الهيئة العامة للطيران المدني
GENERAL CIVIL AVIATION AUTHORITY

United Arab Emirates

Air Accident Investigation Sector

Accident

- Final Report -

AAIS Case Nº: AIFN/0009/2019

Severe Turbulence during Cruise

Operator:	Emirates
Make and Model:	Airbus A380-861
Nationality and Registration:	The United Arab Emirates, A6-EEM
Place of Occurrence:	Airspace over the Bay of Bengal
State of Occurrence:	The Republic of India
Date of Occurrence:	10 July 2019

This Investigation was conducted by the Air Accident Investigation Sector of the United Arab Emirates pursuant to Civil Aviation Law No. 20 of 1991, in compliance with Air Accident and Incident Investigation Regulations, and in conformance with the requirements of Annex 13 to the Convention on International Civil Aviation.

This Investigation was conducted independently and without prejudice. The sole objective of the investigation is to prevent future aircraft accidents and incidents. It is not the purpose of this activity to apportion blame or liability.

The Air Accident Investigation Sector of the United Arab Emirates issued this Final Report in accordance with National and International Standards and best practice. Consultation with applicable stakeholders, and consideration of their comments, took place prior to the publication of this Report.

The Final Report is publicly available at:

http://www.gcaa.gov.ae/en/epublication/pages/investigationReport.aspx

The Air Accident Investigation Sector
General Civil Aviation Authority
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Occurrence Brief

Occurrence file number	:	AIFN/0009/2019
Occurrence category	:	Accident
Name of the Operator	:	Emirates
Manufacturer	:	Airbus SE
Aircraft model	:	A380-861
Engines	:	Four, Engine Alliance GP7270
Nationality	:	The United Arab Emirates
Registration	:	A6-EEM
Aircraft serial number	:	0134
Type of flight	:	Scheduled passenger
Flight number	:	UAE449
State of Occurrence	:	The Republic of India
Place of Occurrence	:	Indian Ocean over the Bay of Bengal
Date and time	:	10 July 2019, 2153:25 UTC
Total crewmembers	:	29 (four flight crew and 25 cabin crew)
Total passengers	:	378
Injuries to passengers and crew	:	27 (one serious, 26 minor)

Investigation Process

The Air Accident Investigation Sector (AAIS) of the United Arab Emirates was notified of the Accident by phone call from the Operator to the AAIS Duty Investigator (DI) Hotline number +971506414667.

The Air Accident Investigation Bureau of the Republic of India, being the State of Occurrence, was notified of the occurrence, however they did not acknowledge the notification. The AAIS, being the investigation authority of the State of the Operator and State of Aircraft Registry, opened an investigation into this occurrence. In accordance with the UAE Civil Aviation Regulations and in line with Annex 13 obligations, the AAIS assigned Accident Investigation File Number AIFN/0009/2019, appointed an investigator-in-charge (IIC) and formed an investigation team.

Due to a serious injury to one passenger, the AAIS classified the occurrence as an Accident.

The AAIS notified the Bureau d'Enquetes et d'Analyses pour la securite de l'aviation civile (BEA), being the authority of the State of Manufacture and State of Design of the Aircraft. An Accredited Representative was assigned by the BEA who was assisted by Advisers from Airbus. In addition, the Operator assigned a technical expert to the IIC.

The scope of this Investigation was limited to the relevant flight operations, related aircraft systems and cabin safety during the turbulence occurrence.

Notes:

1. Whenever the following words are mentioned in this Report with the first letter capitalized, they shall mean the following:
   - (Accident). This investigated accident.
   - (Aircraft). The aircraft involved in this accident.
   - (Commander). The Commander of the flight.
   - (Captain). The operating captain during the occurrence.
   - (Copilot). The operating copilot during the occurrence.
   - (Cabin Manager) The purser in-charge of the cabin.
   - (Investigation). The investigation into the circumstances of this accident.
   - (Report). This accident investigation Final Report.
2. Unless otherwise mentioned, all times in this Report are UTC time. Local time in the United Arab Emirates is UTC plus 4 hours.
3. Photos and figures used in this Report are taken from different sources and adjusted from the original for the sole purpose of improving the clarity of the Report.

