DUTCH SAFETY BOARD

Cabin crew injured during flight as a result of turbulence

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The Hague, June 2018

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The Dutch Safety Board

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	Dutch Safety Board		
Chairman:	T.H.J. Joustra E.R. Muller M.B.A. van Asselt		
Secretary Director:	C.A.J.F. Verheij		
Visiting address:	Lange Voorhout 9 2514 EA The Hague The Netherlands	Postal address:	PO Box 95404 2509 CK The Hague The Netherlands
Telephone:	+31 (0)70 333 7000		
Website: E-mail:	safetyboard.nl info@safetyboard.nl		

N.B. This report is published in English, a Dutch summary is available. If there is a difference in interpretation between versions, the English text prevails.

INDEX

GLOSSARY OF ABBREVIATIONS

ACARS	Aircraft Communications Addressing and Reporting System
AEMET	Spanish Meteorological Institute
AEP	Aerodrome emergency plan
AIRMET	Airmen's Meteorological Information
ALT	Alternate
ASR	Air safety report
ATC	Air traffic control
ATIS	Automatic terminal information service
ATPL(A)	Airline transport pilot license aircraft
Ca	Cabin attendant
Cb	Cumulonimbus (thunderstorm clouds)
CBT	Computer based traning
CIAIAC	Comisión de Investigación de Accidentes e Incidentes de Aviación Civil (Spanish Air Safety Investigation Agency)
CPL	Commercial pilot license
CSM	Cabin safety manual
CVR	Cockpit voice recorder
dBz	Number of water drops per volume unit
DEP	Departure
DEST	Destination
DSB	Dutch Safety Board
EASA	European Aviation Safety Agency
EFB	Electronic flight bag
EHAM	Amsterdam Airport Schiphol
FCOM	Flight crew operating manual
FCTM	Flight crew training manual
FDA/FOQA	Flight Data Analysis/Flight Operations Quality Assurance
FDR	Flight data recorder
FL	Flight level
FSM	Flight safety manual
Ft	Feet
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFR	Instrument flight rules
ILS	Instrument landing system
IMC	Instrument meteorological conditions
IR(A)	Instrument rating airplane

KNMI	Dutch Meteorological Office
LDW	Landing weight
LECB	Barcelona FIR
LEPA	Palma de Mallorca Airport
LH	Left hand
LPPR	Oporto Airport
METAR	Meteorological Aerodrome Report
MSL	Mean sea level
MTOW	Maximum take-off weight
ND	Navigation display
NM	Nautical mile
NTSB	National Transportation Safety Board (USA)
OM	Operating manual
OPC	Operational planning centre
PA	Public address call
PF	Pilot flying
PM	Pilot monitoring
RPM	Rotations per minute
SIGMET	Significant meteorological message
SOP	Standard operating procedures
SWC	Significant weather chart
TAF	Terminal Aerodrome Forecast
TOW	Take-off weight
U/S	Unserviceable
UTC	Coordinated universal time (Greenwich mean time)

1 FACTUAL INFORMATION

1.1 History of the flight

1.1.1 Notification

On September 24th 2016, the Dutch Safety Board (DSB) was notified by the Spanish Comisión de Investigación de Accidentes e Incidentes de Aviación Civil (CIAIAC) that on September 23rd, at about 15.00 UTC[1], the Dutch registered aircraft PH-HXA had been involved in an accident. This aircraft, a Boeing 737-800, operated by Dutch airline Transavia, encountered unexpected turbulence during the flight from Amsterdam to Palma de Mallorca, which resulted in three cabin attendants being severely injured. The CIAIAC informed the Dutch Safety Board that it would not be launching an investigation as the accident occurred over international waters out of the territory of Spain. The DSB informed the CIAIAC that it will investigate the accident in accordance with Regulation (EU) Nr. 996/2010.

1.1.2 The flight

Transavia flight HV5625 was a scheduled passenger flight from Amsterdam Airport Schiphol (EHAM) to Palma de Mallorca Airport (LEPA) in Spain on September 23rd 2016.

That day, the flight crew was scheduled for three stretches with the same aircraft; first from Amsterdam to Oporto (LPPR) in Portugal and vice versa, followed by the flight to Palma de Mallorca where they would stop over. Flight preparations for all three flights were made between 00.22 and 01.13 that morning by Transavia Dispatch and included, amongst others, weather information for flight HV5625 to Palma later that day. The flight crew reported at 03.10 and started with their flight preparations. At 04.28 PH-HXA took off for the flight to Oporto. The flight was uneventful and the aircraft landed at LPPR at 06.40. In Oporto the flight had a turnaround time of 50 minutes. The return flight was uneventful as well and the aircraft was back on blocks at EHAM at 10.14. Scheduled departure time for the flight to Palma was 11.00, i.e. 46 minutes after arrival in Amsterdam. The expected time of arrival at LEPA was 13.25.

The weather forecast for LEPA at the time of the flight preparation by Dispatch, before the crew reported for duty, mentioned possible thunderstorms at the expected time of arrival[2]. Before departure from Oporto the flight crew received relevant weather information for the return flight to Schiphol. En route the crew extracted the latest weather forecast for LEPA via ACARS[3], which predicted essentially the same

1 All times in this report are UTC unless otherwise specified. Local (Dutch and Spanish) time is UTC + 2.
2 Prob40 TEMPO 2313/2320 4000 TSRA BKN022 SCT 025CB=
3 Aircraft Communications Addressing and Reporting System (ACARS) a digital form of radio communication between aircraft and ground stations.

thunderstorms around the airport. Flight preparation for the flight to Palma was done in the aircraft. Based on the forecast the crew decided to load extra fuel (324 kg) during the stop at Schiphol.

At Schiphol a new cabin crew, consisting of one purser and three cabin attendants, joined the flight crew for the flight to Palma de Mallorca. Regarding the forecast, the cabin crew was notified before departure that some turbulence might be expected during the descent to LEPA. Flight HV5625 departed EHAM at 11.26. On board were two flight crew members, the cabin crew of four and 184 passengers. The captain was pilot flying (PF) and the first officer was pilot monitoring (PM).

Due to the fact that one of the air conditioning systems of the aeroplane was inoperative, it was not permitted to fly above 25.000 ft. Therefore the en route segment of the flight was performed at FL250.

The flight was uneventful until shortly before top of descent towards the airport of Palma de Mallorca. The flight crew visually spotted two thunderstorm clouds (Cb)[4] which were also visible on the first officer's weather radar screen. The captain had no weather radar data displayed at that time on his navigation display (ND). The position of the thunderstorms and their routing was such that they were of the opinion that they could fly between them to waypoint "LORES", where the arrival route to LEPA started.

At 12.49:58 the purser entered the cockpit for a chat. At 12.59:56, the latest landing information of the airport of Palma de Mallorca (ATIS[5] information C) was received via ACARS. The weather information included in this information, indicated thunderstorms in the vicinity of the airport, described as "*cumulonimbus, thunderstorms without precipitation*". This information led to the remark that the descent might be a bit bumpy. The purser responded with the remark that "*basically they were ready*".

At 13.00:51 the first officer asked if he should "*switch the ice on*" which was affirmed by the captain. However, FDR data showed that the anti-ice was not switched on. At 13.01:03 it was noticed that the aircraft picked up some ice and the purser made the remark that some ice accumulated on the windshield wipers.

The flight entered clouds shortly before the aircraft crossed the coastline of the Spanish mainland just south of Gerona, around 13.01, and from that moment on the crew had to rely on their weather radar screens for information about the thunderstorms. At 13.02:17 the purser left the cockpit, some 7 minutes before the occurrence took place. After she had left, the expression "*thunderstorms without precipitation*" was discussed between the flight crew and this led to the remark that it possibly would cause extra turbulence during approach.

4 Cb is the abbreviation of "Cumulonimbus"; a thunderstorm cloud.
5 Automatic Terminal Information Service

Around 13.03 the captain switched on his weather radar screen as well, in automatic mode. The range selected by the captain was 160 NM, and the first officer had 80 NM selected, in manual mode. The DSB was unable to establish the value of the altitude setting of the radar screen of the first officer because he could not remember if or how he changed the altitude settings. Both pilots did not change the gain setting of the weather radar. The distance to the airport was approximately 60 NM at that time. Neither pilot noticed any thunderstorms directly ahead, i.e. in the path of the aircraft, on their weather radar screens. The captain started the crew briefing with information from the EFB[6] and the weather information as received via ACARS. At 13.04, about 5 minutes before the occurrence, the engine anti-ice protection was switched on again. Also the pilots discussed the cold weather operation and concluded that the current track was still good to fly in between the clouds visible on the weather radar.

Two minutes and 25 seconds before the occurrence, the captain switched his range of the ND back to 80 NM. The first officer had done so almost 4 minutes earlier, and now reduced his range further to 40 NM and subsequently, at 1,5 minutes before the occurrence, to 20 NM. No remarks were made between the pilots about thunderstorms or reasons for the range reduction as the crew briefing continued. At 13.08:37, 40 seconds before the occurrence, the first officer interrupted the captains crew briefing and suggested to maneuver clear of a small red return on their radar screens. The captain agreed and started a 30 degrees right turn in two steps from heading 185 to heading 215. The first officer, in the meantime, asked permission for this from ATC. This was granted immediately, and also instructions were given to descend to FL200. At less than 15 seconds before the occurrence, the captain, too, switched the range of his ND to 20 NM and at 13.09:09 he decided to switch on the 'fasten seat belts' sign. As the aircraft turned to the selected heading, a short burst of about 5 seconds of hail was encountered, with associated turbulence lasting 8 to 9 seconds. This happened at 13.09:17, almost 17 NM before waypoint LORES on airway UP84. The flight crew expressed their surprise about the severity of the encountered turbulence, and the captain decided to make a short announcement to the passengers regarding the turbulence.

After the 'fasten seat belts' sign was switched on, the three cabin attendants, who had been seated in the pantry in the back of the aircraft, all stood up; two with the intention to check if the passengers had fastened their seatbelts and one in order to check the pantry for any loose items. At the moment they got up, the aircraft encountered the turbulence. All three were smashed to the ceiling and thrown around the pantry, before falling on the floor. The cabin attendants were not aware of expected turbulence.

6 Electronic Flight Bag; a computer with performance data and airport charts. No meteorological information was available.

The purser was seated in the front pantry when the aircraft encountered the turbulence. She was lifted from her crew seat and landed on her crew seat again. She instructed the passengers immediately to take their seat and to fasten their seatbelts. It turned out that some passengers had not fastened their seatbelts during the turbulence. Some of them were also lifted from their seats and landed back on their seats. When the purser checked whether all passengers did follow the instructions, she was confronted with the situation in the aft pantry.

At 13.11:27 the purser then called the flight crew and told the pilots that "we have three people lying on the floor".[7] Three minutes later the purser called the cockpit again to inform the captain that the three cabin attendants had fallen during the occurrence and were not able to stand anymore. She also told the captain that one of the passengers, a doctor, was attending the injured cabin attendants, and that she needed more time to prepare the cabin for the landing. A minute later the captain informed ATC that the flight had encountered "heavy turbulence" and requested three ambulances upon landing as three cabin attendants were seriously injured.

The captain decided not to declare a mayday message because the purser needed more time to stabilize the situation. During the subsequent descent the flight crew circumnavigated several thunderstorms and asked for delaying vectors even though ATC indicated that they would get priority. Fifteen minutes later ATC asked if they needed only three ambulances or also "a doctor on board". The crew affirmed the three ambulances and the need of a doctor. Two minutes later the purser reported that the cabin was prepared for landing, and that they were ready. At that moment the cockpit crew requested priority for landing and, again, confirmed the need for a doctor. An uneventful landing was made on runway 06L at Palma de Mallorca at 13.41:36.

1.2 Injuries to persons

Injuries	Crew	Passengers	Other
Fatal	-	-	-
Serious	3	-	-
Minor	-	-	-
None	3	184	-
Total	**6**	**184**	**-**

7 Translation from Dutch: "…er liggen er drie op de grond".

1.3 Damage to aircraft

After landing at Palma de Mallorca the aircraft underwent a severe turbulence inspection which revealed no damage. The aircraft returned to EHAM on the next day with only flight crew on board.

1.4 Other damage

None

1.5 Personnel information

1.5.1 Captain

Age	42
Nationality	Dutch
Licence	ATPL(A)
Ratings	B737 300-900, IR(A), valid until 30-04-2017
Medical certificate	Class 1, valid until 08-06-2017
Total flight hours	10.850 hrs
Flight hours on type	9.270 hrs
Flight hours previous 90 days	172:33 hrs
Flight hours previous 30 days	35:57 hrs
Rest before the first flight	14 hrs
Employed since	2001

1.5.2 First officer

Age	23
Nationality	Dutch
Licence	CPL(A)
Ratings	B737 300-900, IR(A), valid until 30-04-2017
Medical certificate	Class 1, valid until 21-03-2017
Total flight hours	535 hrs
Flight hours on type	361 hrs
Flight hours previous 90 days	273 hrs
Flight hours previous 30 days	51 hrs
Rest before the first flight	72 hrs
Employed since	2016

1.5.3 CA1/Purser

Age	36
Nationality	Dutch
Licence	Valid, aircraft type B737-700-800
Medical certificate	Valid until 02-03-2021

1.5.4 CA2

Age	47
Nationality	Dutch
Licence	Valid, aircraft type B737-700-800
Medical certificate	Valid until 26-06-2019

1.5.5 CA3

Age	34
Nationality	Dutch
Licence	Valid, aircraft type B737-700/800
Medical certificate	Valid until 28-05-2020

1.5.6 CA4

Age	23
Nationality	Dutch
Licence	Valid, aircraft type B737-700-800
Medical certificate	Valid until 10-12-2020

1.6 Aircraft information

Make and model	Boeing 737 – 8K2
Serial number	62149
Year of manufacture	2016
Airworthiness Review Certificate	Valid until 01-03-2017
Engines	2 CFM56-7B26E
Weights	TOW: 66565 kg MTOW: 74975 kg LDW: 61194 kg MLDW: 66360 kg
Deferred items	LH air conditioning pack u/s, ultimate repair date 04-10-2016

1.7 Meteorological information

1.7.1 Actual meteorological situation

The Spanish Meteorological Institute AEMET provided the following information.

Overall weather situation

In medium and high levels of the atmosphere, a large low-pressure area was moving from the Atlantic across the Iberian peninsula from west to east. It had several vortices, one in the general vicinity of Cuenca, with a cold anomaly at medium levels of about -16° C, and a trailing wind of about 50 kts pushing the vortex toward the southeast. In these conditions, the area of highest storm activity spread out over much of the eastern peninsula and the Balearic Islands. On the surface, there was a high-pressure area from central Europe to Catalonia, favoring low-level winds from the east throughout the Mediterranean coast and contributing to instability in the area. There were active storms over parts of the Iberian System (see figure 1).

