Bundesstelle für
Flugunfalluntersuchung

German Federal Bureau of
Aircraft Accident Investigation

Investigation Report

EX005-0/05
July 2010

Identification

Type of Occurence:	Serious Incident
Date:	18 July 2005
Location:	Nuremberg
Aircraft:	Civil Air Transport
Manufacturer / Model :	Embraer / EMB 145
Injuries to Persons:	None
Damage:	Slight Damage to Aircraft
Other Damage:	None
Source of Information:	Investigation by BFU

Factual Information

History of the flight

On 18 July 2005 the Embraer EMB 145 took off from Zurich at 17:30[1] hrs with a crew of three and 16 passengers for a flight to Nuremberg. The departure from Zurich-Kloten was delayed eight minutes by vigorous thunderstorms. During the subsequent climb the aircraft was subject to turbulence and ice accretion.

The approach to Nuremburg was flown through rain showers and turbulence. The crew subsequently reported that they had been prepared for a landing on a wet runway. The approach was flown with 22° of flaps set; in view of the wind conditions they increased the approach speed (VAPP) commensu-rately to 148 kt.

[1] Unless otherwise specified, all times are indicated in local time

The aircraft landed on Nuremberg Airport's rain-swept runway 28 at 18:16 hrs.

The crew reported that braking action failed to bring the aircraft to a stop before the end of the runway. The pilot-in-command was at the controls and steered the aircraft at high speed left into runway exit F, which is at 90° to runway 28. The aircraft ground looped about 200° to the left, leaving the runway tail first and coming to rest with the main landing gear units on the grass.

Aircraft position after the occurrence Photo: Fire-fighter

Air Traffic Controllers in the tower subsequently reported that, prior to touchdown, the aircraft had floated for a greater distance along the runway than was usual. (Appendix 1)

There were no injuries to persons; damage to the aircraft was limited to the landing gear tyres.

The passengers disembarked using the on-board stairs and were transported to the terminal by bus.

Personnel information

Pilot-in-command

The 39 year-old pilot-in-command had a Swiss Air Transport Pilot's Licence (ATPL (A)) issued on 4 March 1999 and valid to 30 June 2010. She was type rated as pilot-in-command on the EMB 135/145 and for CAT III instrument approaches, valid to 4 August 2006. She was further qualified as a Training Instructor and Flight Simulator Instructor.

She qualified as a commercial pilot at the end of 1995 and had been employed by the operator since January 1996. She had a total flight time of 5,545 hours, of which about 2,500 were on Embraer aircraft.

In the previous 24 hours she had a total duty time of about two hours, of which 0:45 hours were flown immediately prior to the incident. In the previous 90 days she had flown about 110 hours. Her rest period prior to the incident was 63 hours.

Her medical certificate was valid on the day of the incident.

On the day of the incident the crew duty time was about 7 hours.

Second Pilot

The 29 year-old second pilot had a JAR Air Transport Pilot's Licence (ATPL(A)) issued in France on 26 September 2003 and valid to 26 September 2008. His co-pilot rating on the Embraer 135/145 was valid to 28 February 2006.

His total flight time was 3,341 hours, of which about 2,905 hours were on the Embraer 145.

In the previous 24 hours he had a total duty time of about two hours, of which 0:45 hours were flown immediately prior to the incident. In the previous 90 days he had flown about 159 hours. His rest period prior to the incident was 39 hours.

His medical certificate was valid to 31 December, with the limitation that spectacles must be worn.

Aircraft information

The aircraft was an EMB 145-LU built in Brazil by Embraer in 2002 with the manufacturer's serial number 145570. The aircraft was powered by two tail-mounted Rolls-Royce engines with no reverse thrust unit. Total operating hours were about 7,800 hours. The aircraft was maintained according to a regular maintenance schedule; the most recent scheduled maintenance was a Check-C undertaken on 13 July 2005.

The aircraft had been registered in Switzerland with the Civil Aviation Authority since 15 March 2002.

The maximum take-off weight was 21.550 kg, and on the day in question was about 17.058 kg. The maximum landing weight was given as 19.300 kg; the landing weight at Nuremberg was 16.000 kg. The computer load sheet indicated the centre of gravity was within the standard range limits.

The aircraft was equipped with an automatic ice warning system. As soon as this system detects the presence of icing conditions, these are reported to the flight crew via the Engine Indication and Crew Alerting System (EICAS); the Stall Protection System then increases speed (SPS/SPEED) by about 5 to 7 kt. This increase in SPS/SPEED is software-governed and cannot be cancelled during the flight.

