

# Factual Report

The Investigation Report was written in accordance with para 18 of the Law Relating to the Investigation into Accidents and Incidents Associated with the Operation of Civil Aircraft stating facts only.

## Identification

Type of Occurrence:	Serious incident
Date:	30 September 2005
Location:	East of Frankfurt/Main
Aircraft:	Airplane
Manufacturer / Model:	Boeing / B 737-300
Injuries to Persons:	None
Damage:	None
Other Damage:	None
Information Source:	Investigation by BFU
State File Number:	BFU 5X018-05

## Factual Information

During approach to Frankfurt/Main Airport the airplane was subject to rolling motions; initially 23° to the right and then 62° to the left.

## History of the Flight

The following information was deduced from crew statements, radar and flight data recordings.

The Boeing 737-300 (B737) was on a flight from Turin, Italy, to Frankfurt/Main, Germany. Five crew members and ninety passengers were on board. At 0735 hrs<sup>1</sup> during approach to runway 25L, the airplane succeeded a Boeing 747-400 (B747) on approach to the parallel runway 25R 5 Nautical Miles (NM) ahead. The airplane rolled 23° right and then left with a maximum bank angle of 62°. At the time of the incident the autopilot was engaged, the flaps were extended in position 1 and the airplane had a speed of 200 - 210 kt. The autopilot counteracted the roll to the right. During the subsequent stronger roll to the left, the autopilot was disengaged and the normal flight attitude recovered manually. The approach was continued slightly above the glideslope until a safe landing. The incident occurred in 2,700 ft approximately 9.8 NM prior to the threshold of runway 25L.

## Aircraft Information

The Boeing B737-300 is a transport aircraft in all-metal construction, equipped with two jet engines. It was manufactured in 1990 and had the manufacturer's serial number 24565. The airplane is 33.4 m long and has a wing span of 28.9 m. Maximum take-off mass is 56,470 kg.

The Boeing B747-400 is a transport aircraft in all-metal construction, equipped with four jet engines. It is 70.6 m long and has a wingspan of 64.44 m. Maximum take-off mass is 396,893 kg.

## Meteorological Information

The Deutsche Wetterdienst (German meteorological service provider, DWD) stated, that at the time of the incident the wind velocity in approximately 1,000 m was 280° with 10 to 12 kt. Ground visibility was more than 30 km. The barometric air pressure (QNH) was 1,024 hPa.

## Aids to Navigation

For the approach the Instrument Landing System (ILS) for runway 25L was used.

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<sup>1</sup> All times local, unless otherwise stated.

## Radio Communications

The aircraft was in radio contact with the responsible air traffic control unit. Radio communications were recorded and made available to the BFU as transcript. The information was not relevant for the investigation.

## Aerodrome Information

At the time, Frankfurt/Main Airport had two asphalt runways. The two runways with the orientation 07L/25R and 07R/25L had a length of 4,000 m each. Runway 07R/25L was 45 m wide and runway 07L/25R 60 m wide. A third runway had the direction 18 and was 4,000 m long and 45 wide. It was a concrete runway.

## Flight Recorders

The B737 Flight Data Recorder (FDR) and the radar recordings of both airplanes were available for analysis.

Based on the FDR data, Image 1 (Appendices) depicts the situation prior to and after the disengagement of the B737 autopilot. Initially the airplane rolled 23° to the right and then within 11 seconds 62° to the left.

## Tests and Research

The German Aeronautic and Space Centre (DLR) Institute of Flight Systems participated in the investigation of the serious incident. Based on the available data, the task of the Institute was to verify if the B737 had encountered the wake turbulence of the preceding B747. The analysis was based on the FDR data of the B737, the radar data of both airplanes and the weather data.

First, the flight paths were determined using radar data. The radar positions of both airplanes were recorded every five seconds.

The Images 2 and 3 (Appendices) depict the 3D images of the approach sequence and the flight path above ground. The last 11 NM of the ILS flight path are depicted in black. The significant flight path deviation of the B737 at the beginning of the final approach characterises the place where the serious incident occurred.