Abbreviations

AAIS	The Air Accident Investigation Sector of the United Arab Emirates
ACARS	Aircraft communication addressing and reporting system
ALT CRZ	Altitude hold of the cruise flight level
AP	Autopilot
ATA	Active turbulence alleviation
A/THR	Autothrust
AUTO	Automatic
CB	Cumulonimbus cloud
CMS	Central maintenance system
CPDLC	Controller/pilot datalink communication
CVR	Cockpit voice recorder
EFB	Electronic flight bag
EFIS CP	Electronic flight instrument system control panel
FCOM	*Flight crew operating manual*
FCTM	*Flight crew techniques manual*
FDR	Flight data recorder
FL	Flight level
FSB	Fasten seat belt
ft	feet
G	G load
GCAA	The General Civil Aviation Authority of the United Arab Emirates
IIC	Investigator-in-charge
kt	knots
LAF	Load Alleviation Function
Mach	Mach number is the ratio of true airspeed to the speed of sound
MCL	Maximum climb thrust
MMO	Maximum operating Mach
MSL	Mean sea level
NAV	Navigation mode
ND	Navigation display
NM	Nautical miles
NZAA	Auckland Airport
OFP	Operational flight plan
OM	Operations manual
OMDB	Dubai International Airport

PF	Pilot flying
PFR	Post flight report
PM	Pilot monitoring
PTA	Passive turbulence alleviation
QAR	Quick access recorder
RTS	Return to seat
SEP	Safety and emergency procedures
SIGMET	Significant meteorological information
TURB	Turbulence
UTC	Coordinated universal time
VD	Vertical display
WX	Weather radar mode
WXR	Weather radar

Synopsis

On 10 July 2019, an Emirates Airbus A380 Aircraft, registration A6-EEM, was operating a scheduled passenger long-range flight, UAE449, from Auckland Airport (NZAA), New Zealand, to Dubai International Airport (OMDB), the United Arab Emirates. The flight had 407 persons onboard consisting of four flight crew, 25 cabin crew and 378 passengers. In Indian airspace above the Bay of Bengal, the Aircraft experienced severe turbulence at around 2153 UTC, approximately 13 hours after departure from NZAA.

The flight crew during the turbulence encounter was a Captain and a Copilot, who were the augmenting pilots. The Copilot in the right seat was the pilot flying. During cruise at flight level (FL) FL400, the Aircraft encountered turbulence as it flew over an area affected by convective activity with isolated embedded cumulonimbus clouds. The Aircraft airspeed increased and the maximum operating speed was momentarily exceeded. The autopilot and autothrust remained engaged during the turbulence. The thrust adjustment commanded by the autothrust system and the automatic speed brakes deployment were not sufficient to fully avoid the transient speed exceedance.

Fifteen cabin crew were on duty performing passenger services, and nine cabin crew and two flight crew were on scheduled controlled rest. About five minutes before the Aircraft encountered the turbulence, the flight crew had turned the passengers' seat belt sign to ON. The on duty cabin crew were not aware that the seat belt sign was ON and no announcement was made for passengers to return to their seats and fasten seatbelts.

The turbulence lasted for about four minutes. Twenty-seven persons onboard suffered injuries. These included thirteen passengers and thirteen cabin crewmembers who sustained minor injuries, and one passenger whose injury was assessed as serious after hospitalization. Several cabin ceiling panels were damaged.

The flight continued to the destination where the Aircraft landed uneventfully.

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1. Factual Information

1.1 History of the Flight

On 10 July 2019, a scheduled passenger long-range flight, UAE449, operated by an Airbus A380 Aircraft registered as A6-EEM, took off from Auckland Airport (NZAA) in New Zealand at 0835 UTC[1] for a 17-hour flight to Dubai International Airport (OMDB) in the United Arab Emirates. The flight had 407 persons onboard consisting of four flight crew, 25 cabin crew[2] and 378 passengers. Seventy-eight of the passengers were on the upper deck and 300 passengers in the main cabin on the lower deck.