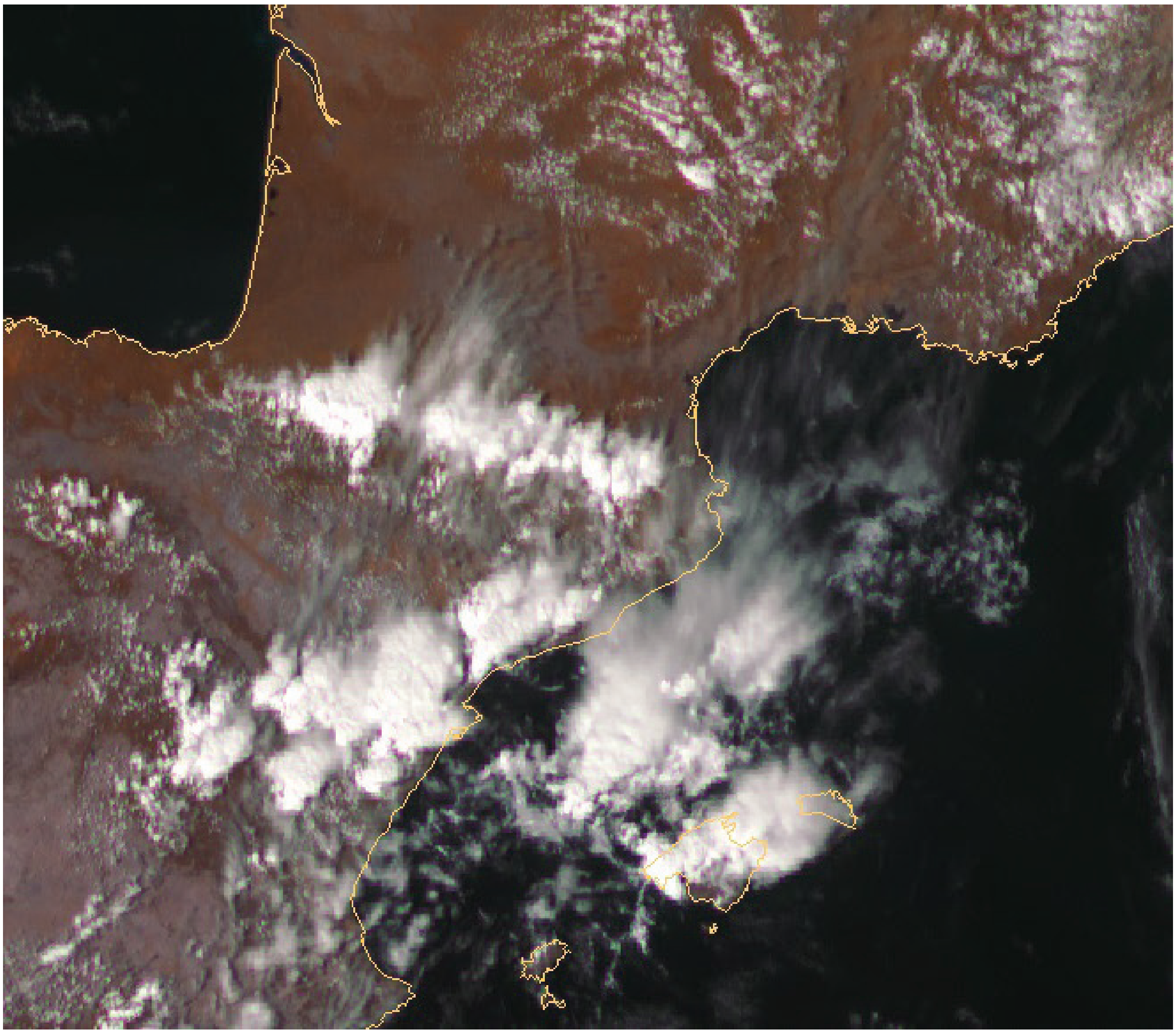


Figure 1: Satelite image of the overall situation on 13.15u. (Source: KNMI)

Weather situation in the area of the accident between 13.00 and 13.30

In the area of the occurrence (located north of the island of Mallorca), storm activity was present both in the hours before and immediately around the time of the occurrence, as shown in the aggregate lightning strike images in figure 2. The radar images show a line of activity north of the Balearic Islands, with the highest intensity returns occurring at around 13.20.

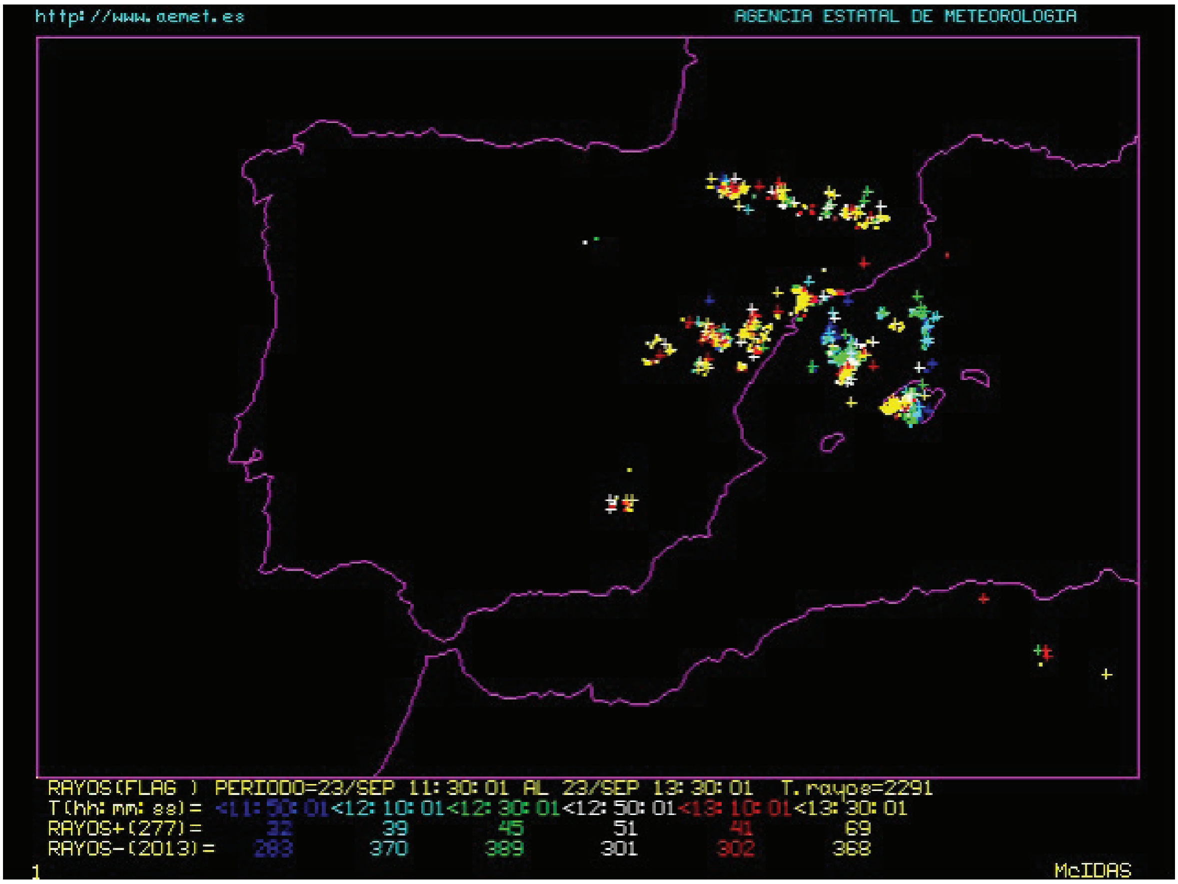


Figure 2: Lightning strikes between 11.50 and 13.30 in the area of the flight. (Source: AEMET)

Figure 3 shows the development of clouds in the area of the occurrence between 13.00 and 13.30 in intervals of 10 minutes. In the middle between the two large areas of clouds, which the flight crew saw, a third cloud was developing quickly (in the red circle). The different colors indicate the number of drops per volume unit (dBz).

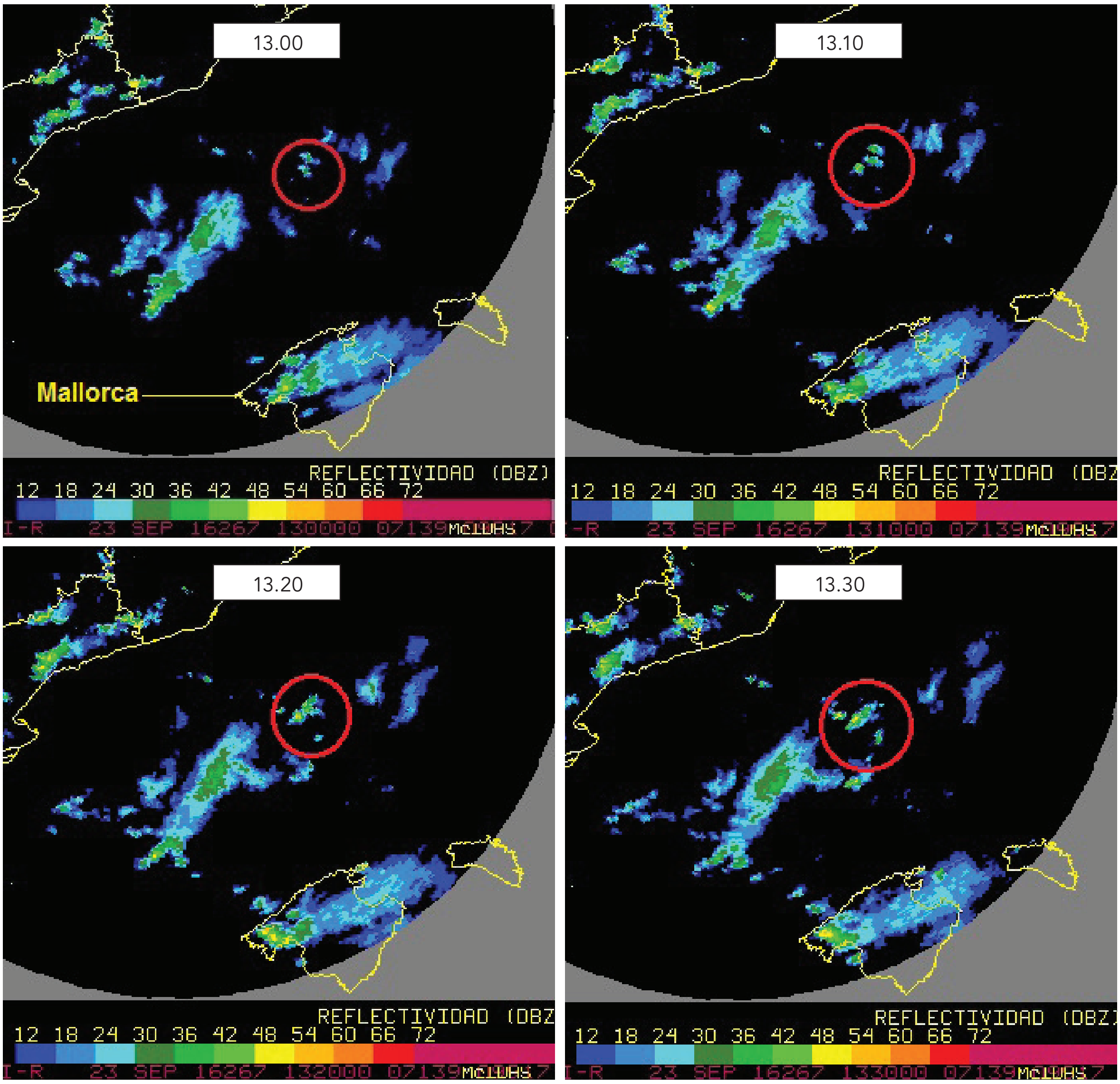


Figure 3: Radar reflectivity in the area of the incident (red circle) for different time stamps showing the development of the clouds. The colours in the bar correspond to the colours on the radar images and the numbers give an indication of the drops per volume unit (dBz). (Source: AEMET)

Figure 4 depicts the airways, waypoints and an overlay of the radar reflectivity around the time of the occurrence at the location of the occurrence. HV5625 followed airway UP84 into LORES.

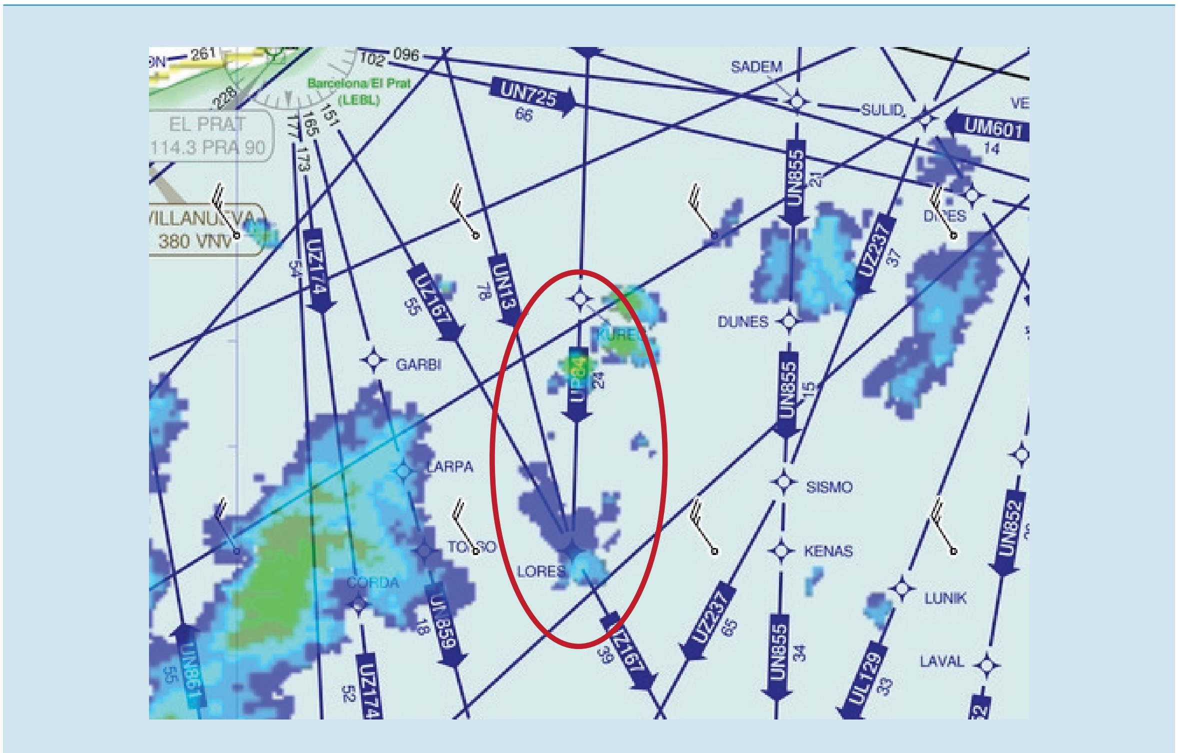


Figure 4: High altitude airways and waypoints together with an overlay of the radar reflectivity at 13.10. (Source: Dutch Safety Board)

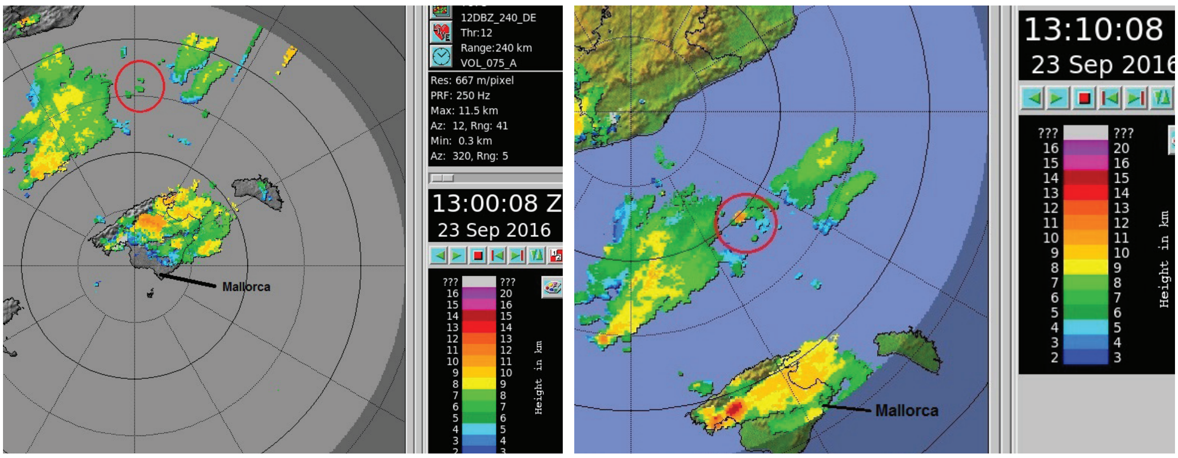


Figure 5: Satellite-derived cloud top height in kilo meters above sea level, at the location of the occurrence at 13.00 and 13.10. (Source: AEMET)

In addition to the radar reflectivity charts, AEMET provided satellite-derived information about cloud top height, shown in figure 5. This information shows that at 13.00 the cloud top height at the location of the occurrence (between KUREG and LORES) was within the 5-7 kilometer range. At 13.10, the cloud top height increased to approximately 10-11 kilometer.