The distance between the two airplanes was calculated based on the radar data. At the time the autopilot of the Boeing B737 was disengaged the two airplanes had a

distance of 4.6 NM. At the time the wake turbulence was generated by the preceding airplane (B747) the distance to the succeeding airplane (B737) was approximately 6 NM.

Speed and altitude of the B747 at the time the wake turbulence was generated were determined based on radar data. The altitude in which the wake turbulence was generated and the radar height were equated. The speed was determined by differentiation of the radar positions. The result was that the wake turbulence, which the succeeding B737 encountered, had been generated in 1,000 m at a speed of 90 m/s (175 kt). The speed information was used to determine the initial strength of the wake turbulence. In addition, it was assumed that the B747 had an approach mass of 278 t: Operating Empty Weight (OEW) 180 t, maximum payload 64 t, and fuel 34 t (20% of maximum fuel). In accordance with KUTTA-JOUKOWSKY (describes in aerodynamics the proportionality between dynamic lift and circulation) an initial circulation of  $490 \text{ m}^2/\text{s}$  was calculated based on the approach speed of  $90 \text{ m}^2/\text{s}$ . Using a calculation model the decay of the wake turbulence was calculated for calm atmosphere based on the data available. This resulted in a certain strength of the wake turbulence at a certain age.

Needed were the values for the wind, speed, and direction. The FDR and meteorological data provided them. The FDR data was only available for an altitude of less than 1,300 m and showed a strong variance. In the respective altitudes the FDR data showed high peak values for wind speed and direction. Observations during in-flight tests showed, that these peaks are typical for the generation of wake turbulences and are signs for atmospheric disturbances.

The behaviour of the wake turbulence was simulated based on the radar positions of the preceding B747. The simulation included the data for the decay of the wake turbulence, the drift from the wind data, and the induced descent of the wake turbulence.

Image 4 (Appendices) depicts the 3D image of the flight paths of the two airplanes at the moment the autopilot of the B737 had been disengaged. The wake turbulence of the preceding B747 is marked green. Images 5 and 6 (Appendices) depict the side view and the flight path above ground. The variance of the wind data caused the bumpy course of the wake turbulence graph. A "black diamond" indicates the area of the wake turbulence closest to the succeeding airplane at the time the autopilot was disengaged. The area where the wake turbulence was generated is also marked on the flight path of the preceding B747.

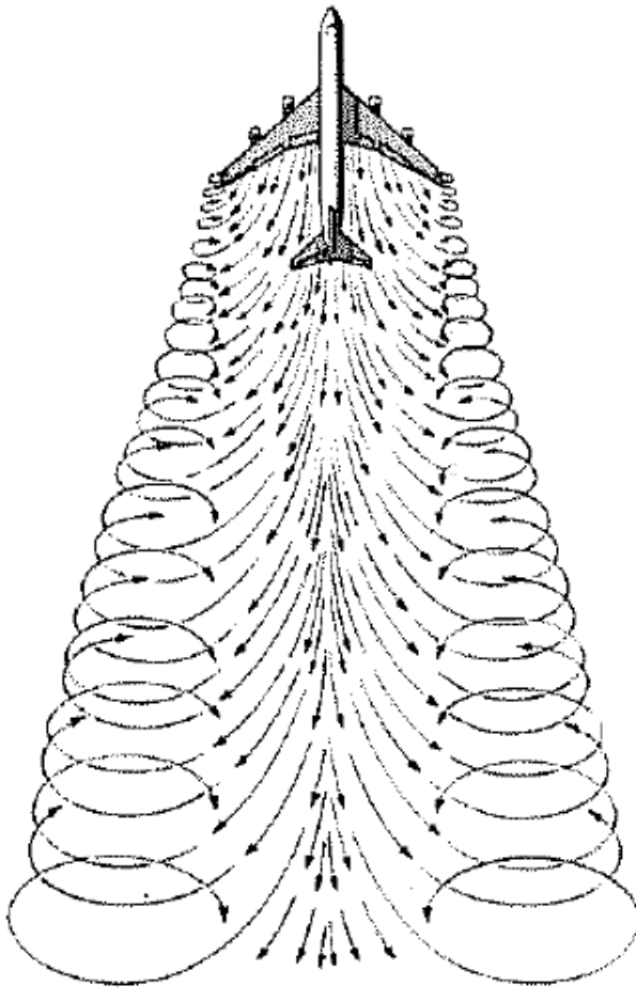
Due to the wind conditions the wake turbulence drifted to the flight path of the B737 approaching the parallel runway. Due to the higher altitude of the B747 (above the ILS) the wake turbulence descended toward the B737 approaching the glideslope below the ILS. Based on the simulation the distance between the wake turbulence and the B737 was estimated as 48 m vertically and 273 m laterally. The resulting circulation of the wake turbulence at an age of 99 s was then 380 m<sup>2</sup>/s. For a category Medium airplane this is strong wake turbulence which can cause this particular reaction if encountered in relevant distance. Based on the layout of the runways, the prevailing wind direction, the estimated distances, and the inaccuracy of the prevailing wind data, it can be assumed that the succeeding airplane had come close to strong wake turbulence or had encountered it.