In preparation for the flight, the four flight crew had received the Operational Flight Plan (OFP) which was produced at 0558 on 10 July 2019 by the Operator's flight dispatch. The significant weather charts in the OFP were valid from 1800 on 10 July 2019 for flight levels FL100 to FL450. The planned flight route directed the Aircraft over the Bay of Bengal in Indian airspace. There were no amendments to the original planned route.

The four flight crew, consisted of the flight's Commander and a copilot who were assisted by an augmenting Captain and Copilot. For the flight, they had briefed the alternate airports, the weather en route, fuel required and the schedule of the planned crew rest. The flight crew stated that there was nothing significant about the weather and they were aware that it was the monsoon season which affects the Bay of Bengal at this time of the year. Some turbulence was forecast over Australia. During the preflight briefing, the Cabin Manager[3] was briefed about the expected turbulence along the route.

Approximately one hour prior to the turbulence encounter the augmenting flight crew had taken over command of the Aircraft as the operating flight crew took their planned rest in the crew rest compartment.

During the handover between the flight crewmembers, the outgoing crew mentioned that there was weather activity ahead of the Aircraft close to waypoint IDASO, and that other aircraft pilots were asking for deviations.

For this sector of the cruise, the Copilot was the pilot flying occupying the right pilot's seat.

During the flight, the weather radar 'WXR' and 'TURB' functions were in AUTO mode and the 'WX' push button was selected on the electronic flight instrument system control panel (EFIS CP) which enabled the display of weather information on the navigation display (ND).

At 2148, as a precaution, with the Aircraft about 40 NM away from the location of the turbulence encounter, the Captain decided to turn ON the seat belt sign. There was no call from the Captain to the Cabin Manager that the seat belt sign was turned ON. No passenger announcement was made for passengers to return to their seats and fasten seat belts.

At this time, the Aircraft gross weight was 382 tons with the Aircraft in clean configuration[4] at the selected cruise flight level (FL) FL400. The selected speed was 0.84 Mach

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1 Unless otherwise mentioned, all times in this Report are UTC time. Local time in the United Arab Emirates is UTC plus 4 hours.

2 One cabin crew on board was a deadheading crew member.

3 The purser in-charge of the cabin.

4 Clean configuration means flaps and slats were retracted.

with pitch angle of positive 2 degrees and a heading of 302 degrees. Autopilot 2 and both flight directors were engaged and the autothrust was active in MACH mode with the four thrust levers in maximum climb thrust (MCL) detent. The thrust levers remained in this position throughout the turbulence encounter. The wind information from the flight data recorder (FDR) indicated that the average wind was 65 kt coming from 080 degrees with a tailwind component of 55 kt together with a crosswind component from the right of approximately 40 kt.

At 2153:25 UTC (Indian local time 0323), approximately 13 hours into the flight, the Aircraft encountered different levels of turbulence that lasted until 2157:30. Severe turbulence was encountered within the first 20 seconds. This occurred close to waypoint IDASO (approximately 200 NM east of Chennai), over the Bay of Bengal, whilst in the cruise at FL400. The FDR data indicated that the Aircraft entered an area with significant wind variations.

During the interview with the crew, the Captain stated that on the ND “about 80 miles [NM] away, there was a couple of red spots [displayed on the ND] but they were well left and right of the track. The red spots disappeared as the aircraft got closer”. The flight crew stated that they adjusted the weather radar range on the EFIS CP between 160 NM for the Captain and 80 NM for the Copilot. The weather radar gain control, located on the SURV panel, was set at 85 percent for the Captain and 50 percent for the Copilot. The Captain stated that the Airbus A380 aircraft weather radar can determine what weather is relevant and what is not, which is referred to as on-path and off-path. He further explained that a decision to deviate is normally taken before the aircraft gets within 40 NM of the weather.

The flight crew stated that they had dimmed the cockpit lights to observe the lightning activity in the area, which occurred approximately every minute to 30 seconds. Because it was night time, during the lightning, they were able to see the tops of the weather and the weather below the Aircraft. However, as the tracking of the Aircraft was through a clear area with few clouds, they decided to continue with the planned flight route because the weather radar display on the ND was showing the weather as off-path.

The Captain stated that he also selected manual gain of the weather radar to have a better awareness of the weather and he reduced the range on the ND to 40 NM. The flight crew discussed flying through the squall line which they said was about 80 miles long and directly across the Aircraft’s flight path.

