 2, it is a system response generated by the dynamic system consisting of the:*
>
> > *a) pavement surface;*
> >
> > *b) tire;*
> >
> > *c) contaminant; and*
> >
> > *d) atmosphere.*
>
> *4.2 It has been a long-sought goal to correlate the system response from a measuring device with the system response from the aircraft when measured on the same surface. A substantial number of research activities have been carried out that have brought new insight into the complex processes taking place. Nevertheless, to date, there is no universally accepted relationship between the measured coefficient of friction and the system response from the aircraft although one State uses the coefficient of friction measured by a decelerometer and relates it to aircraft landing distances.*

The circular contained the following explanation for the use of friction measuring devices:

> *4.3 Friction measuring devices have two distinct and different uses at an aerodrome:*

a) for maintenance of runway pavement, as a tool for measuring friction related to the:

1) maintenance planning level; and

2) minimum friction level;

b) for operational use as a tool to aid in assessing estimated surface friction when compacted snow and ice are present on the runway.

5.11 Loose contaminants (standing water, slush, wet or dry snow above 3 mm). These contaminants degrade μ_{max} to levels which could be expected to be less than half of those experienced on a wet runway. Microtexture has little effect in these conditions. Snow results in a fairly constant μ_{max} with velocity, while slush and standing water exhibit a significant effect of velocity on μ_{max}.

5.12 Because they have a fluid behaviour, water and slush create dynamic aquaplaning at high speeds, a phenomenon where the fluid's dynamic pressure exceeds the tire pressure and forces the fluid between the tire and ground, effectively preventing physical contact between them. In these conditions, the braking capability drops drastically, approaching or reaching nil.

In May 2011, the Norwegian Accident Investigation Board (AIBN) published the report *Winter Operations, Friction Measurements and Conditions for Friction Predictions.* It presents findings from 30 occurrences which had occurred in Norway on contaminated runways over a period of 10 years. This report included the formulation of the so-called 3-Kelvin Spread Rule. It states that at air temperatures of +3°C or less and a dew point spread of 3°C or less, the runway surface condition may be more slippery than anticipated on ice and snow. The narrow temperature spread is an indication that the air mass is close to saturation, i.e. often connected with precipitation or fog. According to the AIBN report such conditions were found in 21 of the 30 analysed cases.

1.19 Useful or Effective Investigation Techniques

1.19.1 Determination of the Touch-down Point

The determination of the touch-down point with the parameters the FDR had recorded was not possible. Due to the poor visibility the controllers could not observe the touch-down.

The BFU therefore used the following sources:

- A sequence of radar targets of the final approach and the landing which contained the coordinates including UTC time stamp and the altitude transmitted by the transponder.
- The radio communications including UTC time stamp recorded by the air navigation service provider.
- The CVR recordings with their relative time information.
- The FDR recordings with their relative time information; the values of the following parameters were used: longitudinal acceleration, pitch, vertical acceleration, pressure altitude, Calibrated Airspeed (CAS), engine N1, and the actuation of the push-to-talk button on the VHF radio.
- Charts and data from the AIP to get ground coordinates and distances between these points, respectively.

Initially the BFU synchronised the FDR and CVR recordings with the radar data and the radio communications recordings in order to match their relative time with UTC.

As reference points for further examinations distinctive points on the ground were selected: The final position of the airplane and the position of the localizer antenna.

By using the recorded loss of power N1 of the inboard engines 2 and 3, the FDR recordings could be correlated with the position of the localizer antenna and the time of collision.

The distinctive increase in vertical acceleration and longitudinal deceleration allowed determination of the time of touch-down.

In general, by integration the speed can be calculated using the time-related acceleration values; the covered distance can be calculated by reapplying integration. In this case double integration was applied to calculate the touch-down point on the runway. Based on the final position of the airplane until the time of touch-down the distance from the final position of the airplane to the touch-down point was calculated.

The recorded longitudinal acceleration values can differ from the actual values due to:

- A percentage of the longitudinal acceleration measured by the sensor was caused by the gravitational acceleration which depends on the airplane's pitch.
- The sensor may have a zero point error so that at zero acceleration values the sensor indicates other values.

- The sensor may have a scaling error so that the proportionality between recorded acceleration values and actual acceleration may not equal one.

Therefore commensurate corrections were applied. The double integration of the acceleration values was continued beyond the touch-down point until the radar targets of the final approach. The resulting distances were compared with the distances calculated from the positions of the radar targets and the corrections adjusted so that the errors were minimised.

The following was considered for plausibility:

- A wind component of 320° and 10 kt during the touch-down of the airplane meant pure cross wind prevailed. At that time, true airspeed and ground speed were therefore equal.
- Given the prevailing meteorological conditions the recorded Calibrate Airspeed (CAS) was about 3 kt higher than the True Airspeed (TAS)

The calculations determined that the airplane touched down between 1,200 ft and 1,600 ft behind the runway threshold. Ground speed was between 155 kt and 160 kt.