## Additional Information

### **Wake Turbulence**

Any airplane causes wake turbulences during the flight. They consist of a pair of wake turbulences originating at the wing tips, rotating against each other. The lift is responsible for the generation of the turbulence and the resulting wake turbulence.

The lift is generated by creation of a pressure differential over the wing surfaces. The lowest pressure occurs over the upper wing surface. On the upper wing surface the air flows inward from the wing tip toward the fuselage. The highest pressure therefore occurs in the middle of the wing lower surface. There the air flows outwards from the fuselage toward the wing tip. The resulting circulation and the downwash effect above the wing cause air turbulence at the wing trailing edge which rolls up in a spiral pattern at the wing tip. After the rolling-up is complete the wake turbulence of an airplane consists of two vortexes rotating against each other.



Der Aufrollvorgang

Source: ICAO

The strength of the vortex is determined by the mass, the speed, and the form of the aircraft's wing generating it. The wake characteristic of an aircraft is influenced by extended flaps, and other devices and a change in flight attitude. The main factor is the mass. The intensity of the wake increases with the increase in mass and load factors in the direction of the wing span.

If an aircraft encounters the wake turbulence of a preceding airplane, structural damages can be the result. The real danger, however, is that the induced and irresistible roll and yaw makes the controllability of the airplane much harder. In-flight tests, where an aircraft was intentionally flown into the core of wake turbulence, showed that the airplane has the tendency to roll with the vortex. If the induced roll can be effectively counteracted depends on the wing span and the effectiveness of the manoeuvrability of the affected airplane.

## Aircraft Separation during Approach

Basis for the conduct of air traffic is Document 4444-ATM/501 Air Traffic Management of the International Civil Aviation Organisation (ICAO). It describes the separation of airplanes during approach to an airport in accordance with their Wake Turbulence Category (WTC). Chapter 4.9 Wake Turbulence Categories lists all three categories which are based on the Maximum Take-off Mass (MTOM) of an airplane; Heavy, Medium and Light. There the following stipulations: Heavy (H) - all aircraft with a MTOM of 136 t or more, Medium (M) - all aircraft with a MTOM of less than 136 t but more than 7 t, and Light (L) - all aircraft with a MTOM of 7 t or less.

Chapter 8.7.4 Radar Separation Minima stipulates the following distances between two aircraft:

Succeeding Aircraft	Succeeding		
	HEAVY ≥ 136 t	MEDIUM < 136 t > 7 t	LIGHT ≤ 7 t
HEAVY	7.4 km (4.0 NM)	5.6 km (3.0 NM)	5.6 km (3.0 NM)
MEDIUM	9.3 km (5.0 NM)	5.6 km (3.0 NM)	5.6 km (3.0 NM)
LIGHT	11.1 km (6.0 NM)	9.3 km (5.0 NM)	5.6 km (3.0 NM)

In this case a Medium category airplane succeeded a Heavy category airplane. Therefore the minimum separation was 9.3 km (5.0 NM).

The ICAO Document Air Traffic Services Planning Manual (DOC 9426 - AN/924), Part II, Section 5, Chapter 3 Wake Turbulence states further information in regard to wake turbulences in air traffic.

## Useful or Effective Investigation Techniques

For the simulation of the wake turbulence of the preceding aircraft the P2P Probabilistic Two-Phase WV transport & decay model developed by the DLR was used.