The flight crew reported that there was no precipitation showing on the ND and the turbulence occurred unexpectedly. They stated that there was a “thunderstorm squall line in the area, but no avoidance was required as the weather was below the aircraft and off-path. Turbulence was encountered downwind of the CBs [cumulonimbus clouds].” They believed that it was clear air turbulence.

The flight crew described that the turbulence happened very quickly and they were “jostled up and down”, and even with their seat belts on for the first minute they had to “brace themselves”. Because the airspeed had suddenly started to increase towards the maximum operating Mach (MMO) speed limit of 0.89, the Copilot tried to maintain the airspeed by immediately moving the speedbrake lever to deploy the wing spoilers and reducing the Mach target number from 0.84 to 0.72 Mach. The flight crew said that they did not observe any speed exceedance. During the turbulence, the autopilot remained engaged and there was no excessive altitude loss.

After the turbulence ended at 2157:30, the flight crew discussed the event and initially thought that the turbulence was moderate. However, within a short time, they decided it was ‘severe’ after calls started to come from the cabin crew that passengers and cabin crew were

injured and that there was damage in the cabin. The Commander of the flight, who was in the crew rest compartment, called the operating Captain and they exchanged information about the occurrence. The Commander and the copilot then proceeded to the cockpit.

At the time of the turbulence, there were 15 cabin crew on duty including the Cabin Manager. Of these cabin crew, three were in first class, four in business class, seven in economy class and one seated in the cockpit. Nine cabin crew were on their scheduled rest in the crew rest compartment, located in the aft cabin, with their waist seat belts fastened. All cabin crew had followed their planned rest cycle of four hours.

For the cabin crew on duty, except for the cabin crewmember in the cockpit, and one other cabin crewmember, the remaining thirteen were standing and performing their normal duties in the cabin.

The Cabin Manager, who was in the first class cabin together with two cabin crew, described “the Aircraft shaking significantly”. As they tried to reach their jumpseats they felt like the “Aircraft dropped”. They saw many items of galley equipment used for passenger service fall to the galley floor.

The Cabin Manager then made a passenger announcement (PA) for the cabin crew and passengers to take their seats after he seated himself on the jump seat. The Cabin Manager then communicated with the Captain via the intercom system to let him know that all cabin crew were seated but there was a possibility of crew injuries.

The four cabin crew assigned to business class reported to the Cabin Manager that they were in the aft galley at the time of the turbulence and had suffered injuries when they “flew up” and impacted the ceiling.

After assessment by the Cabin Manager, it was determined that a total of 27 persons onboard comprising thirteen cabin crew and fourteen passengers, had sustained injuries. One economy passenger injury was assessed as serious after hospitalization.

Several cabin ceiling panels in the main deck aft cabin were damaged by the impact of occupants. Several items of loose galley equipment fell to the floor including beverages and food.

The flight crew established contact with the Operator’s ground medical team to assess the condition of those who had suffered injuries.

The decision was made by the Commander to continue to OMDB as none of the injuries was considered life threatening and the Aircraft systems were not affected by the turbulence encounter.

The remainder of the flight and the landing at OMDB were uneventful.

1.2 Injuries to Persons

Table 1 shows the number of injuries.

Table 1. Injuries to persons

Injuries	Flight crew	Cabin crew	Passengers	Total onboard
Fatal	0	0	0	0
Serious	0	0	1	1
Minor	0	13	13	26
None	4	12	364	380
TOTAL	**4**	**25**	**378**	**407**

1.2.1 Details of injuries

1.2.1.1 Crewmembers

Thirteen cabin crew sustained minor injuries, which included bruises and lacerations to various parts of the body due to impact with various parts of the cabin furnishings. The cabin crew were injured in the following locations:

- Five cabin crew injuries occurred in the upper deck. This included the four cabin crew at the business class aft galley who all impacted the cabin roof. The fifth cabin crew member, seated on the jump seat adjacent to the upper deck L1 passenger door, suffered an injury due to a small silver tray impacting the cabin crew foot. Because of the injuries sustained to the four cabin crewmembers at the aft galley, they did not resume duties for the remainder of the flight.
- One injury occurred to a cabin crew member located in the economy main deck aft galley.
- The nine cabin crew in the crew rest compartment all had their waist seat belts on loosely. Seven of them suffered minor injuries when their heads hit the upper part of the compartment during the turbulence.