1.7.2 SIGMETS

The following significant weather information applicable to the flight to Palma de Mallorca was issued:

SIGMETs 1 to 6 applicable to the Barcelona FIR (LECB) and valid from 02.30 until 16.00 were issued on 23 September. The first SIGMET (nr. 1) was issued on 02.31. All SIGMETS contained warnings for embedded thunderstorms. SIGMET 4 was issued on 10.09 and valid from 10.08 until 12.00 and valid during the turnaround at EHAM. SIGMET 5, was issued on 11.53 and valid from 12.00 until 14.00 and was valid during the time of the occurrence. The contents of SIGMET 4 and 5 were:

WSSP32 LEMM 231009
LECB SIGMET 4 VALID 231008/231200 LEVA-
LECB BARCELONA FIR/UIR EMBD TS OBS AT 1008Z WI N4030 E00030-
N4140 E00250 - N4020 E00350 - N3940 E00150 TOP FL360 STNR INTSF=

WSSP32 LEMM 231153
LECB SIGMET 5 VALID 231200/231400 LEVA-
LECB BARCELONA FIR/UIR EMBD TS FCST WI N3920 E003 - N4010 W001 - N4240 W00002 - N4120 E00410 TOP FL380 STNR INTSF=

The content of these SIGMETS means: Embedded thunderstorms are observed (SIGMET 4) and forecasted (SIGMET 5) within the defined area with tops up to FL360/380 and intensifying, while remaining stationary.

The area as mentioned in SIGMET 5 is depicted in figure 6.

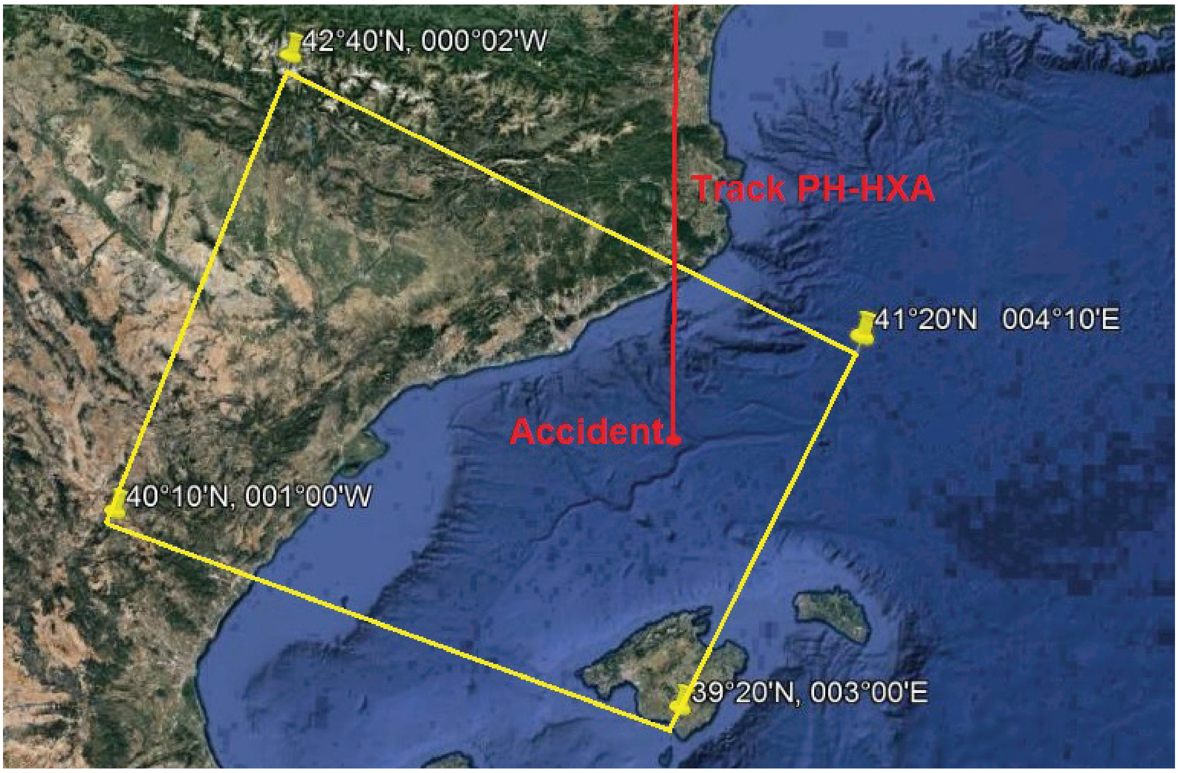


Figure 6: The area with embedded thunderstorms as mentioned in SIGMET 5 and track of PH-HXA. (Source: Dutch Safety Board)

1.7.3 Meteorological information available to the crew

Before and during the flight to Palma de Mallorca, the crew received weather information from different sources.

During flight preparations for the flight to Oporto in the morning, Dispatch provided the crew also with weather information for the flight to Palma de Mallorca, later that day. This information included a Significant Weather Chart (SWC)[8], METAR[9] and TAF[10] of the destination airport and destination alternates. The METAR for Palma de Mallorca Airport (LEPA) was issued 23 September 01.00 and the TAF for LEPA was forecasted for the period between 22 September 23.00 and 23 September 24.00.

Actual:	*230100 VRB01KT 9999 FEW020 20/19 Q1021 NOSIG=*
Forecast:	*222300 2300/2324 04004KT 9999 FEW012 BKN024 TX28/2313Z TN16/2306Z TEMPO 2311/2317 23010KT PROB40 TEMPO 2313/2320 4000 TSRA BKN022 SCT025CB=*
Source:	*Transavia Dispatch 01.13*

The relevant part reads: A probability of 40% of thunderstorms with rain during the period of 13.00 till 20.00 hrs overhead the airport of Palma de Mallorca.

The topics AIRMETS[11] and SIGMETS[12] on the weather briefing stated: 'No WX data available'.

During flight preparations for the flight from Oporto to Amsterdam, the crew received relevant weather information for that flight. It contained information of the origin and destination airports and alternates, and en route weather information. This information also contained a SIGMET warning for the Madrid FIR in which several areas were specified by geographical positions. The planned route from EHAM to LEPA crossed one of these areas. The SIGMET mentioned isolated and embedded thunderstorms and towering cumulus clouds. During the flight, the crew also received weather information of LEPA via ACARS. This information contained the forecast for the next 24 hours and mentioned, amongst others, thunderstorms and rain.

Forecast:	*230600 2306/2406 04004KT 9999 FEW012 BKN024 TX28/2313Z TN17/2306Z TEMPO 2306/2324 FEW025CB TEMPO 2311/2317 23010KT PROB40 TEMPO 2313/2320 4000 TSRA BKN022 SCT025CB=*
Source:	*ACARS 08.25*

8 Significant weather charts present the most important meteorological phenomena particularly relevant for air traffic transport. The charts are issued every six hours (0, 6, 12, 18) and contain forecast valid for the next 12 hours.

9 METAR: Meteorological Aerodrome Report is an aerodrome routine meteorological report containing the actual weather situation on an aerodrome, written in a defined format.

10 TAF: Terminal Aerodrome Forecast is a format for reporting weather forecast information on an aerodrome.

11 AIRMET: Airmen's Meteorological Information is an advise of weather potentially hazardous to all aircraft. It contains (amongst others) the following weather impacted reasons: moderate turbulence and moderate icing. Compared to SIGMETs, AIRMETs cover less severe weather.

12 SIGMET: Significant Meteorological Information is a warning of weather conditions that are potentially hazardous to all aircraft.

During the turnaround at EHAM, the crew did not receive updated weather information for the flight to Palma de Mallorca.

During the flight to Palma the crew also received meteorological information via ACARS about the weather circumstances around Palma de Mallorca Airport, included in the ATIS message C.

> *WIND 060 DEG 15KT MAX 22 MNM 4 KT VRB BTN 050 AND 130 DEG VIS 10 KM OR MORE TS WITHOUT PRECIPITATION CLD FEW 2000 FT FEW CB 2500 FT SCT 3000 FT T 224 DP 16 QNH1024 QFE 1023 NOSIG POSITIVE WIND SHEAR REPORTED IN APCH*
> *Source: ATIS C Palma 12.58*

Furthermore the crew received the actual weather situation at the alternate Menorca via ACARS on 13.03. En route in the Spanish FIR the crew was not informed by any station of the Spanish ATC on the published SIGMETS. No pilot reports were made about significant weather.

That day the crew was provided with two significant weather charts (SWC). The first SWC that the crew received, was included in the flight folder that the crew received from Dispatch at Schiphol before their flight to Oporto. The chart, valid at 12.00, showed that the area of Mallorca was covered with clouds and predicted moderate turbulence from ground to FL250 and moderate icing from FL110 to FL220.

The crew received the second SWC as part of the flight folder for the flight from Oporto to Schiphol. The SWC valid at 18.00 showed a similar, but larger, area that was covered with clouds and predicted moderate turbulence from ground to FL200 and moderate icing from FL110 to FL200.

1.8 Flight data recorders

1.8.1 Flight data recorder

The aircraft was equipped with a solid state flight data recorder (FDR) of the make and model Honeywell HFR5-D. Data from the FDR was successfully downloaded and verified. Relevant data was also used in paragraph 1.1 History of the flight.

1.8.2 FDR data

An overview of the aircraft state parameters together with the selected heading and selected altitude is depicted in figure 7 during time span 13.08:07 to 13.10:17[13].

13 Times indicated in this section are derived from FDR data.

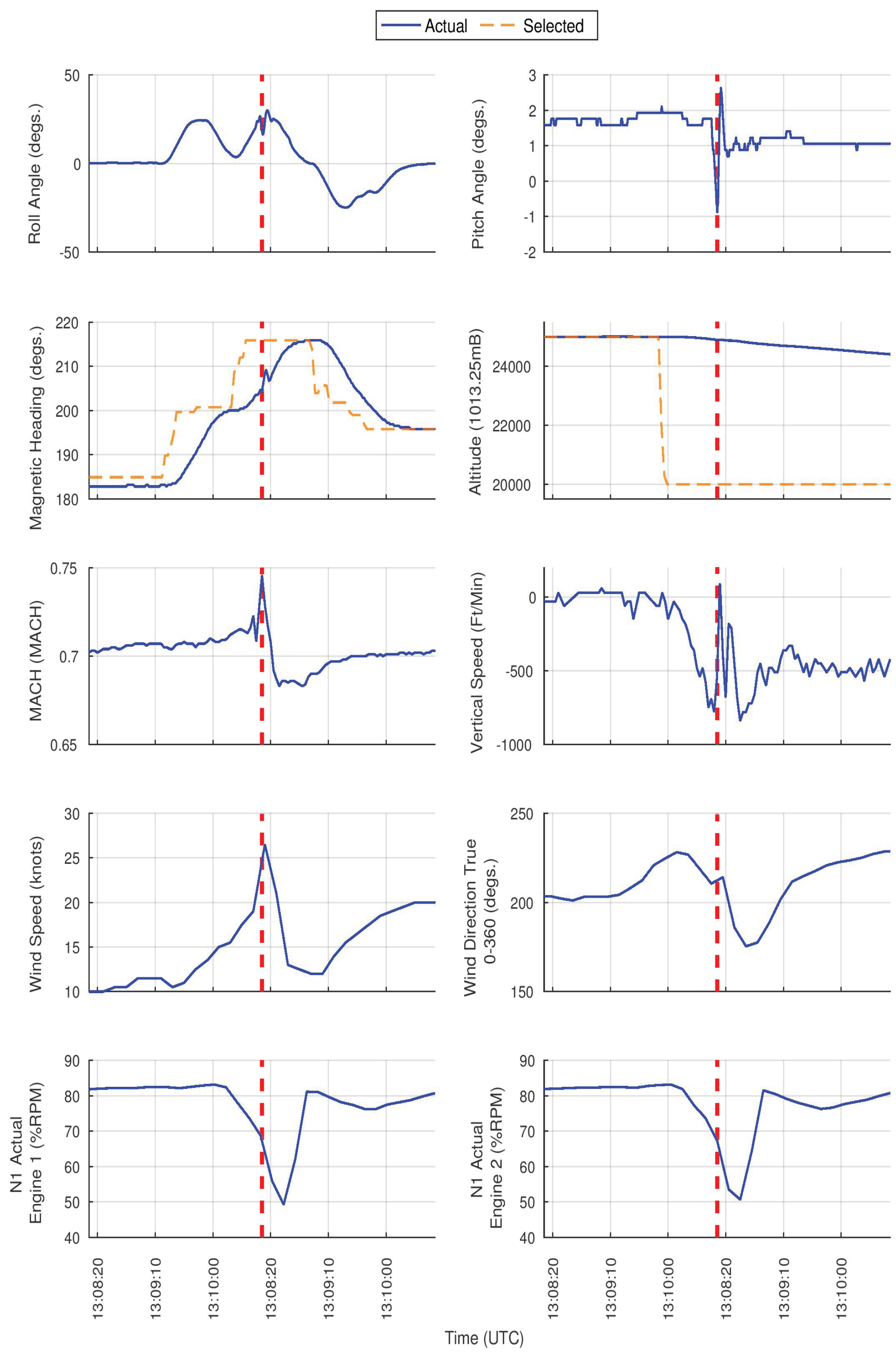


Figure 7: Overview of the aircraft and engine state parameters together with the selected heading and altitude as obtained from the FDR. (The dotted line indicates the moment of the occurrence).

In addition, the (body) accelerations that were measured around the time of the occurrence are shown in figure 8. The accelerations recorded by the FDR were measured by a dedicated accelerometer. In the Boeing 737-800, this measurement device is located on the front bulkhead of the wheel well.

According to the FDR data, at 13.08:20, the aircraft was flying at an altitude of 25.000 ft with zero roll angle and a pitch angle of approximately 1.6 degrees[14]. At that time, the aircraft was flying with a magnetic heading of 183 degrees and a Mach number slightly above 0.7. The observed wind speed was approximately 10 kts with a true heading of 203 degrees. Both engines showed a constant speed (i.e. RPM) of 80% N1.