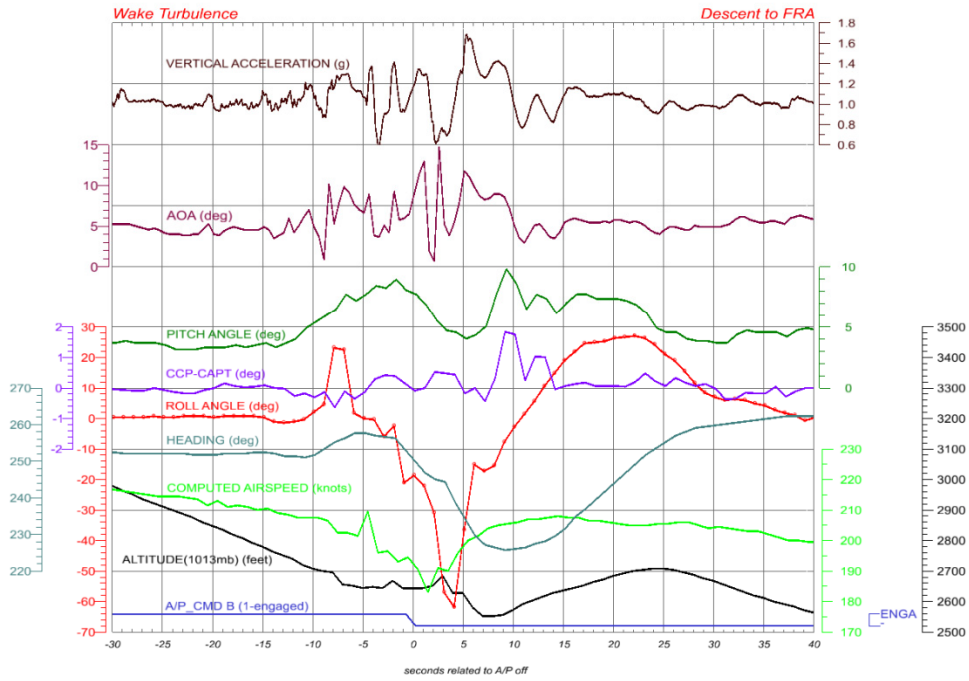
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  Dieter Ritschel  
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Braunschweig, 25 June 2015

## Appendices

Image 1      FDR data B737  
Image 2      3D Flight path overview, B737 following B747  
Image 3      3D Flight path above ground, B737 following B747  
Image 4      3D View of the flight paths and the wake turbulence position  
Image 5      Side view of the glideslope and the wake turbulence position  
Image 6      Flight paths and wake turbulence position above ground