Flight performance data

The BFU calculated the landing distance requirements based on the following data:

The Nuremberg aerodrome elevation is 1,046 ft. An airport pressure altitude of 1,000 ft was used for the calculation. The air temperature was +18° C and the wind direction was 360°/14 kt, giving a headwind component of about 2 kt. Runway 28 at Nuremberg has an available runway length of 2,700 m. The weight of the landing Embraer was 16.056 kg; the calculation assumed a landing weight of 16.000 kg.

The data used for the determination of the approach speed V_{Ref} were: all-up aircraft weight of 16.000 kg; flaps set for a 9° approach; flaps set 22° for landing using 'After Ice Encounter' settings. This calculation resulted in a V_{Ref} of 126.5 kt IAS (AFM page 5-193).

The input data for the 'Landing Distance Diagram' were: air temperature +18 °C; and airport pressure altitude 1,000 ft. This gave an un-factored landing distance of 1,010 m (AFM pages 5-204 to 5-205) and resulted in the following factored landing distances for a range of different runway conditions (AFN page 5-206): normal dry, 1,700 m (factored 1.67 see JAR-OPS 1.515); normal moist 2,100 m (factored 1.92, see JAR-OPS 1.515 and 1.520). These distances were derived without a correction for higher speed.

In view of the fact that there was no clear information about the runway condition at the time of the

incident, the next step was to investigate operations on contaminated runways (Aircraft Flight Manual (AFM) Supplement 11). The data used were as follows: landing weight 16.000 kg; landing flap setting 22°; speed increment 10 kt IAS; air temperature +18° C; headwind component 2 kt; airport pressure altitude 1,000 ft; runway gradient 0°. For different surface water depths (pages S11-52 and S11-52A), this data resulted in the following un-factorised landing distances:
2,010 m (water depth 3 mm)
1,960 m (water depth 5 mm)
1,790 m (water depth 10 mm)

With factor 1.15 (see JAR-OPS) the results are:
2,312 m (water depth 3 mm)
2,250 m (water depth 5 mm)
2,060 m (water depth 10 mm).

Meteorological information

Prior to their departure from Zurich, the flight crew had all the Nuremberg destination weather information and that for all surrounding airports.

At 20:06 hrs the actual weather for Nuremberg gave: Wind 300 degrees at 16 kt; visibility 5 km; thunderstorm with moderate rain; scattered clouds at 500 ft; scattered cumulus at 2,000 ft; broken cloud cover at 8,000 ft. The temperature was 18° C and QNH about 1,010 hPa.

During the approach to runway 28 a new weather bulletin (ATIS 'R') was broadcast, which was copied by the flight crew. The bulletin gave the wind as 290°/ 28 kt gusting 40 kt. During the approach the aircraft flew through heavy rain and strong turbulence. Shortly before the landing, the Approach Controller passed a message giving the wind as 360°/14 kt.

The Aerodrome Controller subsequently reported that 10 minutes prior to the landing, there had been a heavy rain and a vigorous thunderstorm that crossed the airfield and moved away to the east. The runway was wet at the time of the landing; however, the Aerodrome Controller said that there was no standing water on the runway. Immediately prior to the incident in question, another aircraft landed on the runway and left via taxiway D. The crew of this aircraft made no report about the runway condition.

On 18 July 2005 the German Meteorological Service (DWD) issued a weather warning at 13:16 UTC, valid to 22:00 UTC with the following information: "Thunderstorm approaching from the west with hail of 1-2 cm, wind 260°/25 kt, gusts up to 60 kt."

Aids to navigation

The following navigational aids were available for an approach to Runway 28: Instrument Landing System (ILS) with Middle Marker (MM) and Outer Marker (OM); Non-Directional Beacon Rotenbach (NDB RTB); and Distance Measuring Equipment Nuremberg (DME NGD).

Communications

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

Aerodrome information

Nuremberg Airport's runway is 2,700 m long and 45 m wide. The available runway directions are 099° and 279°. When landing in direction 28, the first 1,768 m are finished in asphalt; the remaining 932 m is concrete. The runway is level.

The airport reference point coordinates are: N 49° 29’ 55,12“ / E 011° 04’ 41;18“; the airport is 1,017 ft above mean sea level.