Earlier, at 13.03:04, the aircraft's selected heading was changed from 182 to 185 degrees. At 13.08:42 another series of heading changes was applied; the selected heading was increased to 201 degrees. This led to a change in roll angle (+24 degrees[15]), followed by a change of the actual heading. Shortly after this heading change, the selected altitude was set at 25.000 ft from 20.000 ft at 13.08:57. Approximately 14 seconds later the selected heading was changed again, to 216 degrees. At that time the aircraft had already started descending: the altitude decreased to 24.955 ft and vertical speed started increasing in magnitude to end up at approximately 750 ft/min.

Moments before the occurrence, the wind speed started picking up from 10 to 15 kts, and later from 15 to 20 kts. Wind direction changed slightly to approximately 220 degrees. Also, the measured Mach number increased to 0.72.

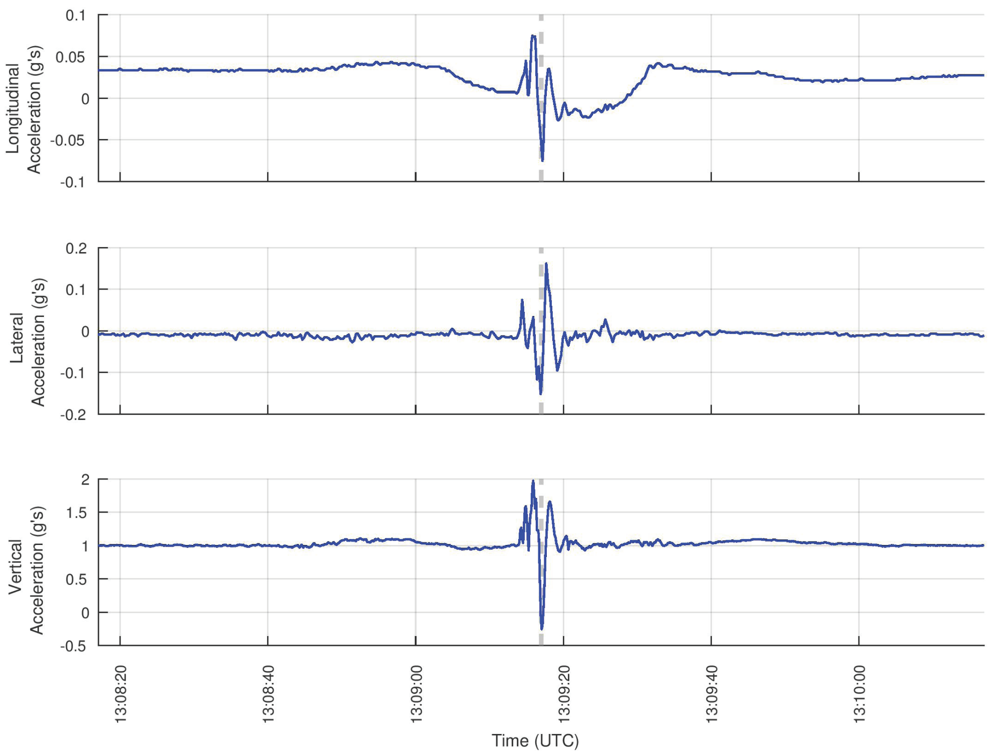


Figure 8: Aircraft (body) accelerations as measured during the incident. (The dotted line indicates the moment of the accident).

14 A nose up pitch is indicated by a positive pitch angle.
15 Note that due to sign convention, a right-hand turn is indicated by a positive roll angle.

According to the FDR data, a series of large peaks in vertical acceleration were observed between 13.09:14 and 13.09:23. Initially, at 13.09:14, vertical acceleration[16] shortly increased to 1.26g[17]. One second later, a vertical acceleration of 1.59g was measured. The largest magnitude peak in vertical acceleration was observed at 13:09:16, with a value of approximately 1.97g. Finally, after momentarily experiencing an upward acceleration (-0.2g at 13:09:17), another large magnitude peak in vertical acceleration with a value of 1.66g was observed at 13.09:18.

During the series of large magnitude peaks in vertical acceleration, a number of peaks were also observed in longitudinal[18] and, more significantly, in lateral[19] acceleration. The lateral acceleration showed recorded values ranging between -0.15g and 0.16g, with the latter peak occurring simultaneously with the 1.66g measurement in vertical direction.

After the first measured peak in vertical acceleration, the pitch angle of the aircraft fell to a minimum value of -0.87 degrees and rose again to a value of 2.63 degrees. After that the pitch angle returned to a steady value of 1 degree. Due to the earlier initiated change in selected heading, the aircraft had a roll angle of approximately 23 degrees. Due to the turbulence, the roll angle first increased to 26.63 degrees, followed by a decrease to 16.57 degrees and again an increase to 29.94 degrees. At the same time, wind speed peaked at an observed value of 26 kts.

After the experienced turbulence, some changes in selected heading were made, gradually changing the heading back to approximately 196 degrees. The Mach number and vertical speed were stabilized again to values of, respectively, 0.7 and -500 ft/min.

16 Note that the vertical acceleration is positive if the aircraft moves downwards. This is due to the definition of the vertical axis, which runs from the aircraft's centre of gravity down, perpendicular to the longitudinal and lateral axes and is positive in downward direction.

17 g is the standard unit for gravitational acceleration and equals an acceleration of approximately 9.81 m/s2 at moderate latitudes.

18 The longitudinal axis, also roll axis, runs from the aircraft's centre of gravity through the nose and is positive in the direction of flight.

19 The lateral axis, also pitch axis, runs from the aircraft's centre of gravity through the wing and is positive in the direction of the right wing.

According to the FDR data, the flight crew changed the weather radar settings several times. Initially the weather information was displayed only on the ND of the first officer; the captain switched on the ND about 5 minutes before the occurrence. Both flight crew changed the range several times. The settings are depicted in figure 9.

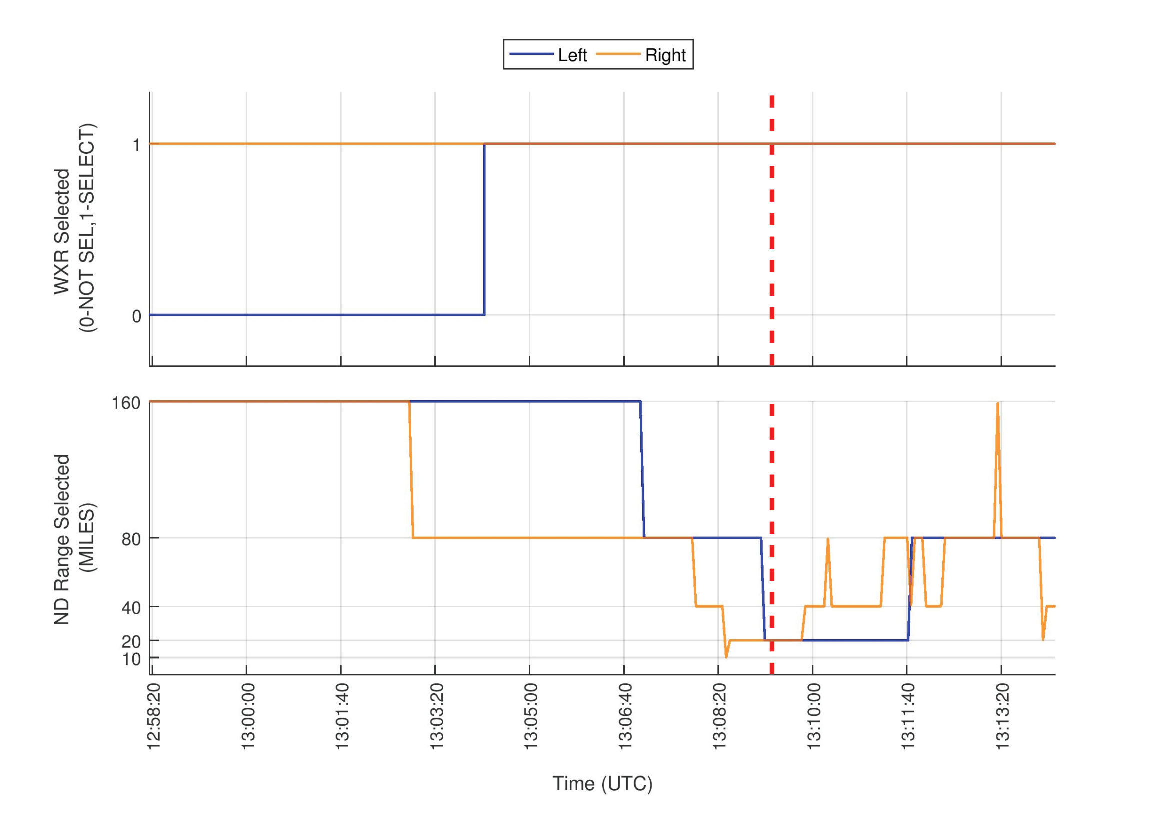


Figure 9: Settings of the weather radar by the flight crew. (The dotted line indicates the moment of the occurrence).

More plots with relevant FDR-data can be found in Appendix B.

1.8.3 Cockpit Voice recorder

The aircraft was equipped with a solid state cockpit voice recorder (CVR) of the make and model Honeywell HFR5-V. Data from the CVR was successfully downloaded. Relevant data from the CVR is used in paragraph 1.1 History of the flight. The recordings did not reveal any aural warnings before, during and after the occurrence.

No warnings or remarks referring to adverse weather or turbulence from other aircraft or ATC were recorded.

1.9 Medical and pathological information

Three from four cabin attendants were seriously injured as a result of the turbulence. After the occurrence they were examined and stabilised by a doctor and two nurses who happened to be on board.

One cabin attendant sustained two fractured vertebrae, a fractured pelvis in five places, a fractured elbow and a fractured pulse bone. The second cabin attendant sustained a fractured vertebra and the third cabin attendant sustained four fractured ribs resulting in lung perforation and a bruised vertebra in the neck. All three were bruised all over their bodies.

1.10 Survival aspects

None of the cabin attendants wore a seatbelt. The purser was sitting on the crew seat in the front galley. The three cabin attendant in the aft galley all stood up from their seats to perform their duties after the seatbelt sign had been turned on.

After the occurrence, at 13.15:20 the flight crew requested via ATC three ambulances and a doctor to be present at the airport after landing. After some clarification by the crew, this request was acknowledged by ATC. After landing at 13.41:36 it turned out that no ambulance was present. After 10 minutes one ambulance appeared, but without a doctor. One injured cabin attendant was taken to hospital by this ambulance. Approximately 15 minutes after the first ambulance, a second ambulance appeared. Eventually, this ambulance took the two other injured cabin attendants to hospital; the third ambulance never arrived, nor did a doctor to assess whether the injured cabin attendants could safely be transported by ambulance.

1.11 Tests and research

1.11.1 Weather Radar

As modern weather radar systems are complex and have many features and possibilities, only the relevant information of the system is described hereafter. The function of airborne weather radar is to allow pilots to identify and avoid potential weather hazards. The radar performs signal processing to estimate the radar reflectivity of the weather ahead.

Weather radar principles and limitations

Weather radar detects droplets of precipitation size. The strength of the radar return (echo) depends on drop size, composition and amount of water. Water particles return almost five times as much signal as ice particles of the same size. See figure 10.

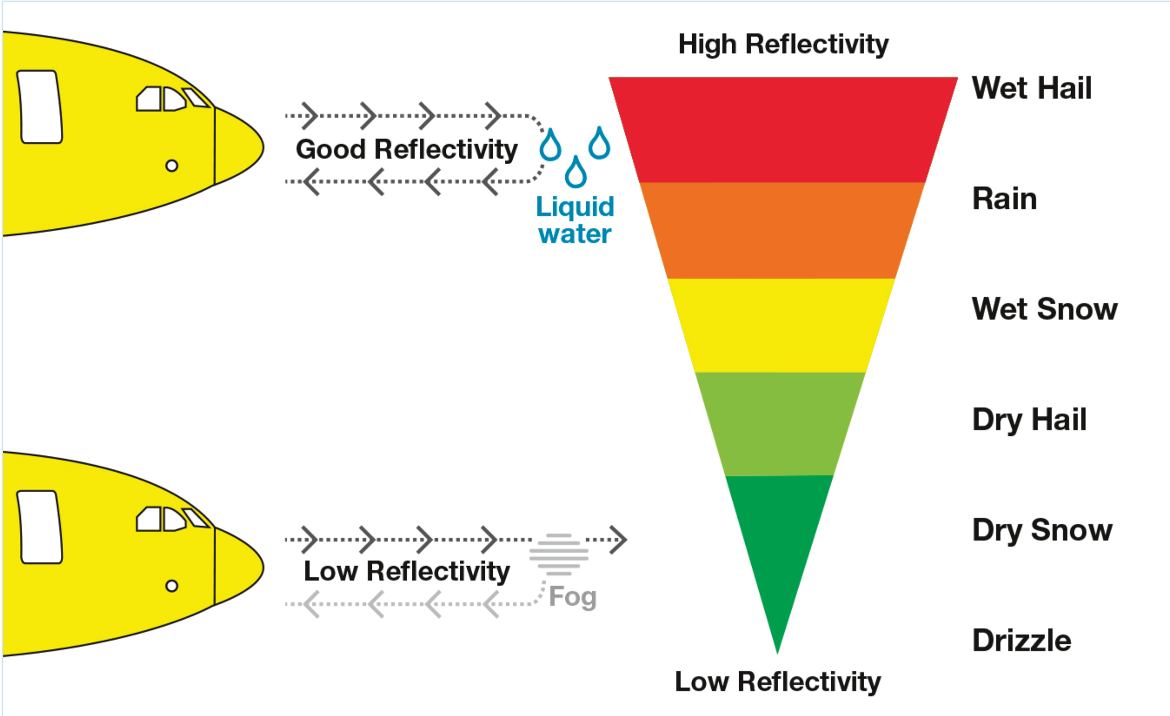


Figure 10: Reflective levels of precipitation (Source: Airbus Safety first magazine)

Clouds, fog, dry hail, ice crystals, volcanic ash and snow are not detected. Clear-air turbulence is also not detected or displayed. Turbulence detection requires the presence of precipitation. Turbulence associated with storm cells (thunderstorms) without precipitation can extend several thousand ft above a storm and outward more than twenty nautical miles, and will not be seen by the weather radar.

Although wet hail is an excellent reflector of radar energy, some hail shafts are extremely small (100 yards or less) and make poor radar targets. If hailstones are cold and dry (dry hail), they give poor returns and might not appear on the display. Reflectivity can be correlated to precipitation rate, and is displayed as green (light), yellow (moderate), and red (heavy) precipitation. The black background is an indication of very light or no returns.

The turbulence mode displays normal precipitation and precipitation associated with turbulence. When the radar detects a horizontal flow of precipitation with velocities of 5 or more meters per second toward or away from the radar antenna, that target display becomes magenta. This magenta area is associated with heavy turbulence. The detection of turbulence is automatically limited to a 40 nautical mile range, regardless of the range selected on the display

The RDR-4000 volumetric scan radar[20]

A volumetric scan radar system differs from a conventional radar system in that it merges different scans at different tilt angles into one synthetic generated total weather picture. The system processes the data to fill the 3D memory and extracts the selected data for display. When operating in the automatic mode, multiple radar scans at pre-selected tilt angles detect short-, mid-, and long-range weather. Tilt and gain inputs are not required. This results in weather detection at all ranges and in all phases of flight. Additional processing ensures data from thunderstorm tops within 5.000 ft of the aircraft remain on the radar display until they no longer pose a danger, thus enabling flying around thunderstorms that may not be visible otherwise.