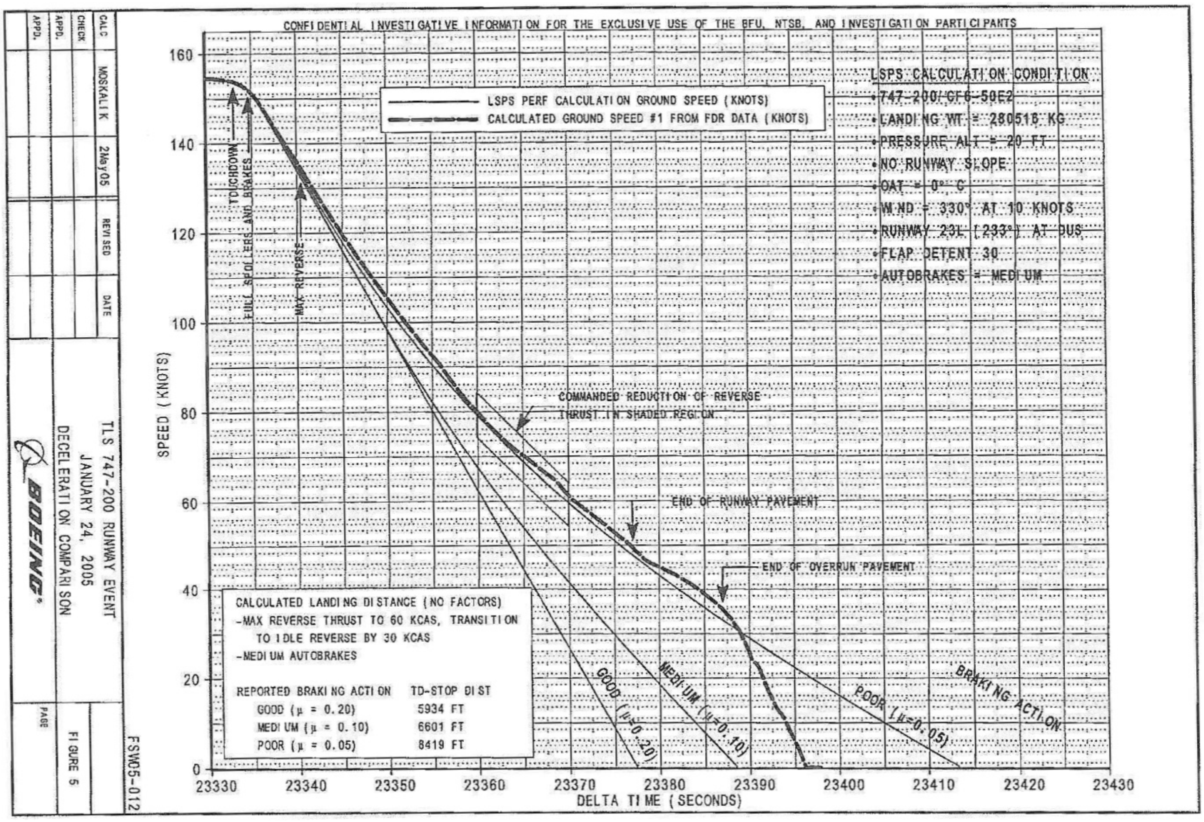
At the beginning of the final approach, i.e. 10 NM prior to the threshold in 3,000 ft AMSL, the calculation determined that ground speed was about 10 kt higher than CAS. Such a value of a tail wind component in 3,000 ft AMSL was not contradictory with the wind information.

1.19.2 Calculations of the Aircraft Manufacturer

In the course of the investigation, the aircraft manufacturer Boeing was asked to compile a second description of the course of events during the landing phase using the FDR raw data and independently of the BFU investigation. This resulted in the following findings:

The aircraft manufacturer analysed the FDR data and calculated that the airplane had touched down between 1,100 ft and 1,600 ft beyond the displaced threshold. According to the FDR at touch-down the normal load factor reached 1.2. Three seconds after touch-down the longitudinal deceleration reached 0.17 g. According to Boeing this correlates with the target value for the deceleration with the auto brake setting medium (6 ft/s^2 or 0.186 g). Within the next 35 seconds deceleration gradually decreased and then reached 0.08 g. At a speed of about 85 kt the thrust was set to reverse idle and then to maximum thrust again. After which the deceleration fluctuated between 0.1 g and 0.05 g.

Boeing conducted a performance evaluation of the FDR data of the landing with the help of Boeing's Low Speed Performance System (LSPS) program. As a result a runway braking coefficient was determined which corresponds with the braking action poor or worse. Under these conditions the LSPS program calculated that the airplane would have needed 8,419 ft (2,566 m) to stop.



Deceleration comparison Source: Boeing

According to the aircraft manufacturer, at braking action poor the airplane deceleration is limited by the runway friction and the anti-skid system operation. Therefore the distance between touch-down and stop would be almost the same independent of the autobrake selection maximum or medium.

For a braking action of medium - medium to good the LSPS program calculated that the airplane would have needed 6,601 ft (2,012 m) to stop.

2. Analysis

2.1 General

The flight was conducted in accordance with the US American aviation regulation *Part 121, 14 CFR*. This is intended to set a flight safety standard that ensures the safe conduct of the flight, including unusual weather situations.

The investigation did not reveal any technical deficiencies, particularly on the thrust reverse, the spoilers or the wheel brakes, relevant for the accident.

Focal points of the investigation were the weather situation, the measurement of the braking coefficient, the reporting of this information, and the decision making process regarding the conduct of the landing.

2.2 Flight Operational Aspects

2.2.1 Pre-Flight Preparation

The documentation of the pre-flight preparation shows that the crew was aware of the predicted snow showers at the arrival aerodrome Düsseldorf and the alternate aerodrome Copenhagen prior to departure due to the Terminal Aerodrome Forecast (TAF). The documentation also shows that the TAFs for Düsseldorf the crew had available were 12 hours old or more and only two TAFs were valid for the expected time of arrival.