About 30 minutes after the landing a runway inspection measured the brake coefficient. The measurement protocol was provided to the BFU for evaluation. The braking action was 'good' through-out all three runway sections.

Flight recorders

The aircraft was equipped with a Honeywell Solid State Flight Data Recorder (SSFDR) for 197 parameters for a minimum recording time of 25 hours, and a Honeywell Solid State Cockpit Voice Recorder (SSCVR) with a recording endurance of two hours. Both recorders were in working order and the data were evaluated by the BFU.

Reconstruction of the flight based on Flight Data Recorder evidence (Appendix 2):

- The crew conducted an ILS approach to Runway 28 using the autopilot and in accordance with company procedures. At 500 ft the aircraft was stabilised and in landing configuration.

- The crew switched off the autopilot at a height of 350 ft. The aircraft continued very unevenly down the 3° ILS glideslope, with deviations from the glideslope above and below.

- The aircraft crossed the runway threshold at a height of 54 ft and a speed of 150 kt.
- The reduction in engine turbine speed N1 began at about 110 ft height and on reaching 15 ft had reduced to the minimum power setting of about 27%.
- The aircraft landing gear made contact with the runway 14 seconds after crossing the threshold. At this point, the aircraft had travelled 981 metres from the threshold.
- At first contact with the ground the aircraft had an Indicated Air Speed (IAS) of 130 kt; it touched down two seconds later at a speed of 128 kt.
- At the time of touchdown, the ground spoilers deployed automatically.
- During the subsequent 22 seconds, the brake pressure in the left and right main landing gear increased by 400 to 500 PSI; the braking action was about -0.14 g (1.37 m/s^2), after which reducing to -0.07 g (0.67 m/s^2); the brake pressure fluctuated between zero and 250 PSI.
- 35 seconds after touchdown the brake pressure in the left landing gear increased briefly to 3,000 PSI, while the pressure in the right landing gear remained constant at 3,000 PSI for 7 seconds. The braking action remained at -0.07 g.
- 32 seconds after touchdown and at a speed of 52 kt, the aircraft commenced a 200° ground loop to the left, starting on a heading of 280° and finishing at 080°. At the same time, the ground spoilers retracted.

Wreckage and impact information

Aircraft position on coming to rest Photo: BFU

The aircraft came to rest at the end of the runway about 30 metres south of the runway centreline with the main landing gear on the grass. The aircraft nose was pointed east, opposite to the direction of landing. The landing gear tyres were damaged. Light-coloured brake marks – which looked as if they had been formed by steam cleaning – from the main landing gear were found on the runway. In addition, a large quantity of flaked foam rubber was found on the runway.

Additional information

Observations on Appendix 2:

The aircraft touchdown point was calculated from the ground speed and the delay between the Middle Marker crossing time and the landing gear ground signal time.

The Flight Data Recorder parameter GROUNDSPEED is subject to gross errors at low speed. For this reason, the ground speed was derived by mathematical integration from the acceleration values recorded in the three axes.

Starting point was the Middle Marker crossing time. The distance from the Middle Marker to the runway threshold was 0.6 NM, or 1,111 m. The distance from the Middle Marker to the aircraft touchdown point was 2,092 m.

Analysis

Technical aspects

This aircraft has an automated SPS/SPEED system that raises the speed by about 5 to 7 kt when encountering icing conditions in flight. The associated software does not allow cancellation in flight of the added speed; cancellation is only possible after landing. In other words, this additional airspeed remains even if no further ice is likely to be encountered during the approach. This contributes to a longer landing distance.

Flight data recorder evaluation

The Flight Data Recorder trace showed that the approach to land was very uneven and unstable as a result of strong turbulence. There were sudden variations in speed, and the engine power (N1) required constant correction.

It was apparently quite difficult for the crew to keep the aircraft on the 3° glidesplope; there was deviation from the glideslope both above and below.

The additional speed of 20 kt, applied because of the gusty crosswind on top of V_{Ref} , gave a V_{APP} of 148 kt. This resulted in a longer float phase over the runway and thus unavoidably to a longer landing distance. The headwind component was only 2 kt and gave no reduction in the landing distance.

The low braking action of -0.14 g (the normal value is about -0,3 g) in the first 22 seconds after the landing indicates a wet runway. Nevertheless, the friction was sufficient to impart the rotation required to deploy the ground spoilers.

22 seconds after the landing, braking action was halved to -0,07 g; in all probability, this was the moment at which aquaplaning set in.