file: pitch\_z

Created: February 12, 2014

BFU Germany

Image 1: FDR-Data B737

Source: BFU

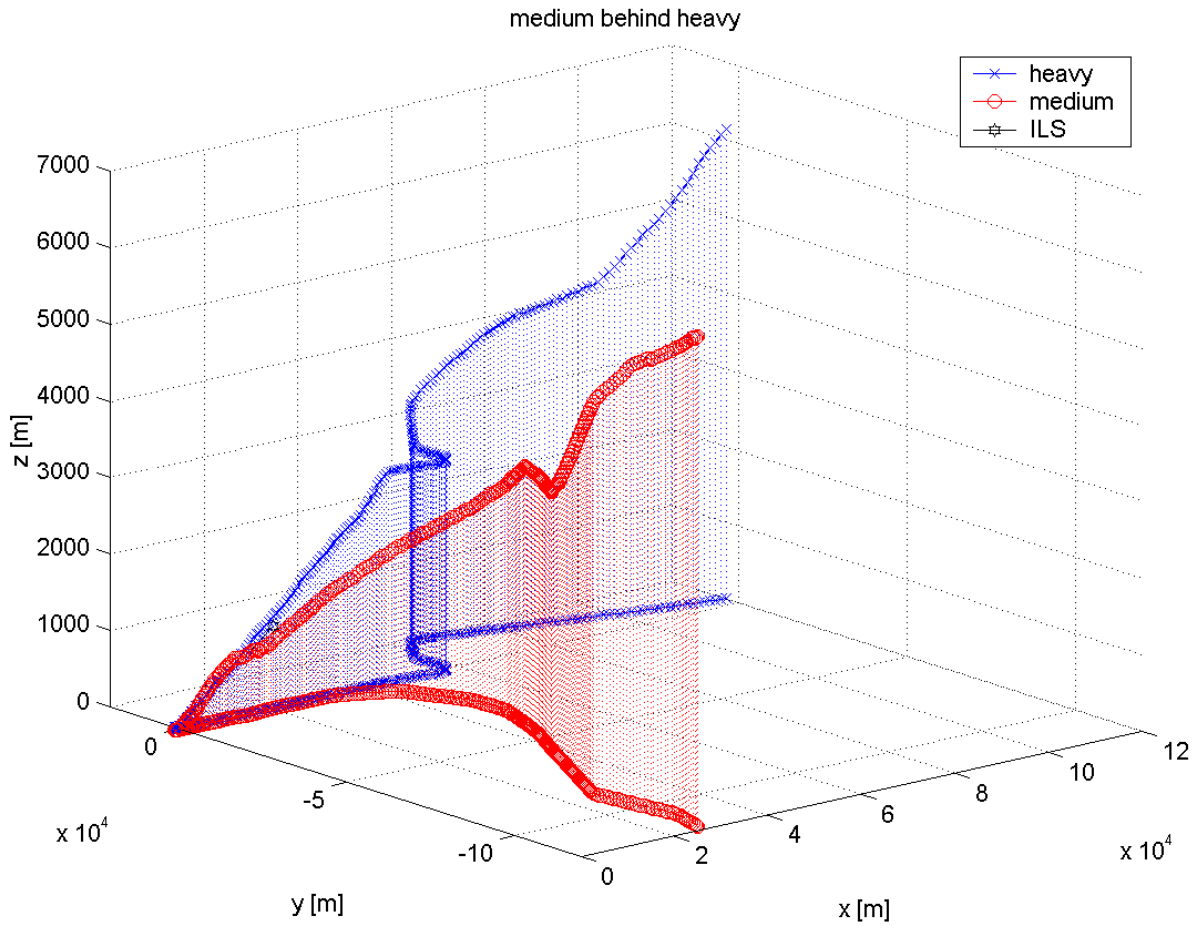


Image 2: 3D Flight path overview, B737 (red o) following B747 (blue x)