Weather targets are color-coded based on the intensity of the return. The display correlation to reflectivity and approximate rainfall is as follows:

Colour	Returns	Reflectivity	Rainfall rate
Black	Very light or none	Less than 20 dBz	Less than 0.7 mm (0.028 in) /hr
Green	Light	20 – 30 dBz	0.7 – 4 mm (0.028 – 0.16 in) /hr
Yellow	Medium	30 – 40 dBz	4 – 12 mm (0.16 – 0.47 in) /hr
Red	Strong	40 dBz or greater	Greater than 12 mm (0.47 in) /hr
Magenta	Turbulence	N/A	N/A

Table 1: Correlation to color and reflectivity and rainfall rate (Source: Pilots guide Honeywell RDR-4000)

The Electronic Flight Display and control panel(s) are devices where the radar mode or status, weather returns, wind shear, turbulence, and ground map data are displayed and selected. The control panel contains means to select automatic mode or manual mode with altitude setting and gain (sensitivity) parameters. The control panel is split into two identical halves to enable both pilots to select any weather display views independently.

Figure 11: Control panel of the RDR-4000 (Source: Pilots guide Honeywell RDR-4000)

20 Source: Pilot's guide Honeywell RDR-4000.

MAP – MAP mode provides an extended ground map picture by piecing together individual scans and combining them in the memory for display. The ground map is generated automatically and simultaneously with weather.

AUTO - Automatic weather mode provides weather, turbulence, and predictive wind shear detection. Weather targets are color-coded by the intensity of the return. The flight path weather that fills the 3D memory is the detected weather in front of the aircraft out to 320 NM, and from ground level up to 60,000 ft mean sea level (MSL). In AUTO mode, weather that is far above or below the aircraft's flight path is displayed in a different pattern than "flight path weather".

MAN – Manual weather mode provides a means to assess storm cell height and development by providing selectable altitude slices. These slices from the 3D memory are corrected for the curvature of the earth, providing a view at a constant MSL altitude level. Selecting MAN on the mode selection knob enters the manual mode. Upon initial selection, the altitude slice is set to the current aircraft altitude (nearest 1000 ft). The altitude (ALT) knob is used to select the desired altitude slice from 0 to 60,000 ft MSL in 1,000 foot intervals. Turbulence information is removed in MAN mode to enhance analysis of weather reflectivity. Selected altitude is shown on the Electronic Flight Display.

GAIN - Manual – Rotating knob out of CAL varies gain between MIN and MAX. The MIN position reduces gain approximately 16 dBz below the CAL setting. The MAX position increases gain 10 dBz over the CAL setting.

1.12 Organizational and management information

1.12.1 Introduction of a new weather radar system.

With the delivery of the new B737-800 PH-HSW on 28 April 2009, a new type of weather radar was introduced in the fleet of the operator; the Honeywell RDR-4000 volumetric scan weather radar. This type of weather radar was a new generation of 3D automatic weather radar system which scans the entire sky in front of the aircraft. The old RDR 4 radar remained also in service, and is still found in approximately 50% of the fleet.

1.12.2 Information from Honeywell

The Honeywell IntuVue RDR-4000 weather radar was first certified on the B737NG (-600, -700,-800 & -900) aircraft in July 2008. Honeywell issued Pilots Guide Rev. 2 in November 2008. In October 2009 a PowerPoint training module "RDR-4000 Radar Training" was distributed to the users. Honeywell also issued a PowerPoint presentation on the subject of a RDR-4000 technology Roadmap in June 2011. A Computer Based Training (CBT) module called: "RDR-4000 IntuVue Weather Radar Pilot Training for Boeing Aircraft" aid was made available, dated July 2013.

1.12.3 Weather radar training of pilots

Initially the training in Transavia had to be conducted by self-study of the relevant chapters in the FCOM with the help of an associated Cockpit Bulletin and a Pilot's Guide on the RDR-4000 weather radar, at the time of introduction of the PH-HSW in April 2009.

In winter 2009/2010 a technical recurrent training was given to all pilots. One of the topics, amongst others, was the Honeywell RDR-4000 multiscan weather radar. In winter 2013/2014 the RDR4000 was for the second time one of the topics during the technical recurrent training. During line training the weather radar is hands on discussed on day 4 of the line training. Since the operator has been using two different models of weather radar in its aircraft, it depends on the installed model if the RDR4000 is discussed. In simulator training the RDR 4 model is used, as this is the model installed

1.12.4 Reported problems with the multi scan weather radar.

Soon after the introduction in service of PH-HSW, the airline's flight operations department started receiving questions about the RDR-4000 and complaints regarding the (in)correct functioning of the weather radar. The first air safety report on this subject dates from August 2009. From its introduction onwards, pilots were able to ask questions to the technical pilot, who received several questions regarding the correct functioning and how to operate certain features.

These reports and questions can be summarized as follows:

- Weather information suddenly disappears from the radar image when closing in on the weather system displayed on the navigation display;
- Weather radar shows significant weather, but when looking outside, the sky is clear;
- At very low altitudes, significant weather is present in the area, but not shown on the weather radar.

As a result a notice from the technical pilot to all operator's pilots was issued in November 2009, which explained actions and feedback on reports of possible false presentations on the weather radar.

In another notice of November 2010 the engineering department reported to the pilots: "It's noted by engineering that there are a lot of write ups by pilots regarding the RDR-4000 WXR system in the last months. The RDR-4000 weather radar system is installed in the aircrafts which are delivered from 2009 (YC095-YF803). In a meeting between Transavia engineering and a Honeywell design engineer, we discussed the different issues which Transavia experienced with the RDR-4000 WXR system."

On September 26th, 2014 an official Information Bulletin, IB/14/013, from Flight Operations was issued with the subject: "Weather radar – Limitations and Amplified operating procedures". It states:"*This information bulletin serves to provide flight crew with essential background information of both weather radars (RDR-4000, RDR-4B) currently in use with transavia.com. Basic principles, operational limitations of WXR's in general and observations by flight crew are described in-depth and with the relevant technical information. If after reading this IB any questions arise they can be directed to the technical pilots." …"The motivation of this information bulletin is because several reports and questions about the RDR-4000 have been received by flight operations.*"

The operator sought support and technical advice from Honeywell on all reported matters, trying to establish the nature of the reported problems, i.e. whether the problems were caused by the device or by handling of the RDR-4000 radar.

1.12.5 Response by Honeywell to reported problems

In 2009 approximately 10 reports were received from Transavia by Honeywell about problems with radar returns. Honeywell analysed these problems and together with Transavia it was concluded that some issues were to be corrected by further modifications, and other issues were due to sub-optimal handling of the RDR-4000 radar by pilots. By mid-2011 an update became available that solved many of the outstanding issues. Honeywell continued to improve its radar with updates on algorithms and hardware as well, with help from operators.

From the time of introduction in 2009 until September 2016, 29 air safety reports (ASR's) were filed by Transavia pilots regarding presentation problems with the Honeywell RDR-4000 weather radar. The first 16 ASR's were written in the first 2 years, i.e. between May 2009 and September 2011. Other operators reported problems as well. These reports indicated similar problems as the problems that were encountered by Transavia crews.

When asked for comment, Honeywell emphasized that weather radar systems have functional limitations which are mentioned in the manual. Because the strength of the radar return depends on drop size, composition and amount of water, clouds containing relatively little humidity will give low radar returns. Most of the reports referring to the functioning of the RDR-4000 could be attributed to a reduced understanding of the limitations of the weather radar, according to Honeywell. Honeywell stated that it might be possible that in this case the late appearance of the Cb on the radar screen was caused by a combination of a fast growing cell containing low humidity.

Transavia safety department still receives informal reports about the RDR-4000 weather radar.

1.12.6 Reported problems with the volumetric scan weather radar by other operators

The investigation showed that other operators also received ASR's in relation to the functioning of next generation weather radars from their flight crews. The main problem encountered, was the same problem as the one that caused the occurrence under consideration: present significant weather was not, or very late shown on the weather radar. No defects on the weather radars were found and the reported troubles were attributed in general to overrating the auto mode capabilities of the weather radar and non-optimal use of the weather radar system.

1.12.7 Airline manuals regarding turbulence

Airline Operating Manuals (OM) consist of several parts: part A is a publication by the operator based on the requirements of the regulator. It deals with general, and airline specific, aspects of operating their aircraft. Type specific instructions are found in OM part B, the Flight Crew Operating Manual (FCOM).

Transavia procedures referring to turbulence in OM part A and B are mainly directed at warning and preparing the cabin crew and passengers for the effects of anticipated turbulence by switching on the 'fasten seat belts' sign, and trying to avoid area's with thunderstorms.

As the OM part A and B are mainly intended for flight crews, a separate Flight Safety Manual (FSM) or Cabin Safety Manual (CSM) is issued by the airlines for use by the cabin crew. Turbulence procedures in the CSM for the cabin crew deal mainly with preparations such as stowing and securing equipment, galleys and loose baggage. When the 'fasten seat belt' sign is switched on, the cabin crew is instructed to check if passengers are seated with their seat belts fastened and to ensure that all equipment not being used and loose baggage is properly secured. The manuals do not contain any procedures aimed at ensuring the personal safety of the cabin crew.

The commander decides when the cabin crew shall be seated. This will be communicated by the commander or purser. In that case the cabin crew shall discontinue service, secure all remaining equipment and galleys, be seated as soon as possible and fasten their seat belts.

Neither the OM, nor the CSM of Transavia mentions procedures in situations of unpredicted turbulence.

1.12.8 IATA Guidance on Turbulence Management

The International Air Transport Association (IATA) has compiled a "Guidance on turbulence management". This publication is aimed at giving tools to airlines for developing turbulence management[21] procedures and strategies to prevent turbulence injuries. Relevant items from this guidance are mentioned below.

The IATA report states:

- *Turbulence is the leading cause of injury in non-fatal accidents*
- *Turbulence accidents accounted for 13% of the total accidents reported in 2014 "Cabin crew members are injured due to turbulence at a disproportionate rate compared to passengers. Cabin crew injuries occur at a higher rate as their duties require them to be standing and moving about in the passenger cabin and/or galleys, unseated and therefore not always secure with their seat belt during flight. Cruise is the predominant phase associated with turbulence-related injuries. However, cabin crew members also sustain physical harm during climb, descent and approach."*

Another important point is considered to be the establishment of Standard Operating Procedures (SOPs) for various segments of flight with regard to anticipated and unanticipated turbulence. On that, the guidance publication states:

> ***8.3 SOPs for Cruise***
> *At all times during turbulence and especially during moderate levels and above, the most appropriate response for cabin crew is self-preservation. The cabin crew should be informed of routine turbulence and if the cabin crew experience uncomfortable turbulence without notification from the flight crew, they should secure themselves in their seats and inform the flight crew.*

21 http://www.iata.org/whatwedo/safety/Documents/IATA-Guidance-on-Turbulence-Management.pdf

8.3.3 SOPs for unanticipated turbulence

If there is sudden moderate to severe, unanticipated or imminent turbulence requiring immediate action, the flight crew will switch on the fasten seat belt sign. The flight crew will make a standard PA (as per their SOPs) such as: "All passengers and crew please fasten your seat belts immediately". Immediately is the key word that communicates the urgency of the situation to the cabin crew. The cabin crew must cease all duties, secure themselves in the first available seat and remain seated until advised by the flight crew or until the fasten seat belt sign is switched off. Compliance checks should only be performed and items secured if this presents no delay in securing themselves in a seat.

The above mentioned examples of SOP's, show that self-preservation of cabin staff is paramount in order to reduce and avoid injuries to cabin staff, and procedures are put in place to address the different levels of turbulence.

1.12.9 Establishment of Route Charts

According to "IATA guidance on turbulence management[22] "airlines can raise awareness of turbulence encounters on particular routes in their network. An airlines' flight data department can gather statistics to determine the specific zones and periods of the year where more turbulence events occurred, with this information airlines can adapt their procedures accordingly. Airlines can issue such information to crews and they can discuss it during pre-flight briefings. Making cabin crew alert to the probability that turbulence could be encountered will help them be more prepared and safety-minded during their duties throughout the flight and could help them manage cabin activities in a more efficient manner." Below a relevant line of the route chart matrix in the report.

Europe	Summer/Autumn	Mediterranean Sea	Thunderstorm/WS

The Mediterranean sea is mentioned in summer and autumn as an area where thunderstorms may cause significant turbulence.

1.12.10 Turbulence management by other operators

Flight Crew Operating Manuals of a number of other operators with regard to turbulence and cabin safety were studied, showing that all airlines have more or less the same procedures for anticipated turbulence. Most, but not all, airlines have procedures that, to a greater or lesser extent, address the "immediate" aspect of actions to be taken in the case of unanticipated moderate to severe turbulence.

1.12.11 Similar events

Over the years several similar serious incidents and accidents have occurred. The latest, known to the DSB, occurred at 4 June 2017 in the descent to Hong Kong International Airport. Another similar accident occurred in the same region at 23 June 2014. In all these cases unexpected turbulence was encountered and passengers and cabin crew were (severely) injured because they were not seated with their seatbelts fastened.

22 https://www.iata.org/whatwedo/safety/Documents/IATA-Guidance-on-Turbulence-Management.pdf

Although it is very difficult to retrieve a complete survey of all turbulence related occurrences, some data was found:

- The National Transportation Safety Board (NTSB) published an overview of turbulence related incident and accidents in the USA. Between 1998 and 2013 432 occurrences in commercial aviation (air carriers) were counted, resulting in 225 serious injuries[23] and 1109 minor injuries.
- The IATA STEADES Safety Trend Analysis report[24] states that: "during the year 2003, 128 incidents were reported regarding turbulence-related injuries sustained by cabin crew. 39% of those injuries took place when the cabin crew performed safety-related duties like securing service equipment in the galley or while verifying that the passengers were safely fastened in their seats.

1.12.12 Weather information provision Transavia

Flight Preparation Instructions are described in the Operations Manual part A. With regard to weather information, paragraph 5. states, amongst others: The operations controller will provide the flight crew with all relevant (pre-flight) information for each flight to be undertaken at the home base. This information is accompanied with a briefing of all flight particulars. Prior to the commencement of the flight, the flight crew shall review the pre-flight briefing information.

The pre-flight information consists of:
(…)
- The meteorological bulletin covering the planned route, the airports planned to be used fordeparture, destination and alternates;
(…)

This part of the Operations Manual does not state how recent the weather information for a flight should be and how to act in case the weather changes.
The responsible department for supplying pre-flight information is Dispatch. The tasks of Dispatch are described in the Operational Planning Centre (OPC) Handbook. Summarized, the weather related tasks with respect to flight preparations are:

Weather (DEP,DEST, (en-route) ALT)

- *Check the weather by means of the conditions in Operating Manual A 8.1.6.*
- *Check the suitability of the departure and destination stations (reference to OM-A 8.1.3 Operating Minima).*
- *Check the suitability of the 1st alternate (ref OM-A 8.1.3 Operating Minima).*
- *Check the suitability of the 2nd alternate, if the weather of the destination airport is below the limits or not available.*

Nothing is mentioned about checking the weather during flights and providing flight crews with updated or significant weather information.