The airport

Runway braking action measurements made about 30 minutes after the landing allow few conclusions to be drawn about the runway conditions at the time of the accident.

Section A of the trace – the last one third of the runway – reveals several sudden drops in friction values. These might be the result of smooth areas on the runway. (Appendix 4).

The BFU judges that, during the landing in question, the braking action was medium to poor. Braking action of -0,07 g is comparable with an icy runway.

Air traffic control

A review of the radio communications revealed that the airport had passed the crew no information about the runway condition, other than the wind vector.

An aerodrome operator is obliged to make all information available to Air Traffic Control Services (DFS) that is necessary for the safe conduct of flight operations. Under item 314.23 of the Manual of Operations Air Traffic Control Services (BAFVK) is the note: "It is the responsibility of the aerodrome operator to provide the aerodrome control tower with current information on aerodrome conditions."

Item 221.23 of the BAFVK says that the aerodrome controller's tasks include the following: "to transmit information *required for the safe, orderly and expeditious conduct of flights, such as: - essential aerodrome information."*

Essential aerodrome information is described in more detail under item 314.2:

"Essential aerodrome information is information concerning the condition of the movement area and associated facilities which is necessary for the safe operation of aircraft. It shall be issued whenever deemed necessary by the controller on duty in the interest of safety, or when requested by a pilot. ...."
"It shall include the following information, as appropriate:

Item 314.23: "Snow, slush, ice or water on a runway, a taxiway, or an apron."

Item 314.231: "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."*

Item 314.232: "Pilot reports about the braking action shall be transmitted to approaching aircraft, the

validity of the message shall be taken into consideration."

Given the weather situation, there should have been more frequent runway inspections.

Both, the marks on the runway and the molten tyre rubber on all four wheels of the main landing gear were indicative of a rare type of aquaplaning known as Rubber Reversion Hydroplaning.

Traces of aquaplaning on the tyres

Molten rubber flakes Photos: BFU

This type of aquaplaning can already happen on moist runways. If the wheel rotation should become blocked, the combination of frictional heat and moisture on the runway result in the formation of a steam cushion between the tyre and the runway surface supporting the aircraft. This can occur at speeds below the otherwise usual aquaplaning speeds.

Operational aspects

Landing distance calculations disregard reverse thrust, but this is the sole effective means of speed reduction under aquaplaning conditions. Aircraft landing without reverse thrust under conditions of aquaplaning decelerate only by virtue of the normal airframe drag and rolling resistance. For this reason, the latest runway surface condition is of particular importance. All available information on the runway condition must be obtained and be incorporated in the decision taking process. If the situation is unclear, a diversion or a holding procedure should be an acceptable option.

Landing distance calculation

Because it was not possible to reconstruct the runway surface condition at the time of the landing with absolute certainty, all possible scenarios were taken into consideration when making the landing distance calculation. The runway surface condition seen as being most probable resulted in a landing distance of 2,100 m for a moist surface and 2,312 m for 3 mm depth standing water. The landing distance calculations are based on the assumption that the crew flew the aircraft in accordance with all the required parameters. Given the actual braking distance measured, the BFU concludes that the runway surface was contaminated with water, and that this would have required a landing distance of about 2,312 m. Given that the available runway length was 2,700 m, only about 400 m remained as a reserve.

Given that the approach flown was uneven and unstable; further that the aircraft crossed the threshold 4 ft higher than the target height and that V_{Ref} was about 25 kt faster: it was virtually impossible for the aircraft to arrive on the calculated 1,000 ft touch down point (300 m from the commencement of runway 28) based on the ideal landing profile. The actual touch down point was 981 m further on, reducing the available braking distance by some 600 m. This was insufficient for the aircraft to brake to a full stop on the runway.

Landing technique on contaminated runway or wet runway

If there is any expectation of reduced braking conditions e.g. if the runway surface is wet or contaminated, it is important to adhere to the recommended landing technique (see AOM 1.02.79, page 13).

It is good practice to achieve a 'positive landing'; in other words, to touch down with a deliberate slight bump so that the tyres displace runway surface water when making first contact. The ground spoilers will not deploy unless the wheels rotate at a rate commensurate with at least 25 kt forward speed. A soft landing increases the risk of aquaplaning.