1.2.1.2 Passengers

Fourteen passengers suffered injuries, 13 categorized as minor and one as serious. Ten of these injuries occurred in economy and four in business class. The minor injuries included bruises and lacerations to various parts of the body due to impact with the cabin structure.

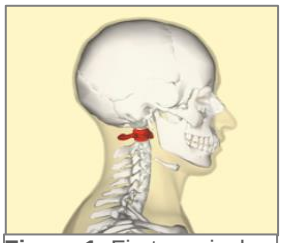

Figure 1. First cervical vertebra (Atlas) shown in red

The economy class passenger who sustained a serious injury was in the aft cabin washroom at the time of the severe turbulence encounter and hit her head on the washroom ceiling. The passenger had no lacerations and remained conscious, but complained of neck pain. Upon arrival at OMDB, the patient was hospitalized where a computed tomography (CT) scan was performed. After review of the CT scan results, the injury was classified as serious because medical examination revealed that the passenger

had suffered a fracture to the right lateral mass of the first (C1) cervical vertebra (Atlas). See figure 1.

1.3 Damage to Aircraft

Several cabin ceiling panels located in the aft cabin main deck, close to the L5 passenger door, were damaged, as illustrated in figure 2, as a result of impact by persons. Some ceiling panels were also damaged in the upper deck aft galley and several cabin ceiling exit signs had detached.

Figure 2. Main deck aft cabin celling panel damage

1.4 Other Damage

There was no damage to the Aircraft, other than in the cabin.

1.5 Personnel Information

The flight crew roster and cabin crewmembers' roster indicated that they all met the rest period requirements of the UAE regulations.

The flight crew pilot licenses and medical licenses were valid at the time of the Accident.

All the cabin crew licenses, and medical licenses were valid at the time of the Accident.

Every twelve calendar months, in accordance with the Operator's annual recurrent safety and emergency procedures (SEP) training 'Duties to be undertaken in the event of encountering turbulence' was attended by the flight and cabin crew.

1.5.1 Flight crew information

Table 2 illustrates the flight crew data.

Table 2. Flight crew data

	Commander	Copilot	Augmenting Captain (In-seat during turbulence encounter)	Augmenting Copilot (In-seat during turbulence encounter)
Age	52	35	50	43
Type of license	ATPL	ATPL	ATPL	ATPL

Valid to	12 February 2027	5 June 2022	26 March 2024	1 October 2019
Rating	Airbus A380	Airbus A380	Airbus A380	Airbus A380
Total flying time (hours)	10,922	9,742	7,890	5,259
Total on A380 (hours)	1,091	5,345	4,250	4,522
Total last 90 days (hours)	97	83	183	196
Total last 7 days (hours)	13	7	21	22
Last proficiency check	1 August 2019	6 May 2019	01 April 2019	1 April 2019
Medical validity	30 November 2019	25 November 2019	4 November 2019	30 November 2019
Medical limitation	VNL[5]	Nil	VDL[6]	VDL

1.6 Aircraft Information

1.6.1 General data

The Aircraft, an Airbus A380-861, is a Very Long Range (VLR), subsonic, civil transport aircraft that has two passenger decks certified for maximum number of passengers of 853. It was configured for 489 passengers with 14 first class and 76 business seats on the upper deck, and 399 economy seats in the main deck.

All Aircraft records and maintenance records were valid and current with no significant technical defects at the time of the Accident.

1.6.1.1 Aircraft and engine data

Table 3 illustrates the general Aircraft and engine data.