In addition, three newer TAFs for Düsseldorf Airport had been available prior to departure in Dubai but had not been made available to the crew. The BFU is of the opinion, however, that these TAFs were not significantly different to the older versions.

2.2.2 Conduct of the Flight

In preparation of the approach the crew noted weather data from ATIS Information India of 0350 UTC which did not report or predict any show showers in the filled-in landing chart together with the calculated speeds for the approach in Düsseldorf. Sixteen minutes prior to landing the crew established radio contact with approach control Düsseldorf and the controller advised the crew of ATIS Information Kilo which the crew then listened to. Information Kilo reported moderate snow showers and temperature (0°C) and dew point (-0°C). Based on the information the controller had given: "I just talked to the tower … braking action on all parts of the runway is supposed to be good", the runway condition did not pose a problem for the crew. The flight engineer conducted a landing data check with the updated data and it resulted in a landing distance required of 8,456 ft (2,577 m) with the auto brake setting minimum. The PIC decided to select medium due to the snow.

For the crew the runway condition was confirmed when the controller radioed about 10 minutes prior to landing: "... the friction tester has reported braking action to be good for the moment ..." At the same time the crew was informed of the continuing snowfall and the expected worsening of the braking action. According to the operator's stipulations, the crew had no reason to consider abortion of the approach because of the information they received regarding the runway condition.

The crew had to take into consideration the worsening visibility and the reported tail wind component of 2 kt after they had received the weather information about five minutes prior to the landing. The reported wind velocity was 340°/11 kt and resulted in a tail wind component of 3 kt. The CVR recordings show the crew talked of a tail wind component of 2 kt.

At the time when the co-pilot established radio contact with Düsseldorf Tower the crew began to complete the landing checklist. On the altitude selector 4,000 ft were selected as preparation for a missed approach.

At 0559:26 hrs the tower controller gave the crew the updated friction values: "... the braking action was measured to be medium at all parts. And ah the visibility dropped right now due to the heavy snow showers at the field ah. The RVR value at the touch down zone is presently nine hundred meters, at the mid-point one thousand one hundred meters and ah stop end one thousand one hundred meters."

Prior to arrival in Düsseldorf the crew took a landing mass of 283.3 t as basis for the calculation of the landing distance. This value was 2,462 kg below the maximum allowable landing mass of 285,762 kg. The freight was weighted and the mass was 573 kg higher than was taken as basis for the planning of the flight. Based on the fuel quantity of 110.8 t entered into the operational flight plan and the used fuel quantity of 86.91 t indicated in the cockpit, the remaining fuel quantity was 23.89 t. The fire brigade stated they had removed about 29,000 litres of fuel. At an assumed fuel temperature of 0°C this equals a fuel quantity of 23.9 t and therefore matches the calculated value. By subtracting the used fuel quantity of 86.9 t from the take-off mass of

368.3 t, the resulting actual landing mass was 281.39 t. It was therefore 4,372 kg below the maximum allowable landing mass and 1,910 kg below the value the crew had calculated. Based on the AOM, available to the BFU, the landing distance required for the landing mass of 283 t calculated by the crew and the actual landing mass of 281 t was less than the landing distance available of 2,700 m and would have been sufficient for the braking action good and medium with thrust reversers. At a mass of 283 t and of 281 t and a braking action of less than medium the landing distance required would have been above the landing distance available of 2,700 m. In this case the crew would have had to abort the approach.

The CVR recordings and the statement of the PIC do not indicate that one of the crew members had doubted the braking action given by the controller.

The FDR recording show that, given the prevailing weather conditions, the final approach on the ILS of runway 23L occurred without any significant deviations until touch-down on the runway. The crew received the landing clearance in 1,000 ft above the touch-down zone. At that time all criteria for a stabilised approach (instrument approach) were met and therefore the BFU understands the decision to continue the approach.

When the minimum was reached, i.e. directly prior to touch-down, the tower controller gave the prevailing wind as 10 kt with 320°; in relation to the landing direction of 233° this means 87° from the right. The cross wind component was below the maximum of 15 kt recommended in the flight operations manual of the operator for a landing on a slippery runway. This was also true for the recommendation in the airplane operations manual regarding the braking action medium and medium to poor.

The criteria stipulated in the operations manual of the operator for the continuation of the descent at the decision height were met (The touch-down zone can be reached with the normal rate of descent, visibility is not below the minima stipulated for the approach, visual references are in sight). The BFU therefore understands the PIC's decision to land.

The speed during the final approach was about 160 kt and in normal range given the prevailing weather conditions. During touch-down speed was 157 kt, six knots, i.e. 4%, higher than V_{REF}.

According to the calculations of the BFU and the aircraft manufacturer the airplane touched down between 1,100 ft and 1,600 ft behind the runway threshold. The recorded load factor of 1.2 indicates a normal touch-down and a resulting normal load on the landing gear. The aircraft manufacturer stated that the deceleration of -0.17 g reached after three seconds is the normal target value for the auto brake selection medium.