Conclusions

Findings

- Both pilots were in possession of the licences and ratings required for the conduct of the flight. Their total flight time and experience on type was commensurate with the task.
- The aircraft was properly registered and maintained in accordance with the then current regulations and approved procedures.
- The investigation found no evidence of technical defects.
- The Load- and Trim-Sheet demonstrated that both the landing weight and centre of gravity were within the approved limits.
- The aircraft was not equipped with reverse thrust units.
- The approach was flown 20 kt faster than V_{Ref}, with the result that the aircraft crossed the threshold at 150 kt, contributing to an extended flare and float prior to touch down.
- If the aircraft had flown in strict accordance with all the factors incorporated in the landing distance calculation, runway 28 would have been long enough. However, the aircraft touched down after 981 m. Given the then current conditions, the remaining landing distance was inadequate both in theory and in practice.
- Ice was encountered in flight and resulted in an increase in SPS/SPEED. As far as the landing distance is concerned, this is seen by the BFU as a disadvantage, because the software determines that this additional speed cannot be reduced until the aircraft is on the ground again.
- The long flare and float increased the required runway length by about 600 m, and was a considerable factor in overshooting the runway.
- The soft landing on the wet or water-contaminated runway facilitated the development of aquaplaning.
- The assumption can be made that the runway was wet in view of the fact that the braking action was only -0,14 g. The fact that the braking action reduced by a half to -0,07 g in the last one third of the runway can only be explained by aquaplaning.
- The actual runway surface condition was not fully described in the METARs broadcast on the ATIS frequency.
- The airport did not provide the crew with adequate information on the runway surface condition. However, given the current weather situation and the most recent weather reports, they could have deduced the likelihood of reduced braking conditions on a wet runway.
- There were no arrangements in place to maintain a continuous watch on changing runway surface conditions, in a weather situation that could result in very rapid changes to the surface and braking action.

Causes

The cause of the runway overshoot was aquaplaning on a rain-soaked runway surface.

Additional factors were:

- the crew had insufficient information on the actual runway surface condition
- the approach flown was unstable due to gusty wind
- the speed flown was 20 kt above V_{ref}
- the aircraft was above the target height on crossing the runway threshold, and the consequential late touchdown.

Investigator in charge Müller

Assistance Ritschel

Appendices

1. Aerodrome Chart
2. Flight Data Recorder Trace
3. Runway Braking Action Trace

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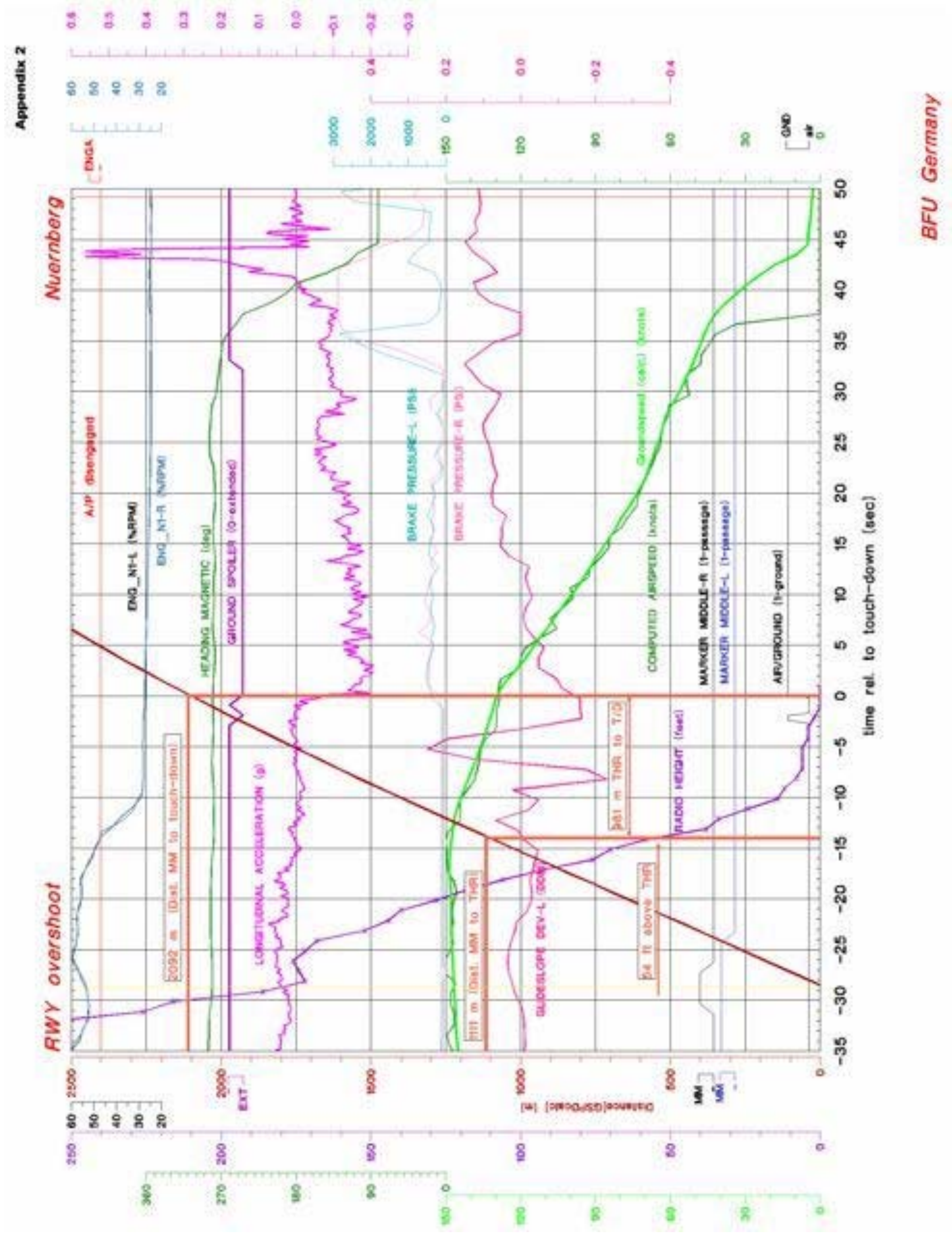
INTERSECTION TAKE-OFF