23 http://www.ral.ucar.edu/general/TurbulenceImpactMitigationWorkshop2/Presentations/Day1/Eick_TurbulenceRelatedAccidents.pdf
24 IATA STEADES, 2004-1 Safety Trend Analysis

Air Traffic Control
ICAO Annex 11 Air Traffic Services describes amongst others the content of flight information service. Paragraph 4.1.1 mentions:

Flight information service shall be provided to all aircraft which are likely to be affected by the information and which are:

a) provided with air traffic control service; or
b) otherwise known to the relevant air traffic services units.

Paragraph 4.2.1 mentions:
4.2.1 Flight information service shall include the provision of pertinent:
a) SIGMET and AIRMET information;
b) (…)
c) (…)
d (…)
e) (…)
f) (…)
and of any other information likely to affect safety.

It remained unknown or/how Spain has implemented these Standards into the legislation and or/how Spanish ATC uses these Standards in practice.

1.12.13 Medical services on airports

After the occurrence, the crew made a request for three ambulances and a doctor to be present after landing to take care of the seriously injured cabin attendants. ATC asked for some clarification and after the crew explained the severity of the injuries, the request was passed on. Despite this request only two ambulances showed up considerable time after landing of the aircraft. The first ambulance arrived around 36 minutes after the first request and it took around 51 minutes before the second arrived and no doctor was present.

According to the airport authorities one medical doctor, one nurse and one advanced life support ambulance driven by a emergency medical technician, are present at all times at the airport. The medical team was attending a serious medical urgency at the time the plane landed. That is the reason why the usual protocol for requesting external health support was followed. The ambulances had to come from an off-airport hospital, which took a considerable amount of time.

ICAO Doc 9137-AN/898 Part 7 'Airport Emergency Planning' i.e. provides recommended practices on the handling of aircraft accidents on airports. According to this document an Airport Emergency Plan (AEP) should have been established. "*The purpose of the emergency plan documents is to set out in manual form the responsibilities and required actions/roles of the various personnel/agencies involved in dealing with emergencies affecting the airport.*"[25]

25 Art. 2.1.1 of ICAO Doc 9137-AN/898 Part 7.

Airport Medical Services are mentioned in Appendix 3 to this document. It states, among other things that: "*adequate medical services and supplies should be available at an airport*"[26] and that: "*ideally, each airport should have available at least one on-call ambulance for routine medical emergencies. Written agreements with off-airport based ambulances should be prepared to provide for emergency transportation services.*"[27]

Based on these ICAO recommended practices and according to ADR.OPS.B.005 of Commission Regulation (EU) No. 139/2014 of 12 February 2014, the aerodrome operator shall have and implement an aerodrome emergency plan that:

(a) is commensurate with the aircraft operations and other activities conducted at the aerodrome;
(b) provides for the coordination of appropriate organizations in response to an emergency occurring at an aerodrome or in its surroundings; and
(c) (…)

According to GM1 ADR.OPS.B.010(a)(1) to Regulation No. 139/2014: "*….the role and responsibilities of ambulance and medical services during an emergency situation should be included in the aerodrome emergency plan (AEP), according to GM3 ADR. OPS.B.005(a).*"

The AEP of Palma de Mallorca airport (LEPA), part 01.13 Medical Emergency Services (SMU) version 1.2, contains medical provisions in case of an aviation accident. It states, amongst other things, that the airport medical doctor is responsible for the coordination and organization of the medical emergency services. The provisions of the AEP refer to a large extend to an aviation accident at the airport. Nothing is mentioned about medical assistance to a landing carrying injured person aboard. Also the presence or availability of ambulances in not mentioned in this part of the AEP.

26 Appendix 3, Airport Medical Services, General under '1'
27 Appendix 3, Airport Medical Services, General under '23'

2 ANALYSIS

2.1 Weather

2.1.1 General weather patterns and weather synopsis

According to the "*IATA guidance on turbulence management*" airlines can raise awareness of turbulence encounters on particular routes in their network by providing information about areas where the possibility of turbulence is considerable. With this knowledge flight- and cabin crew could be more prepared and safety-minded during their duties throughout the flight.

Charts with areas where turbulence is more likely can be compiled by using FDA/FOQA statistics, according to the IATA study. IATA included an example of such route charts. In this example the Mediterranean Sea is mentioned as an area that is prone to turbulence caused by thunderstorms during summer and autumn. Transavia did not compile such charts.

2.1.2 Actual weather

Satellite images of the area of the accident show the build-up of clouds between the southeast coast of Spain and the island of Mallorca between 13.00 and 13.30. The two thunderstorm clouds seen by the flight crew are clearly visible. The images also show that between these two clouds, another cloud was quickly developing. This cloud developed in size, both horizontally and vertically. Furthermore, the dBz (indicator for number of drops per volume unit) also increased quickly. The blue color on the satellite image of 13.00 showed a low dBz; between 12 and 18. According to the RDR-4000 manual, this would result in no or a very low return. At 13.10 the dBz was increased to 30-42, which must have been visible on the ND. This was confirmed by the crew statements.

Shortly before the occurrence, hail was audible on the CVR. This hail was not visible on the weather radar in the form of a strong return. Thunderstorms with large amounts of wet hail return stronger signals than those with rain or dry hail. This suggests that the audible precipitation consisted of dry hail, and/or that the core of the hail shaft was very narrow. Also the meteorological information "cumulonimbus, thunderstorms without precipitation" that was received, indicated that these clouds contained no or little precipitation resulting in low reflectivity that could be detected by the weather radar.

The difference between the satellite images of 13.00, 13.10 and 13.20, which was the time frame in which the occurrence happened, is a strong indication that this Cb was developing very quickly during that time. This indication is supported by satellite images of the height of this Cb: the height of its top increased between 13.00 and 13.10 from about 5-7 kilometers to about 10-12 kilometers, so it almost doubled in 10 minutes.

The thunderstorm that caused the occurrence developed very quickly.
Initially the thunderstorm must have been hardly visible on the weather radar due to low dBz returns.

2.2 Weather information available to the crew

The flight crew reported for duty at 03.10 for the flight Amsterdam-Oporto, followed by the return flight to Amsterdam. There after the flight crew was scheduled for the flight to Palma de Mallorca. The crew had received a weather briefing package for the three flights together when they reported for duty.

This briefing package contained the absolute minimum on weather information. Only actual station reports, a forecast and a Significant Weather Chart (SWC) were provided. No general synopsis of the weather situation nor upper wind charts were provided. Based on the SWC and weather reports available to the pilots, it would have been very difficult to grasp the general instability present in the medium and upper levels of the atmosphere, which was characteristic for rapid development of thunderstorms.

The weather package was compiled between 00.22 and 01.13. Given the fact that weather forecasts can change quickly, such a briefing package can hardly be representative of the weather situation in the afternoon. The latest relevant information must be available to the crew and be used by the crew when preparing a flight.

When the crew returned at Schiphol and prepared for the flight to Palma, the flight crew did not receive an updated weather briefing package form Dispatch, although new, and relevant, weather information was available in the form of issued SIGMETS for the destination area. Based on the weather information (SWC, TAF and METAR LEPA) the crew had collected during the return flight from Porto to Amsterdam, the crew saw no reason to ask for an update of the weather briefing package. The Terminal Aerodrome Forecast (TAF) for the destination LEPA, they received when reporting for duty, was basically the same as the one they collected themselves during the return flight from Porto to Amsterdam. From their point of view no new relevant information was required, but when preparing for a flight while at the aircraft, crews have no access to all information available.

However, on 23 September 2016, several SIGMETS were issued, concerning thunderstorms over the Balearic sea. The first SIGMET applicable to the flight to Palma was issued at 02.31, i.e. after the time the briefing package was put together by Dispatch but before the crew reported for duty. SIGMET 4 was available and valid during the turnaround at EHAM. A SIGMET is a warning for actual hazardous weather. As SIGMETS are especially drafted and issued to warn flight crews on short notice about hazards to a safe flight, they present a powerful tool to warn and prepare crews for possible actual adverse weather.

During flight crews are able to retrieve actual weather reports via ACARS, as they did with Palma and the alternate Menorca as well as a forecast, but no SIGMETS. The latter have to be transmitted to the aircraft, usually done by Dispatch. Although the issued SIGMETS must have been available to Dispatch, the crew was not informed about this. According to the tasks of Dispatch, as described in operating Manual A and the OPC Handbook, only a weather check in advance of a flight, during flight preparations is required. Obviously, flight crews are therefore not provided with relevant weather changes or significant weather. According to Transavia procedures flight crews are expected to check that themselves or ask Dispatch to do so. Crews have no knowledge of the issuing of SIGMETS during flight, and can therefore not be expected to perform this task sufficiently. Especially in the case of significant weather, this might lead to dangerous situations.

Whereas SWCs are produced almost a day in advance and thus reflect a prediction, SIGMETS are a warning for actual hazardous weather. The flight crew was not provided with the latest weather information for the flight to Palma de Mallorca, including the relevant SIGMETS. The only recent meteorological information the crew had was the actual and forecasted weather at Palma de Mallorca airport. The crew anticipated on the forecasted weather near the airport by taking in extra fuel, should they need to enter a holding pattern or divert to another airport due to the local weather situation. According to ICAO Annex 11 Air Traffic Services, Paragraph 4.1.1, the crew should have been informed about the issuing of a SIGMET by Air Traffic Control. Knowledge of the published SIGMETS could have helped the flight crew to make a more complete outline of the weather situation on their intended route.

Because the crew was not aware of the published SIGMETS, containing warning for embedded intensifying thunderstorms in the area of their flight, they were not able to anticipate fully on the hazardous weather situation that could develop over the Balearic Sea.

Based on the SWC and weather reports available to the pilots, it was very difficult for the pilots to conclude that the medium and upper levels of the atmosphere were generally instable, and that this is characteristic of rapidly developing thunderstorms.

By not providing the flight crew with the latest weather updates, in particular SIGMETS, Dispatch and Spanish ATC missed an opportunity to warn the flight crew of developing thunderstorms present en route.

2.3 Weather radar limitations

A weather radar cannot detect turbulence, but detects droplets of precipitation size. The strength of the radar return (echo) depends on drop size, composition and amount of water. Turbulence detection requires the presence of precipitation. So, in order to give a return on a weather radar, a sufficient amount of precipitation has to be present. Strong vertical currents may lift water droplets into layers of air which are well below freezing level, thus forming hail. Hail usually has a film of water on its surface; consequently, a hailstone is often reflected in radar images as a very large water particle. Although wet hail is an excellent reflector of radar energy, some hail shafts are extremely small (100 yards or less) and make poor radar targets. If hailstones are cold and dry (dry hail), they may give returns so low they do not even appear on the display. This means that the absence of weather radar returns in a clouded area with thunderstorms cannot be taken as fact that significant turbulence will not be present.

The volumetric scan weather radar fully automatically generates a synthetic overview of the weather in a wide area around the aircraft. In addition, the radar analyses which weather might affect the aircraft in relation to the intended flight path which will be displayed visually. This automatic feature might lead a flight crew to rely more on the image that is displayed than they would do when using an 'old type' weather radar. The limitations of the weather radar are mentioned in de RDR-4000 manual, and as such should be known to pilots. However analyses by Transavia and Honeywell of filled ASR's, ensuing email conversations and issued bulletins from the operator regarding limitations of the weather radar indicate that flight crews in general might not be fully aware of these limitations of weather radar systems.

In order to give a return on a weather radar a sufficient amount of 'wet' precipitation has to be present. The absence of weather radar returns in a clouded area with thunderstorms cannot be taken as evidence that significant turbulence will not be present.

Flight crews might not be fully aware of the limitations of volumetric scan weather radar systems.

2.4 Introduction and training on the Honeywell RDR-4000 weather radar

The new generation weather radars offer more possibilities of ascertaining the reach of convective weather, as they offer a manual mode which provides means to assess storm cell height and development by providing selectable altitude slices, and automated volumetric scan functionality. However, it requires the pilot to use a different technique of operating the weather radar. In automatic mode a synthetic picture is generated based on an algorithm. So the picture is as good as the algorithm is. For instance it has been proven to be prudent to validate the synthetically-generated picture against "old generation" radar returns, as the synthetic volumetric scan picture was not always fully accurate. Over time this improved with software updates from Honeywell. This can be seen by the diminishing number of ASR's that were written on the volumetric scan weather radar.

Soon after the introduction of the volumetric scan radar, complaints regarding the functioning of the RDR-4000 weather radar as well as questions about the RDR-4000 were received by flight operations. The number of complaints diminished after the software modifications by the manufacturer and more information by the operator but they did not stop. There are indications that most of the complaints were a result of an incomplete awareness of the operational limitations of the system and that the possibilities of the system were not fully utilized. There were no signs that the RDR-4000 volumetric scan radar did not function properly. However, It cannot be ruled out completely that some relevant weather is still filtered out. Occasional reports received over time hint in that direction.

As an introduction to the new volumetric scan weather radar, a Cockpit Bulletin[28] was issued to accompany a FCOM revision, in which these changes were described. A pilots guide[29] of this weather radar was placed on the operator's intranet for pilots to acquaint themselves, by self-study, with this new type of radar. Additional training was given in the technical recurrent in winter 2009/2010 to all pilots in classroom training. It covered the operation, limitation and background information including complaints of the RDR4000 volumetric scan. Operating the weather radar is covered in the line-training syllabus but was depending on the radar type available, since the operator uses two types of weather radar in its fleet. In winter 2013/2014 another technical recurrent classroom training was given to all pilots, in which one of the topics was about the Honeywell RDR4000 volumetric scan weather radar, due to recurrent complaints and questions regarding the correct functioning of the weather radar. This involved an instructor clarifying how the radar should be used to gain optimum results, based on the questions and complaints regarding the functioning of the weather radar.

28 effective date of April 27th, 2009
29 Issued by Honeywell in November 2008

The captain already worked at the airline at the time of the introduction and recurrent training, but the first officer did not. Therefore, the first officer had not received the training of the technical recurrent. The first officer stated that he had received no training with regard to the use of the weather radar, nor had knowledge of the technical recurrent. He had no knowledge of the technical recurrent training content that was published on the operator's intranet. Handling the weather radar as part of his line training was on an aircraft that was equipped with the model RDR4. All this is an indication that the operator did not pay much attention to the use and handling of this type of weather radar, nor theoretical, nor during line training.

It can be concluded that no structured training, regarding the use of the volumetric scan RDR-4000 weather radar, had been given by the operator to pilots that entered the company after winter 2013/2014.

There were no indications in the reported complaints, that the RDR-4000 volumetric scan radar did not function properly.

2.5 Use of weather radar

From interviews with the two pilots it became apparent that they had used the weather radar differently with respect to automatic and manual mode and range settings. Gain control was not used by both pilots. Around the time the aeroplane crossed the coastline just south of Gerona (Spain), the captain selected the weather radar's automatic mode with a range of 160 NM. In contrast, the first officer had selected manual mode[30], and a range of 80 NM. This range can be considered as more appropriate, in view of the distance to the airport (60 NM). By selecting manual mode, the first officer's display did not provide the complete vertical weather information. In manual mode the data is a slice of information from the weather buffer based on the selected altitude in 1.000 ft intervals. As a consequence the first officer was only able to see a 1.000 ft layer of weather in front of the aircraft. Because the selected altitude setting in manual mode was unknown, it cannot be determined if the developing Cb was 'seen' by the weather radar or that the Cb was beneath selected altitude of the slice.