Source: DLR

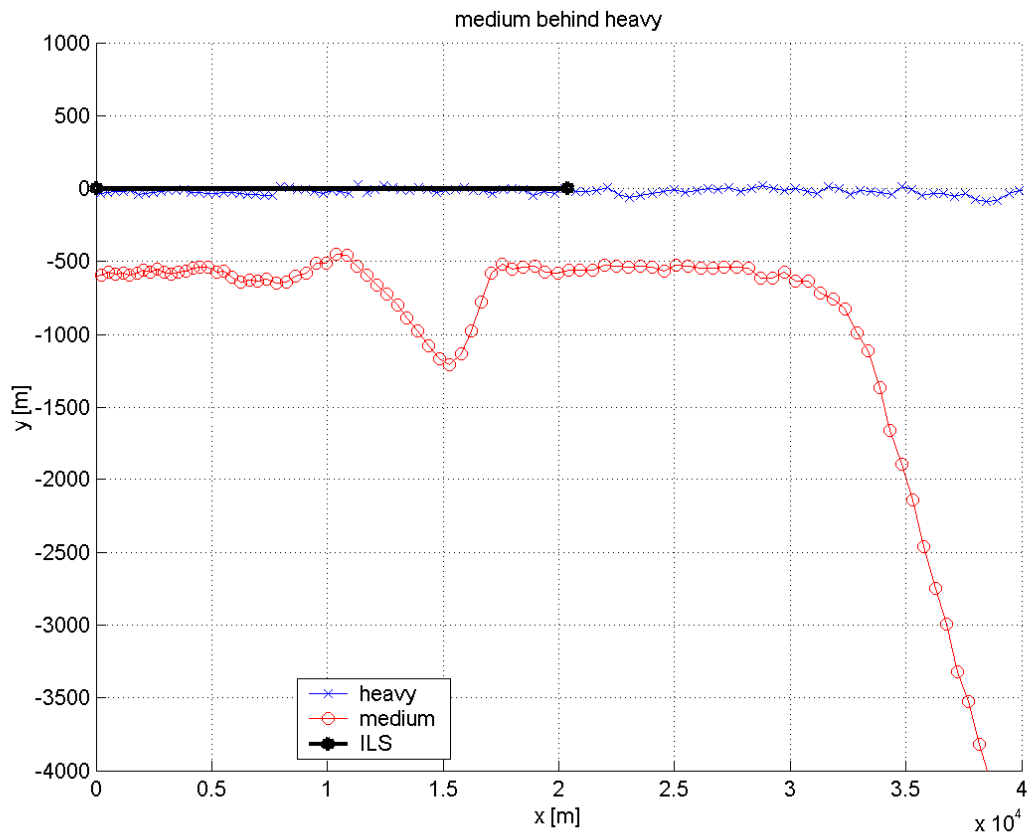


Image 3: Flight path above ground, B737 (o) following B747 (x) (ILS as reference in black)