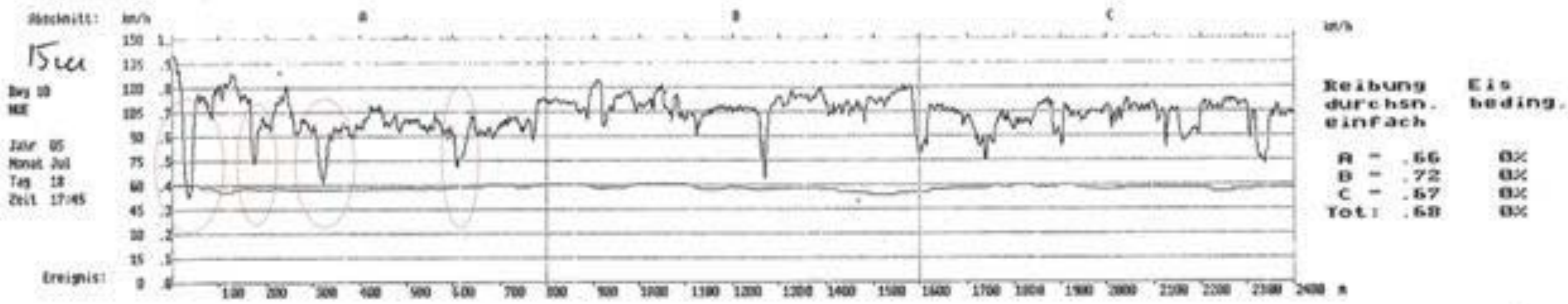
RWY	TWY	TORA	TODA	ASDA
10	E	2300	2360	2300
	D	1900	1960	1900
	C	1450	1510	1450
28	B	1962	2022	1962
	C	1250	1310	1250


Appendix 2
RWY overshoot
Nuernberg
BFU Germany
A/P disengaged
ENG_N1-L (%RPM)
ENG_N1-R (%RPM)
HEADING MAGNETIC (deg)
GROUND SPOILER (0-extended)
LONGITUDINAL ACCELERATION (g)
BRAKE PRESSURE-L (PSI)
BRAKE PRESSURE-R (PSI)
Groundspeed (calc) (knots)
COMPUTED AIRSPEED (knots)
MARKER MIDDLE-R (1-passage)
MARKER MIDDLE-L (1-passage)
AIR/GROUND (1-ground)
RADIO HEIGHT (feet)
GLIDESLOPE DEV-L (DDM)
2092 m (Dist. MM to touch-down)
111 m (Dist. MM to THR)
561 m THR to T/D
54 ft above THR
time rel. to touch-down (sec)

Appendix 3

Braking Action Graph

Landingdirection



Reduced Braking Action in Sector "A"