FDR and CVR data show that immediately after touch-down the thrust reversers were activated. Even though the thrust reversers were activated with an engine thrust of 100% for about 20 seconds, deceleration decreased continuously in this phase. The BFU is of the opinion that the PIC's decision to reduce the engine thrust from 100% N1 to reverse idle after 20 seconds is probably owed to the routine procedure during a landing. In this phase the flight engineer and the co-pilot called the speeds 90 kt and 80 kt, respectively. The PIC realised the airplane was still fast and re-activated the thrust reverse with 100% engine power and began to brake manually. Approximately 10 seconds after the power had been reduced the speed was 60 kt. This means that from this time on the effectiveness of the thrust reversers for deceleration of the aircraft and of the rudder for directional control were no longer given.

The CVR recordings show that from 0601:22 hrs on the crew realised the airplane would overshoot the end of the runway.

Fifty-four seconds after touch-down the vertical acceleration began to fluctuate between 0.4 and 1.6 g. The BFU is of the opinion that the N1 fluctuation of the inboard engines 2 and 3 recorded by the FDR beginning at that time were due to their collisions with the localizer antenna.

The BFU is of estimates that the analysis of the FDR data conducted by the aircraft manufacturer indicated that the braking action was "poor" or worse during the landing.

2.3 Runway Condition Measurement and Communication

2.3.1 Conduct of the Measurement

Approximately 45 minutes prior to the opening of the airport all flight operation areas were de-iced as precautionary action. At 05:30 hrs heavy snowfall began which resulted six minutes later in visible deposits on the operation areas. The driver of the friction tester had reported this at 0539:08 hrs and said he thought a friction survey was necessary. The controller approved the drive on both runways.

The results of this friction survey were: 68, 59, and 52 and 76, 69, and 61. This means the measured friction coefficient matched the braking action good. The driver had reported this to the controller. The BFU is of the opinion that with the remark: "Es ist nur leichter Puderzucker drauf aber es schneit natürlich weiter … ich bin jederzeit bereit, noch mal schnell ne Messfahrt zu machen" (there is only slight "powdered sugar" on them but of course it continues to snow ... I am ready at any time to make another survey) the driver indicated the non-critical condition of the runways. However, he also advised of the possible worsening of the condition and emphasised his willingness to undertake another friction survey and monitor the runway condition.

From the sequence and content of the radio contacts the BFU deduces that the driver conducted another friction survey immediately after the controller had asked him to do so. The driver had been right next to the runway when he was asked at 0552:27 hrs to conduct another friction survey on the south runway. Approximately four minutes prior to the landing of the airplane and already 4.5 minutes after the controller had asked him to conduct the friction survey the driver reported that he had left the south runway.

2.3.2 Reporting the Runway Condition

The driver told the controller that on the way back he had had difficulties with the printer. With his words: " … ich geb Ihnen mal ahm ein Medium weil Teile, stellenweise ist es doch relativ glatt" (ahm I will give you a Medium because parts are still relatively slippery) he indicated the worsening conditions compared to the previous friction survey.

The BFU had the printed measurement plot available. The mean values resulting from both friction surveys were 47 - 32 - 29 and resulted in a mean braking coefficient of 0.36 (braking action medium to good). This shows that the driver had attentively and correctly observed the friction survey. His estimation medium was more conservative than the actual mean measurement result.

For the ground controller the information was not clear. The friction tester driver talked of medium and indicated that it had partially been pretty slippery but had given a mean value of 36 for the drive back which means medium to good but had also said "so ziemlich genau dreißiger Werte" (just about 30 values). This would have corresponded with a braking action of medium or medium to poor. The ground controller asked again: "Also alles aber nur dreißiger Werte, ja?" (So all but only 30 values?). And the driver answered: "Ja, stellenweise mal mit fünfundzwanziger dabei, aber prinzipiell so um die dreißig" (Yes, in places it was 25 but in principle around 30).

This confirmed a braking action of medium or medium to poor with partially even worse values.

The radio communications recordings show that about 15 minutes prior to the landing during the initial radio contact with the crew, the controller had advised the crew of the ATIS Information Kilo and informed them of the then estimated braking action good. He advised of the beginning snowfall and promised to inform the crew of any new results of further friction surveys.

Several radio contacts of the controller with the crew indicate his effort to delay the approach and therefore ensure that the landing will not occur before 0600 hrs when the airport opens.

At 0550:31 hrs, about 10 minutes prior to the landing, the controller had reported good values" ... latest update on the weather situation … the friction tester has reported braking action to be good for the moment." He also said: "However as it's continuing to snow they are ah afraid that it might worsen, so they are going to do another friction test right before you land" and therefore indicated again the possibility of worsening conditions and announced another friction survey. The BFU is of the opinion that the radio contact shows that the indication of the friction tester driver concerning the possible worsening conditions had reached the radar controller and the crew

The tower controller had told the co-pilot during the initial call, that before long he would receive updated braking action values. With his radio communication half a minute prior to landing: "... the braking action was measured to be medium in all parts" the tower controller passed on the estimation of the friction tester driver who had talked of medium. In addition, the tower controller advised the crew of the decrease in RVR values.

The procedure that all braking coefficients have to be measured and reported, stipulated in the snowplan valid at the time of the accident, was changed in regard to the reporting of measured braking coefficients so that the values can be transmitted by taking the runway surface conditions into consideration.

2.3.3 Braking Coefficient Measurement Procedure

The accident shows that the airport personnel made an effort to achieve a proper runway condition. In addition to the precautionary de-icing of the runway, friction surveys were conducted to determine the braking coefficient. The last friction surveys were conducted immediately prior to the landing of the airplane.