Source: DLR

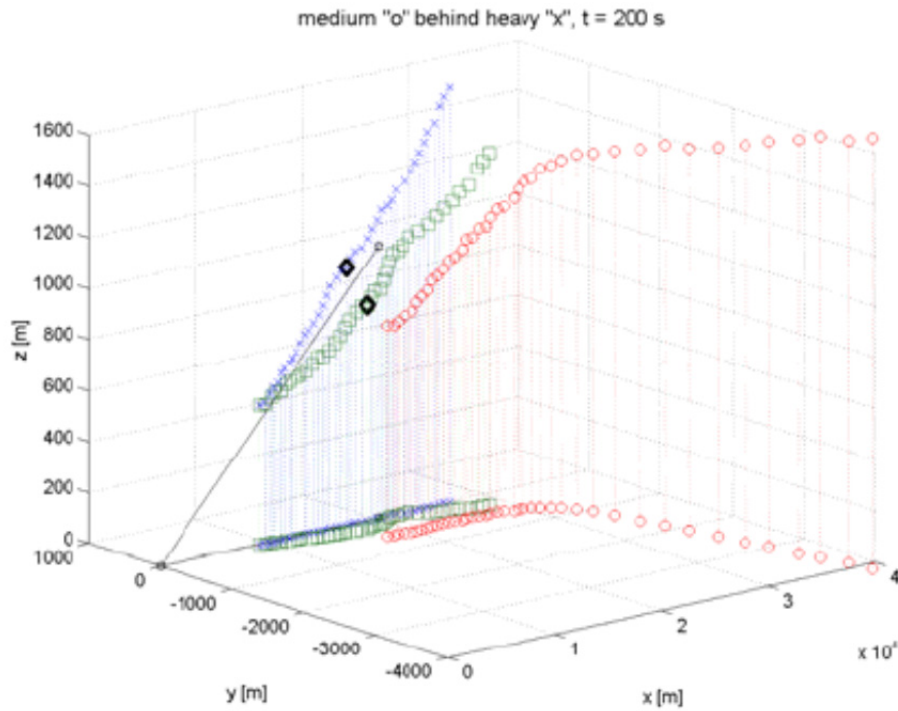


Image 4: 3D View of the flight paths and the wake turbulence position

Source: DLR

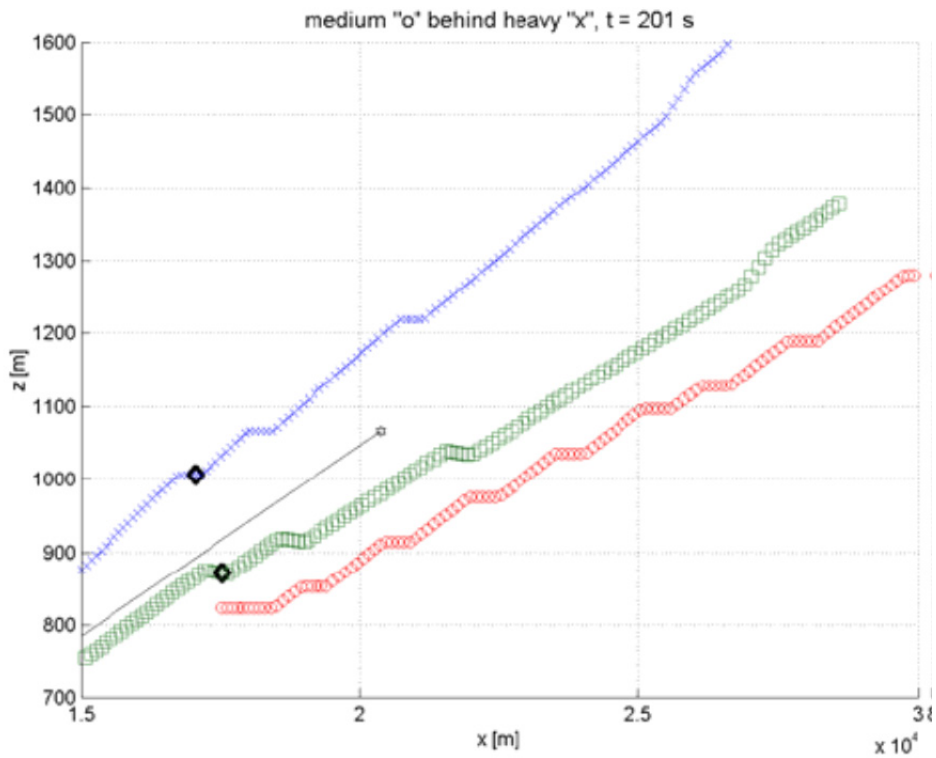


Image 5: Side view glideslopes and wake turbulence position

Source: DLR

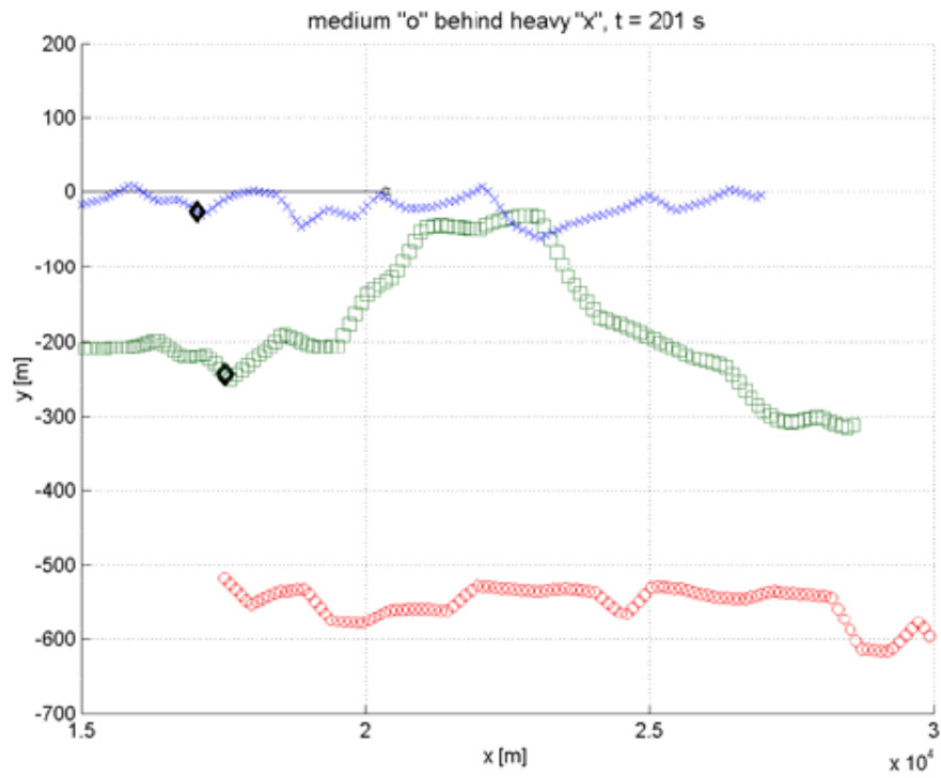


Image 6: Flight paths and wake turbulence position above ground

Source: DLR

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 - FIUUG*) 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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