As a deliberate precaution it can be a good idea to have multiple sources available to establish the altitude of any convective weather, but there is no evidence the pilots deliberated on this subject. At two minutes and 25 seconds before the occurrence, four minutes after the first officer, the captain switched to a range of 80 NM. At 1.5 minute before the occurrence, the first officer reduced his range further to 40 and subsequently to 20 NM, while the range to the perpendicular position of the thunderstorms had reduced to less than 10 NM. No remarks were made between the pilots about thunderstorms or reasons for the range reduction as the approach briefing continued. With a range of 80 NM it is very difficult to detect a small, but fast growing thunderstorm on the radar screen.

30 The Dutch Safety Board was not able to recover the tilt and gain settings of the first officer's radar display.

According to the Pilots Guide rotating the Gain knob to the maximum (MAX) position increases the sensitivity by approximately 10 dBz. When using different gain settings the presence of the quickly developing Cb could have been noticed in an earlier stage. Furthermore, the Pilot's guide states: In manual mode, maximum gain is useful when looking at altitude slices above the freezing level where particles are less reflective.

Although the first officer switched to the manual mode before the descent, the pilots did not use the manual mode in combination with a variable gain to assess the visible storm cells left and right of track before entering IMC conditions.

It can be concluded that the weather radar was partly used according the manufacturer's instructions. Not all useful features of the radar were used.

As the planned route led the flight in between two active thunderstorms, a more active and conscious use of the weather radar might have helped the pilots in an earlier detection of the rapidly growing cell that they eventually encountered.

An appropriate mix of use between auto and manual modes with active range control might have used the full potential of the weather radar in order to get the best possible information about the weather surrounding the aircraft.

The weather radar had not been used to its optimum to detect possible adverse weather.

2.6 Crew actions

The SWC, valid at 12.00 UTC, had mentioned the possibility of moderate turbulence up to FL250 in clouded areas south of the Pyrenees. The flight was conducted at FL250 and, from the Gerona VOR onwards, mostly in IMC conditions. The crew had visually spotted two Cb's before this point. These had also been visible on the first officer's weather radar screen. The crew was aware of the risks of flying in the vicinity of thunderstorms, but considered the estimated distance of 40 to 50 NM between the two Cb's sufficient. This was in accordance with the advice in the weather radar manual, that states: '*When flying between storm cells allow at least 40 NM separation*. The captain at that time still had no weather radar data displayed on his navigation display (ND), but switched that on shortly afterwards. The position of the thunderstorms was such that the programmed route led the aeroplane precisely in between them to waypoint "LORES", where the arrival route to Palma de Mallorca started.

When flying in IMC in a region with developing thunderstorms, precautionary measures are appropriate, as there is no guarantee that the flight will not inadvertently encounter some turbulence. In fact, both SWC's explicitly warned pilots when flying in clouds in that area to expect up to moderate turbulence. The company manual OM part-A stipulates: "*Well in advance of entering an area where considerable turbulence may be expected, the 'fasten seat belt' and 'no smoking' sign (if not already on) should be illuminated.*" Although the crew did discuss the possibility of encountering turbulence, it can be deducted from the CVR recording that this discussion involved the possibility of turbulence in the later (i.e. lower) stages of the approach. Moreover, during cruise flight south of the Pyrenees the 'fasten seat belts' sign was not switched on, nor were any strategies discussed with the purser who was in the cockpit when the pilots spotted the two thunderstorms and encountered some ice accumulation while flying through clouds. Sudden, rapid ice accumulation at that altitude is a sign of vertical movement of air, with possible moderate or even severe turbulence as a consequence. Although the crew had no knowledge of the SIGMETS issued, ample other cues were available to them. More awareness and a more extensive assessment of the weather situation might have led to a better preparation for the possible presence of turbulence. With regard to the company's operation manual referring to entering an area where considerable turbulence may be expected, the passengers and cabin crew should have been prepared for possible turbulence.

With more awareness and a more extensive assessment of all available indications about the weather situation in the area, the possibility of turbulence could have been recognized earlier. Consequently the flight crew missed an opportunity to prepare the cabin crew and passengers well in advance for the effects of the possible turbulence.

2.7 Fatigue

Extensive scientific literature indicates[31] that there are four core physiological factors that are known to underlie fatigue and are relevant to an accident investigation. These factors are: sleep loss (acute and cumulative debt), extensive continuous hours of wakefulness, operation against circadian rhythms and sleep disorders.

The first step to find out if fatigue is a factor in an accident, is to determine whether to include or exclude these fatigue factors as present at the time of the accident. If fatigue factors were present, the second step is to determine whether fatigue-related performance decrements could be identified that were contributory or causal in the accident. To establish if fatigue-related aspects could have played a role in this accident, the previous 72 hours prior to the occurrence were analyzed.

31 Examining Fatigue Factors in Accident Investigations: Analysis of Guantanamo Bay Aviation Accident, Mark R. Rosekind, Kevin B. Gregory Donna L. Miller, Elizabeth L. Co1, J. Victor Lebacqz, and Malcolm Brenner; https://www.ntsb.gov/investigations/process/Documents/fatigue_checklist_V%202_0.pdf

According to their statements both flight crew woke up around 01.00 AM UTC and reported for duty at 03.10 what means that they both were awake for approximately 12 hours when the occurrence happened around 13.10. According to the flight schedule of the captain, this was the third consecutive day that he was scheduled for an early flight, starting around 03.00 AM.

Investigation established that both pilots had a small sleep loss, and operated close to the second circadian rhythm while none of the other fatigue factors were present.

The crew missed the signs that sudden turbulence might be present which could hint to effects of degraded vigilance and /or a degraded judgment. This decreased performance of the crew could have been the result of some degree of fatigue

A detailed assessment of fatigue can be found in appendix A.

It cannot be ruled out that fatigue-related aspects are a contributing factor in the origination of the accident.

2.8 FDR evaluation and analysis

In addition to an evaluation of the recorded aircraft parameters, an analysis was performed to check the kinematic consistency of the measured data. This analysis is used to compensate for inconsistencies in the measured data, to remove sensor biases, to make data from different sources and different sampling rates compatible with each other and to derive additional parameters.

Reconstruction of accelerations at aft section

Between 13.09:14 to 13.09:18 the absolute vertical acceleration went from 1.00g to 1.97g, from 1.97g to -0.2g and from there to 1.66g. The changes between the three peaks, the forces to which the occupants were exposed, are respectively +0.97g; -2.17g and +1.86g. According to ICAO documents[32] accelerations between 0.5g and 1.00g are considered moderate turbulence and accelerations greater than 1.00g are considered severe turbulence.

Calculation of linear accelerations at an offset from the measurement location requires knowledge about the rotation rates and the offset distance. The difference between the actual measured acceleration and reconstructed acceleration is mainly a function of these variables.

As the aircraft's rotation rates, i.e. the rate of change of the rotational velocities around the three body axes, were not available, these were estimated from the roll, pitch and heading angle.

32 ICAO Doc 4444, Appendix 1

Analysis has indicated that the components of the reconstructed linear accelerations produced by the rotation rates were not significantly. For this reason, accelerations experienced in the aft section of the fuselage (where the cabin crew members were injured) are approximately equal to the acceleration components at the measurement location, depicted in Appendix B. However, it must be mentioned that the absolute magnitude of the three acceleration components is relatively large.

2.9 Management of weather avoidance and mitigating aspects

Flying an aeroplane in an area with thunderstorms involves potential risks, such as (severe) turbulence caused by strong vertical air movements. The best strategy to control such risks is to avoid the severe weather, but this is not always possible. Turbulence associated with thunderstorms is not directly detected by weather radar but has to be deduced by the flight crew from the pattern of radar returns, while clear air turbulence (CAT) cannot be detected at all (and can only be forecasted). This is known to equipment manufacturers and airlines alike, and these have designed and implemented procedures to assist crews in dealing with these types of weather.

The operator's manuals, both for flight crews and for cabin crews, hold instructions how to handle in case of turbulence. In the case of anticipated turbulence, the cabin crew are instructed to check if the passengers are seated and wearing their seat belts. Similar instructions were found in manuals of other operators.

It is contradictory that in case of turbulence the passengers are instructed to remain in their seats while cabin crew are instructed to stand up and walk through the cabin. Only if the commander instructs them to be seated, the cabin crew will stop providing their services, but will still have to clear-up equipment first. In general, operation manuals give little or no attention to the safety of cabin attendants in the case of turbulence. This is confirmed by the relatively high number of casualties among cabin crew during turbulence as evidenced by a, limited, survey of similar occurrences. The fact that cabin crew members are relatively often injured due to turbulence when compared to passengers makes it necessary to pay more attention to procedures aimed at ensuring the safety of cabin crew during turbulence. This is also stated in the IATA Guidelines that states that: "*Compliance checks should only be performed and items secured if this presents no delay in securing themselves in a seat.*" In this light, operators should consider whether it is always necessary to let cabin crew check if passengers are seated and are wearing their seat belts when the sign is switched on in case of anticipated turbulence.

Most, but not all, airlines have procedures that, to a greater or lesser extent, address the "immediate" aspect of actions to be taken in the case of unanticipated moderate to severe turbulence. Up to now Transavia does not have procedures for encountering unanticipated turbulence, and therefore also no provisions for an immediate self-preservation of cabin crew members. In the case of unanticipated turbulence or turbulence that is expected on very short notice, instructions for passengers should also apply for cabin crew until the severity of the turbulence has been established. If this is not feasible, operating manuals must pay more attention to self-preservation of the cabin staff.

The IATA Guidelines into this subject can be helpful to develop procedures for mitigating the risk of injuries to cabin crew.

Procedures for unanticipated turbulence are considered to be effective if an immediate action is addressed aimed at self-preservation of the cabin staff.

Transavia's procedures, as in OM part A and B and the CSM, are mainly directed at warning and preparing cabin crew and passengers for the effects of anticipated turbulence. Up to now Transavia does not have procedures for encountering unanticipated turbulence, or immediate self-preservation of cabin crew members.

2.10 Medical care

Despite the crew's request for three ambulances and a doctor only two ambulances showed up considerable time after landing of the aircraft. The first ambulance arrived approximately 10 minutes after landing, around 36 minutes after the first request, and it took another 15 minutes before the second arrived and eventually no doctor showed up. It turned out that neither ambulances nor a doctor were available on the airport of Palma de Mallorca to provide medical assistance because of another medical emergency. The ambulances had to come from an off-airport hospital, which took a considerable amount of time. According to the Aerodrome Emergency Plan (AEP), the airport's medical doctor must be available for coordination and organization of medical emergency services. In the AEP nothing is mentioned about the availability of ambulances. The DSB considers this not to be in accordance with EU Regulations as it speaks of "*commensurate with the aircraft operations and other activities conducted at the aerodrome*".

It may be expected that adequate medical assistance (at least qualified doctor and an ambulance) is available at all times at an airport where commercial jet aircraft of medium size take off and land regularly. Although an ambulance, a doctor and a nurse are available under normal circumstances, the DSB is of the opinion that adequate medical assistance and transportation must be available at very short notice under all circumstances if necessary, even when a medical team is occupied with another medical assistance.

Neither ambulances nor a doctor were present on the airport of Palma de Mallorca to provide medical assistance. If necessary adequate medical assistance and transportation must be available at very short notice under all circumstances.

3 FINDINGS AND CONCLUSION

3.1 Findings

General

- The flight and cabin crew all held valid licenses and ratings to carry out their tasks as assigned.
- The aircraft was airworthy and held valid certificates.
- Three cabin attendants were seriously injured as result of unanticipated turbulence.
- The thunderstorm that caused the occurrence was developing very quickly.
- In order to give a return on a weather radar a sufficient amount of precipitation has to be present. The absence of weather radar returns in a clouded area with thunderstorms cannot be taken as evidence that significant turbulence will not be present.

Organisation

- Flight crews might not be fully aware of the limitations of volumetric scan weather radar systems.
- No structured or effective training, regarding the use of the volumetric scan RDR-4000 volumetric scan weather radar, had been given by the operator to pilots that entered the company after winter 2013/2014. Procedures for unanticipated turbulence are considered to be effective if an immediate action is addressed aimed at self-preservation of the cabin staff.
- Transavia procedures in OM part A and the CSM are mainly directed at warning and preparing the cabin crew and passengers for the effects of anticipated turbulence. Transavia did not have procedures for encountering unanticipated turbulence, or immediate self-preservation of cabin crew members.
- The medical care on the airport was insufficient. Neither the requested three ambulances nor a doctor were present when the aircraft landed. Two ambulances arrived later; the third ambulance and a doctor never showed up.

Flight preparation

- By not providing the flight crew with the latest weather updates, in particular SIGMETS, Dispatch and Spanish ATC missed an opportunity to warn the flight crew of developing thunderstorms present en route.
- Based on the SWC and weather reports available to the pilots, it was very difficult for the pilots to conclude that the medium and upper levels of the atmosphere were generally instable, and that this is characteristic of rapidly developing thunderstorms.

Flight execution

- Initially the thunderstorm must have been hardly visible on the weather radar due to low dBz returns.
- There are no indications that the RDR-4000 volumetric scan weather radar did not function properly.
- The weather radar had not been used to its optimum to detect possible adverse weather.
- With more awareness and a more extensive assessment of all available indications about the weather situation in the area, the possibility of turbulence could have been recognized earlier.
- By not warning the cabin crew and passengers, the flight crew missed an opportunity to prepare the cabin crew and passengers for the effects of the possible turbulence.
- Fatigue related aspects might have had an effect on the origination of the accident.

3.2 Conclusion

The accident happened because the cabin crew was not warned of possible turbulence and the fasten seatbelt sign was switched on only shortly before the aircraft encountered turbulence. The cabin attendants were not seated with safety belts fastened as they stood up to carry out their duties during unanticipated severe turbulence.

Contributing factors
The late appearance of the convective cloud on the weather radar was probably caused by a very quick development of this cloud in combination with its low reflectivity. There are no signs that the RDR-4000 weather radar did not function properly.

Known relevant and important weather information never reached the pilots because the briefing was prepared well in advance of the flight and was not updated by dispatch before the flight commenced.

Although the crew showed knowledge on the general risks of thunderstorms, the possible effects for the cabin crew and passengers of possible encounters with turbulence were not fully appreciated. Fatigue related aspects might have been a factor in this lack of appreciation.

The procedures of Transavia on how to deal with turbulence do not reflect the latest views of the industry, as reflected in a recent IATA study "guidance on turbulence management". Preparing the cabin crew and passengers for unanticipated turbulence is not addressed in the company manuals.

4 SAFETY RECOMMENDATIONS

- Transavia is recommended to review its turbulence procedure, especially with regard to self-preservation of cabin staff.
- Transavia is recommended to ensure that flight crews have the most recent weather information for each flight available.
- The Spanish CAA is recommended to ensure medical care and facilities to be available at short notice, commensurate with the aircraft operations, at the airports under its control.

APPENDIX A

FATIGUE

Extensive scientific literature[33] indicates that there are four core physiological factors that are known to underlie fatigue and are relevant to an accident investigation. These factors are: sleep loss (acute and cumulative debt), extensive continuous hours of wakefulness, operation against circadian rhythms and sleep disorders.