The BFU is of the opinion that this accident emphasises that under the prevailing weather conditions and the existing friction coefficients the used friction tester is appropriate for the planning of winter services but does is not reliably usable for flight operations. This confirms the findings which the Norwegian accident investigation authority and the ICAO Friction Task Force determined in the meantime.

The measurement methods for the determination of braking coefficients available at the time of the accident and the close of the investigation do not allow drawing conclusions as to the braking action of an airplane when weather conditions around freezing point and a marginal spread between temperature and dewpoint prevail.

2.4 Specific Conditions

All crew members held valid licences and medicals and had a substantial total flying experience. The PIC and the co-pilot had a substantial type experience on B747.

At the time of the accident, the crew had completed a duty period of 10 hours. The CVR recordings do not indicate that one of the crew members' performance was impaired due to tiredness (inattention or inactivity).

The weather data and the timeline show a high dynamic in the weather changes and a worsening of the situation during the approach and the landing (Appendices 1 and 2). The data also shows that immediately after the accident the weather improved and within 50 minutes visibility had increased to more than 10 km.

Temperature and dewpoint had the entire time been at 0°C and -1°C and therefore in a range where in the presence of precipitation contamination of the operating areas with wet snow is probable.

According to the weather reports and the statements of the air traffic service provider the wind came from 330° to 340° with 8 to 12 kt during the last 10 minutes of the approach. The last wind information the controller gave prior to the landing was 320° and 10 kt.

2.5 Survival Factors

At the time of the activation of the gas cylinder the escape slide was inside the cabin. This does not correspond with the normal procedure. According to the normal operating procedure the gas cylinder shall activate once the entire component is outside the cabin and fixed to the fuselage. The determined installation errors allowed the gas cylinder to be activated even though the escape slide was still inside the airplane.

Since the main escape route was not usable and door 1L was blocked the crew still had the escape hatch in the cockpit roof available as escape route. This escape route would have led them close to the burning engine 2. It cannot be ruled out that the need to rope down played a role in the decision process. After contact with the fire brigade had been established and they had secured the open manhole, the crew could leave the airplane.

The five minutes between the fire brigade being alerted by the tower and the first fire trucks arriving at the accident site were significantly more than what ICAO requires. However, the ICAO requirements are valid for optimal conditions. The poor visibility and the snow-covered operating areas slowed down the fire brigade.

3. Conclusions

3.1 Findings

- The pilots held the required licenses and ratings to conduct the flight.
- The PIC and the co-pilot had a substantial total flying experience and experience on the type.
- The airplane was airworthy. It had been equipped and maintained in accordance with existing regulations of the State of Registry.
- There were no indications of any technical deficiencies on the thrust reverse, the spoilers and wheel brakes.
- Mass and centre of gravity of the freighter were during the landing within prescribed limits. The actual landing mass of 281.39 t was 4,372 kg below the maximum allowable landing mass.
- About 45 minutes prior to the landing the runway had been de-iced as precautionary action.
- About 20 minutes prior to the landing a friction survey to determine the braking coefficient resulted in values which correspond with the braking action good.
- Using radio vectors the radar controller delayed the approach to ensure the landing would take place around 0600 hrs after the airport opened.
- At the time of the approach and landing instrument meteorological conditions prevailed.
- About four minutes prior to the landing the friction tester driver reported an estimated braking action of medium to the air traffic service provider. About one minute prior to the landing, the air traffic service provider passed a braking action of medium for the entire runway to the crew.
- The required landing distance at braking action medium was below the landing distance available.
- The approach was stabilised.
- The cross wind prevailing immediately prior to touch-down was below the limits the operator and the aircraft manufacturer recommend.

- The meteorological data show a high dynamic in the weather changes and a worsening of the situation during the approach and landing.
- The runway was contaminated with wet snow.
- The prevailing weather conditions corresponded with conditions where the real braking action can be significantly below the braking coefficient determined during friction surveys.
- The airplane touched down within the touch-down zone about 1,100 ft to 1,600 ft behind the threshold. Immediately after touch-down the thrust reverse was activated.
- Twenty-seven seconds after touch-down engine thrust N1 was reduced to idle reverse, then the PIC increased engine thrust again to 100% which was achieved 10 seconds after the decrease had begun.
- The collision of engines 2 and 3 with the localizer antenna caused engine failure and fire.
- The tower controller alerted the fire brigade immediately.
- During the attempt to evacuate the airplane through the crew service door of the upper deck, the escape slide opened inside the airplane. This escape route was therefore no longer usable.
- Door 1L was blocked from the outside and the crew could not use it as an escape route.
- The crew left the airplane through the E/E compartment.
- Due to the poor visibility and pavement conditions the fire brigade's response time was significantly delayed.

3.2 Causes

The air accident is due to the fact that the braking action values reported to the crew did not correspond with the runway conditions which had changed because of the heavy snowfall since the last measurement.

The following factors contributed to the air accident:

- The high dynamics of the weather changes
- The lack of a measurement method providing reliable braking coefficient values under all weather conditions.

4. Safety Recommendation

None

Investigator in charge:	Jens Friedemann
Field investigation:	Thomas Kostrzewa, Andreas Wilke
Assistance:	Fritz Kühne, Klaus Himmler, Dieter Ritschel
Braunschweig	18 October 2013

5. Appendices

Appendix 1 Weather reports at Düsseldorf Airport

Appendix 2 Graphs of the weather and the runway conditions

Appendix 3 Excerpt of FDR data

Appendix 4 Aerial photos of the accident site

The BFU had the following weather information available:

METAR 240320 EDDL 36007KT 9999 SCT013 M00/M01 Q1016 NOSIG

METAR 240350 EDDL 34004KT 9999 SCT012 BKN070 M00/M02 Q1016 NOSIG

METAR 240420 EDDL 32007KT 9999 SCT012 BKN070 M00/M01 Q1016 NOSIG

SPECI 240437 EDDL 33009KT 7000 –SHSN SCT008 BKN013 00/M01 Q1017 TEMPO 4000 SHSN BKN008

SPECI 240440 EDDL 33009KT 2500 SHSN BKN008 00/M01 Q1017 NOSIG

METAR 240450 EDDL 33008KT 1500 SHSN BKN005 M00/M01 Q1017 BECMG 9999 NSW SCT005 BKN015

SPECI 240456 EDDL 33010KT 0800 R23L/1400 R23R/P1500 +SHSN BKN005 M00/M01 Q1017 BECMG 9999 NSW SCT005 BKN015

One minute after the accident the following weather information was broadcast:

SPECI 240502 EDDL 33011KT 0800 R23L/P1500 R23R/P1500 +SHSN BKN005 M00/M01 Q1017 BECMG 9999 NSW SCT005 BKN015

Additional weather reports:

SPECI 240504 EDDL 33011KT 1800 SHSN BKN005 M00/M01 Q1017 BECMG 9999 NSW SCT005 BKN015

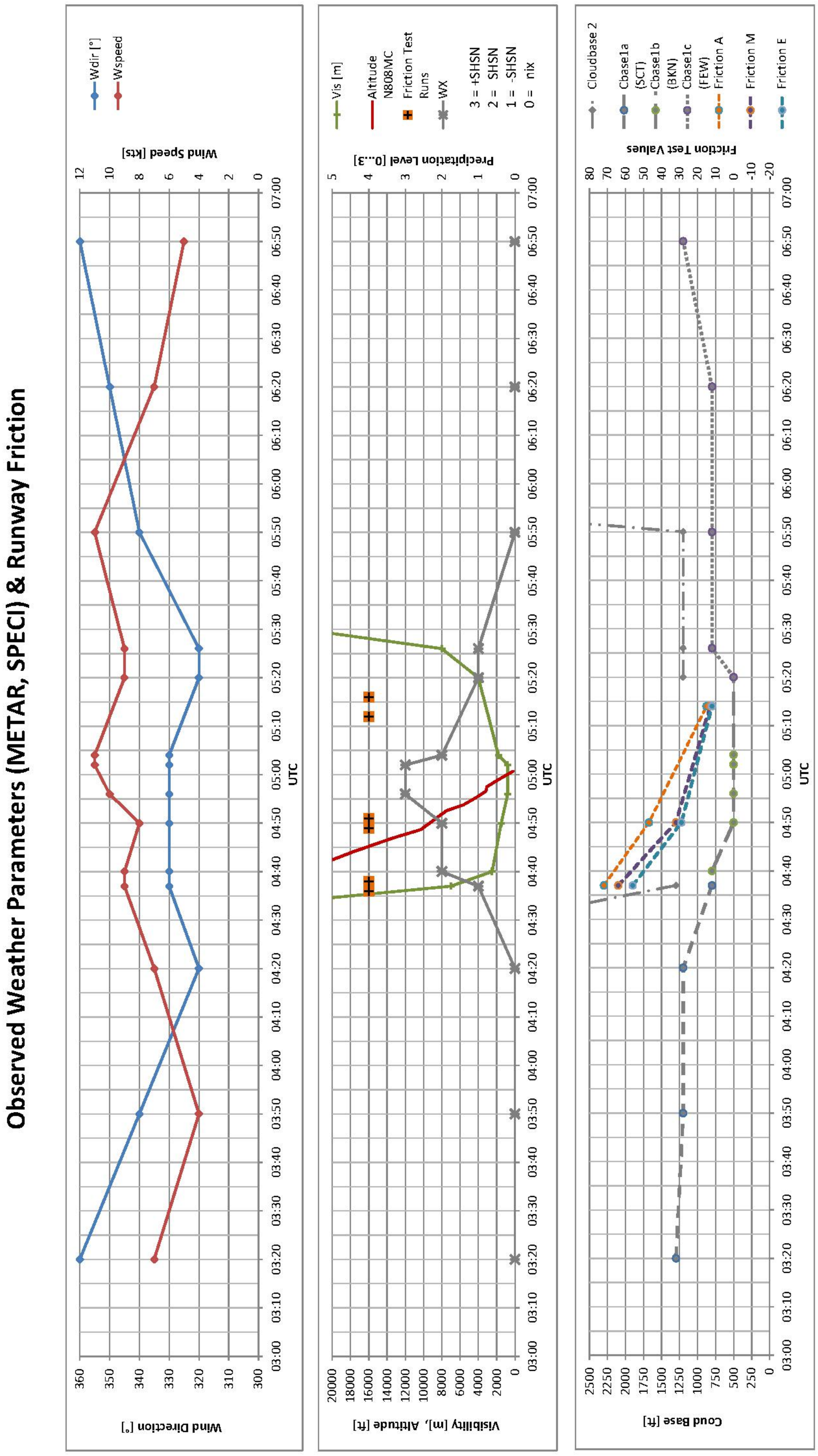
METAR 240520 EDDL 32009KT 4000 -SHSN SCT005 BKN012 M00/M01 Q1017 NOSIG