The first step to find out if fatigue is a factor in an accident, is to determine whether to include or exclude these fatigue factors as present at the time of the accident. If fatigue factors were present, the second step is to determine whether fatigue-related performance decrements could be identified that were contributory or causal in the accident.

To assess if fatigue was a possible factor into an occurrence, initial screening questions have to be answered to establish if fatigue factors are present.

- Does the operator's 72-hour history suggest little sleep, or less sleep than usual?
- Did the accident occur during times of reduced alertness (such as 03.00 to 05.00)?
- Had the operator been awake for a long time at the time of the accident?
- Were there any sleep disorders (Disturbed/Fragmented sleep), medication or drug issues.

First, the following four fatigue related factors need to be evaluated, i.e. their influence on the flight crew assessed during the preceding 72 hours:

a. *Continuous time of wakefulness*: no relevant performance degradation is expected when a crew member has been awake for up to 12 hours. From 16 hours of wakefulness on, degrading of performance is significant.
b. *Sleep duration/loss*: acute sleep loss refers to sleep loss within the preceding 24 hours. Chronic sleep loss is determined over the last 72 hours. Both should be evaluated in relation to the crew member's habitudinal sleep patterns[34].
c. *Circadian factors*: it has to be established if the accident happened during a circadian low point. The primary circadian trough is approximately from midnight to 06.00, especially between 03.00 and 05.00, while a secondary "afternoon lull" occurs at approximately 15.00 to 17.00. this is referenced to the acclimatised time-zone of the crew.
d. *Sleep disorders, medication or drugs*: it has to be determined if sleep disorders (disturbed/fragmented sleep), medication or drugs issues could have played a role.

33 Examining Fatigue Factors in Accident Investigations: Analysis of Guantanamo Bay Aviation Accident, Mark R. Rosekind, Kevin B. Gregory Donna L. Miller, Elizabeth L. Co1, J. Victor Lebacqz, and Malcolm Brenner; https://www.ntsb.gov/investigations/process/Documents/fatigue_checklist_V%202_0.pdf

34 An average of eight hours of sleep is needed per night, with large individual variance. Two local nights with the habitudinal average sleep offsets any sleep loss.

Continuous time of wakefulness
Reporting for duty was at 05.10 lt. The occurrence took place at 15.10 lt. The duty period up to the accident hence was 10 hours. Allowing two hours for waking up and driving to the airport makes a period of continuous time of wakefulness of 12 hours. This leads to the conclusion that the continuous time of wakefulness did not lead to degraded flight crew performance.

Sleep duration / loss:
Based on the obtained data about his habitudinal sleep patterns, the captain had suffered an acute sleep loss of 1 to 2 hours, as well as a chronic sleep loss of 3 to 6 hours. Based on obtained data about his habitudinal sleep patterns, the first officer had suffered an acute sleep loss of a 3 hours, but no chronic sleep loss. The first officer stated that, as it was the third stretch of the day, he felt a little bit tired This leads to the conclusion that both pilots had suffered some sleep loss.

Circadian factors
The duty period of the flight crew was mainly outside the circadian lows. The time of the accident was on the edge of the second circadian low period that occurs at about 3 pm to 5 pm. Since this is not an exact period, it cannot be excluded that this played a role on the alertness of the flight crew. Both pilots were acclimatised to the local time zone, which was one hour later compared to the local Amsterdam time. This leads to the conclusion that circadian factors could have played a (small) role in this accident.

Sleep disorders, medication or drugs
Both flight crew members stated that none of these issues applied to them. With that, it has to be concluded that this was not a factor.

After the establishment of the fatigue factors present, it should be determined whether fatigue-related performance decrements could be identified, that were contributory or causal in the accident.

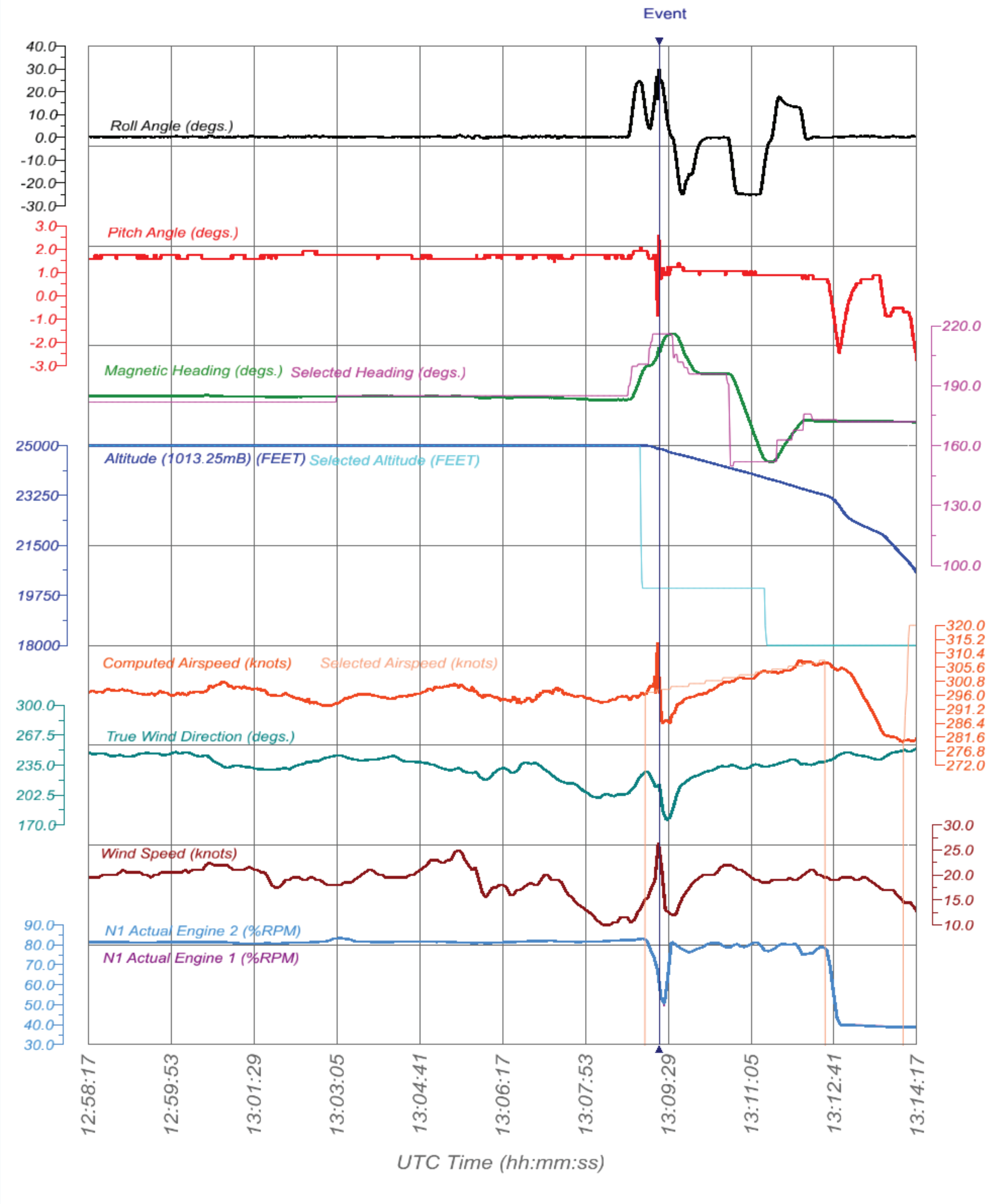
Given the fact that some sleep loss was established, the influence of this factor on the flight crew's performance has to be established. Degraded performance as a result of sleep loss has been shown to manifest itself often as one or more of the following performance factors:

- Degraded judgment and decision making
- Cognitive fixation
- Poor judgment/coordination
- Increased reaction time
- Mood changes; indifferent behavior
- Degraded vigilance

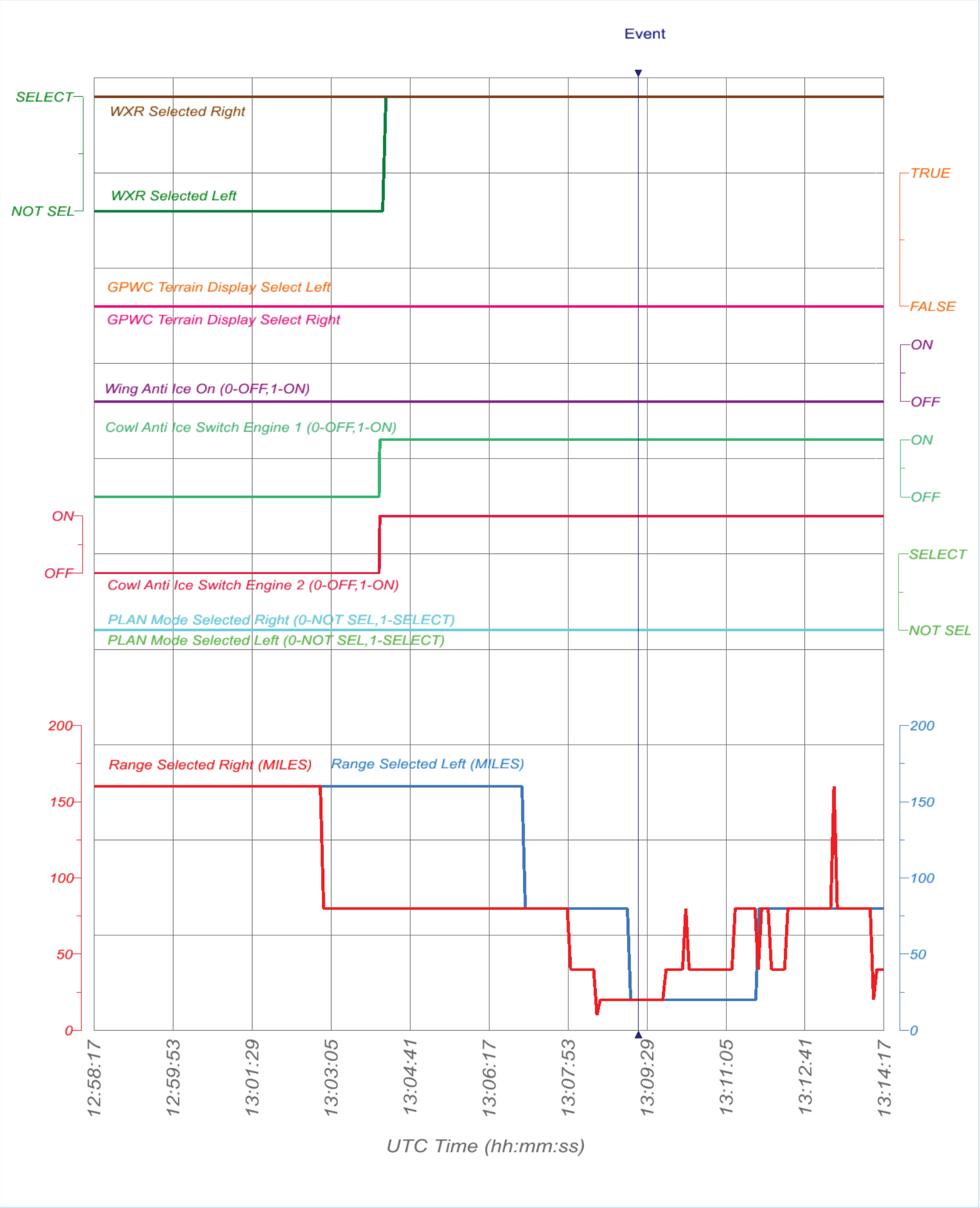
The fact that no precautionary measures were taken with regard to preparing cabin crew and passengers for the effects of possible turbulence while the flight was in an area with known thunderstorms, could hint to effects of degraded vigilance and/or a degraded judgement. This, in turn, could have been a contributing factor in the origination of the accident.

FDR PLOTS

Operational information



Selections



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NOT SEL
WXR Selected Right
WXR Selected Left
TRUE
FALSE
GPWC Terrain Display Select Left
GPWC Terrain Display Select Right
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OFF
Wing Anti Ice On (0-OFF,1-ON)
Cowl Anti Ice Switch Engine 1 (0-OFF,1-ON)
ON
OFF
ON
OFF
Cowl Anti Ice Switch Engine 2 (0-OFF,1-ON)
SELECT
NOT SEL
PLAN Mode Selected Right (0-NOT SEL,1-SELECT)
PLAN Mode Selected Left (0-NOT SEL,1-SELECT)
200
150
100
50
0
Range Selected Right (MILES)
Range Selected Left (MILES)
12:58:17
12:59:53
13:01:29
13:03:05
13:04:41
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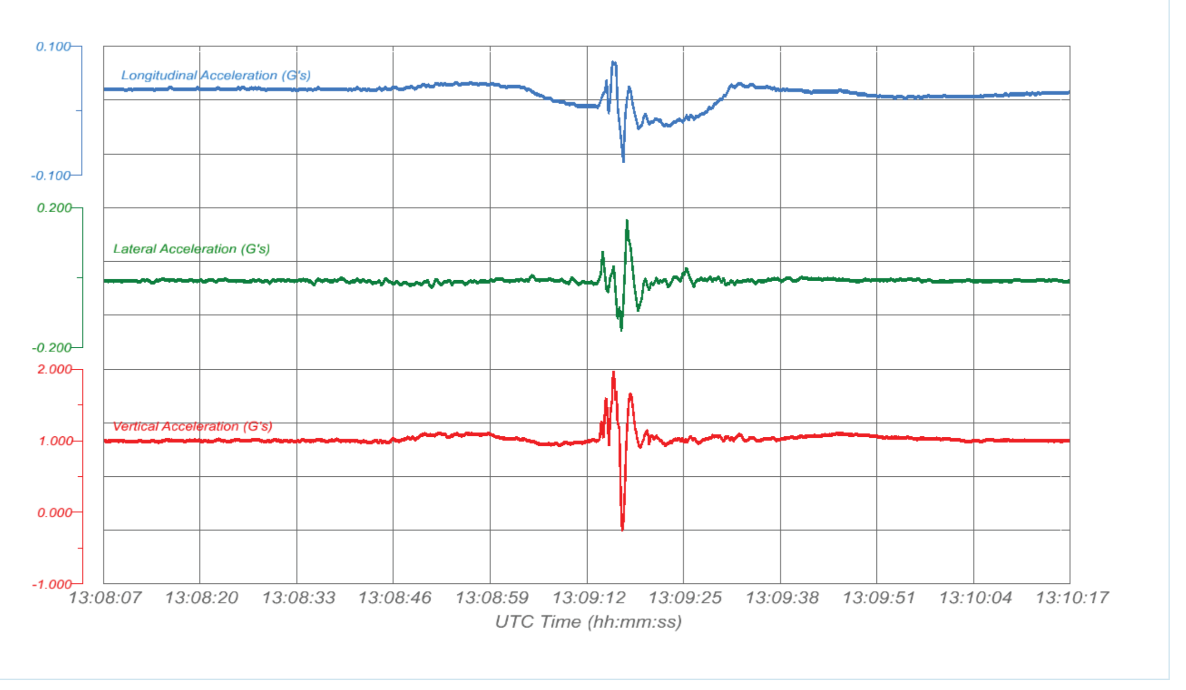
UTC Time (hh:mm:ss)

Accelerations



DUTCH
SAFETY BOARD

Visiting address
Lange Voorhout 9
2514 EA The Hague
T 070 333 70 00
F 070 333 70 77

Postal address
PO Box 95404
2509 CK The Hague

www.safetyboard.nl