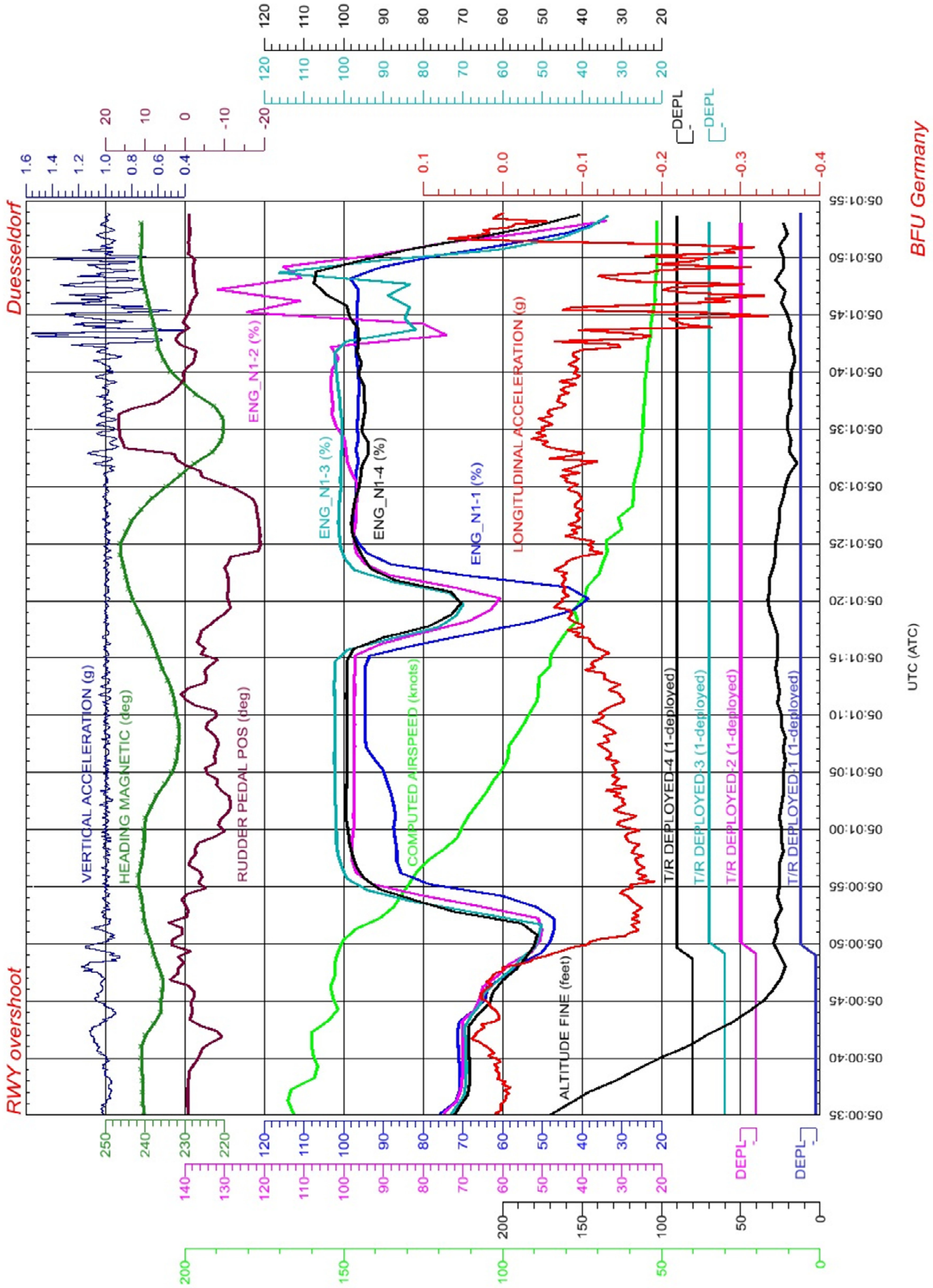
SPECI 240526 EDDL 32009KT 8000 -SHSN FEW008 SCT012 BKN020 M00/M01 Q1017 NOSIG

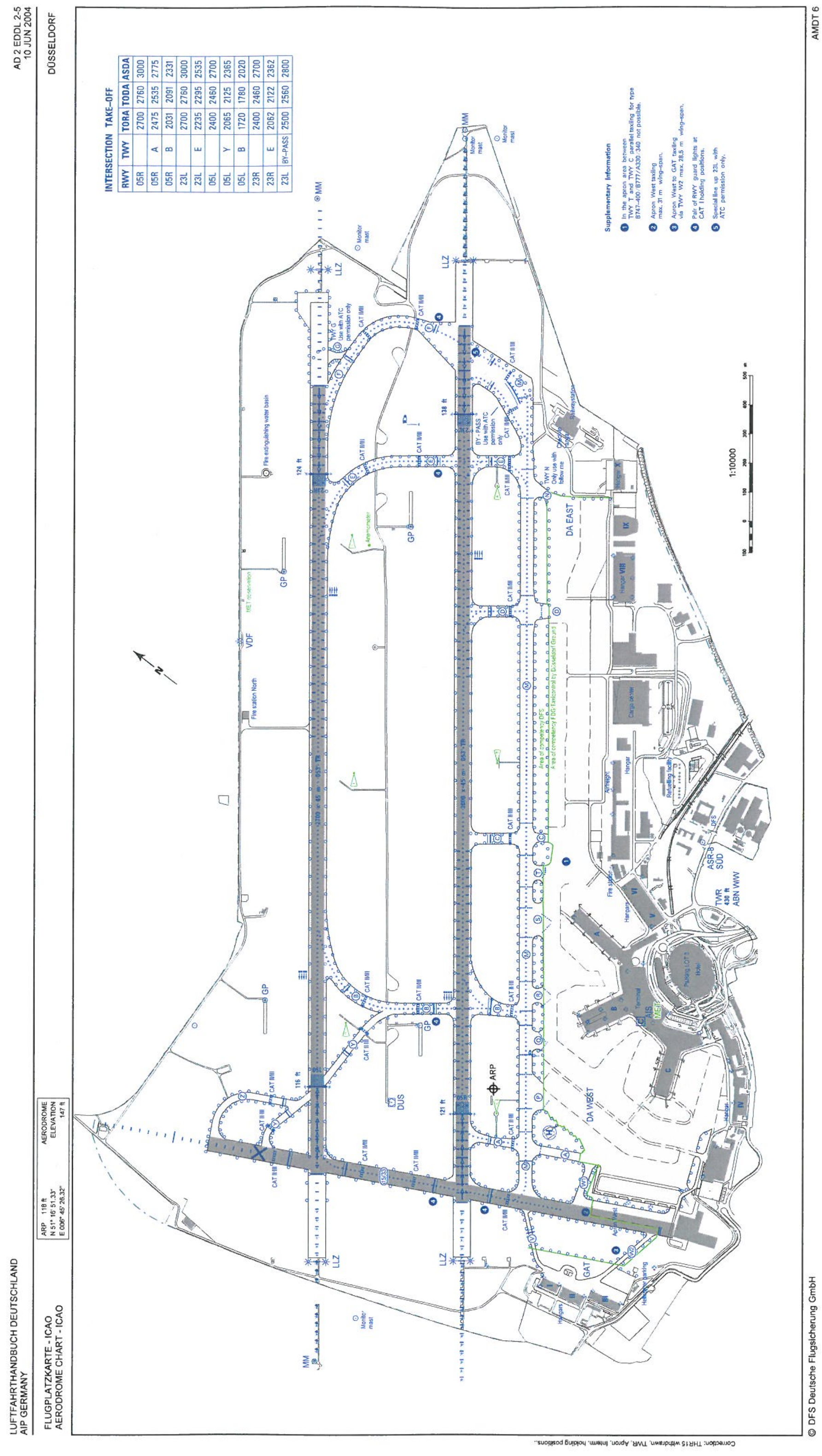
METAR 240550 EDDL 34011KT 9999 FEW008 SCT012 BKN130 M00/M01 Q1017 NOSIG

METAR 240620 EDDL 35007KT 9999 FEW008 SCT250 M01/M02 Q1017 NOSIG

METAR 240650 EDDL 36005KT 9999 FEW012 M02/M03 Q1018 NOSIG


Observed Weather Parameters (METAR, SPECI) & Runway Friction
Wind Direction [°]
Wind Speed [kts]
Wdir [°]
Wspeed
Visibility [m], Altitude [ft]
Precipitation Level [0...3]
Vis [m]
Altitude N808MC
Friction Test Runs
WX
3 = +SHSN
2 = SHSN
1 = -SHSN
0 = nix
Coud Base [ft]
Friction Test Values
Cloudbase 2
Cbase1a (SCT)
Cbase1b (BKN)
Cbase1c (FEW)
Friction A
Friction M
Friction E
UTC


RWY overshoot
Duesseldorf
BFU Germany
VERTICAL ACCELERATION (g)
HEADING MAGNETIC (deg)
RUDDER PEDAL POS (deg)
ENG_N1-2 (%)
ENG_N1-3 (%)
ENG_N1-4 (%)
ENG_N1-1 (%)
COMPUTED AIRSPEED (knots)
LONGITUDINAL ACCELERATION (g)
ALTITUDE FINE (feet)
T/R DEPLOYED-4 (1-deployed)
T/R DEPLOYED-3 (1-deployed)
T/R DEPLOYED-2 (1-deployed)
T/R DEPLOYED-1 (1-deployed)
DEPL
UTC (ATC)
05:00:35
05:00:40
05:00:45
05:00:50
05:00:55
05:01:00
05:01:05
05:01:10
05:01:15
05:01:20
05:01:25
05:01:30
05:01:35
05:01:40
05:01:45
05:01:50
05:01:55



RWY	TWY	TORA	TODA	ASDA
05R		2700	2760	3000
05R	A	2475	2535	2775
05R	B	2031	2091	2331
23L		2700	2760	3000
23L	E	2235	2295	2535
05L		2400	2460	2700
05L	Y	2065	2125	2365
05L	B	1720	1780	2020
23R		2400	2460	2700
23R	E	2062	2122	2362
23L	BY-PASS	2500	2560	2800

Accident site overview | Photo: Police

Overview (2) | Photo: Police