Table 3. Aircraft data

Manufacturer:	Airbus SE
Model:	A380-861
MSN:	134
Date of delivery:	14 November 2013
Nationality and registration mark:	United Arab Emirates, A6-EEM
Name of the owner:	DNA Alpha Limited, Guernsey
Name of the Operator:	Emirates
Certificate of registration:	
Number:	UAE-COR-0602
Issuing Authority:	UAE GCAA
Issuance date:	14 November 2013
Certificate of Airworthiness:	

[5] VNL: Wear multifocal spectacles and carry a spare set of spectacles

[6] VDL: Wear corrective lenses and carry a spare set of spectacles

	Number:	UAE-COA-0183			
	Issuing Authority:	UAE GCAA			
	Issuance date:	14 November 2013			
Airworthiness Review Certificate		ARC-EK-EEM-6 (expiry date 13 November 2019)			
Total hours since new:		27,525:29			
Total cycles since new:		2,939			
Last major inspection check, type, date and hours/cycles:		C check on 8 September 2017			
Last inspection, type, date and hours/cycles:		SVC check on 24 July 2019			
Maximum takeoff weight:		575,000 kg			
Maximum landing weight:		395,000 kg			
Maximum zero fuel weight:		369,000 kg			
Total fuel for departure		206,000 kg			
Engine Data:					
Manufacturer / Model		Engine Alliance / GP7270			
Serial No.		P550260	P550426	P550465	P550362
Date Installed		27 Dec 2018	6 April 2019	5 Nov 2016	6 April 2019
Total hours since new		29,171	18,581	20,327	24,590
Total cycles since new		4,623	2,877	2,656	2,698

1.6.2 Aircraft systems

1.6.2.1 Fasten seat belt

The flight crew command from the cockpit to turn on the fasten seat belt signs throughout the aircraft cabin, is controlled by a three position switch, ON/AUTO/OFF, that is located on the cockpit center overhead control panel. For the passengers, the FASTEN SEAT BELT (FSB) and RETURN TO SEAT (RTS) signs are located throughout the passenger cabin overhead panels including in the lavatories, lounge areas and shower. The cabin crew areas including the galleys and crew rest compartment has FSB signs fitted.

When the switch is placed to the ON position, the FSB and RTS signs come on in the cabin continuously after flashing for five seconds. This is associated with a single low tone chime throughout the cabin, which is meant to draw the attention of the cabin crew and passengers. The Operator's A380 aircraft do not have an automated public address announcement for passengers to return to their seats and fasten their seat belts.

With the switch in the AUTO position, the FSB and RTS signs will illuminate with the associated low tone chime, when the engine start is selected, slats are extended, or when the nose landing gear is down and locked.

With the switch in the OFF position, the FSB and RTS signs in the cabin turn off.

1.6.2.2 Load Alleviation Function

The purpose of the Load Alleviation Function (LAF) is to reduce the fatigue and static loads on the wing. The LAF includes the Passive Turbulence Alleviation (PTA) and the Active Turbulence Alleviation (ATA).

The PTA reduces the static loads in turbulence and during maneuvers, by reducing the wing bending moment. This is done by symmetrically deflecting the ailerons and/or the outer spoilers upwards. The deflection of the ailerons and the extension of the spoilers depend on the aircraft speed and the load factor.

The ATA reduces fatigue and static loads by damping wing bending modes. This is done by symmetrically deflecting the ailerons. The deflection of the ailerons depends on the vertical acceleration measured by six accelerometers, located in the outboard engine pylons.

1.6.2.3 Weather radar system

The Aircraft was fitted with a Honeywell RDR-4000 model weather radar (WXR).

The WXR has a weather (WX) display function, a predictive windshear function, auto-tilt, a turbulence (TURB) detection function and a ground mapping function.

The WXR computes the weather display, along the vertical cut. The weather radar is able to detect the presence of water within rainfall, wet hail, wet turbulence, ice crystals, dry hail and dry snow. On the cockpit main flight display units, the flight crew can display the weather on the vertical display (VD) and on the navigation display (ND) by pressing the WX pushbutton located on the EFIS CP (Figure 3).

The automatic mode (AUTO) is the default mode of the WXR. The WXR continuously scans a volume of space ahead of the aircraft, and stores this data in a three dimensional (3D) buffer. The WXR manual modes can be selected by pulling on the associated control knobs located on the SURV panel (Figure 3) that enables the flight crew to adjust sensitivity of the weather display on the ND.

The cockpit location of the displays and panels can be seen in Appendix A of this Report.

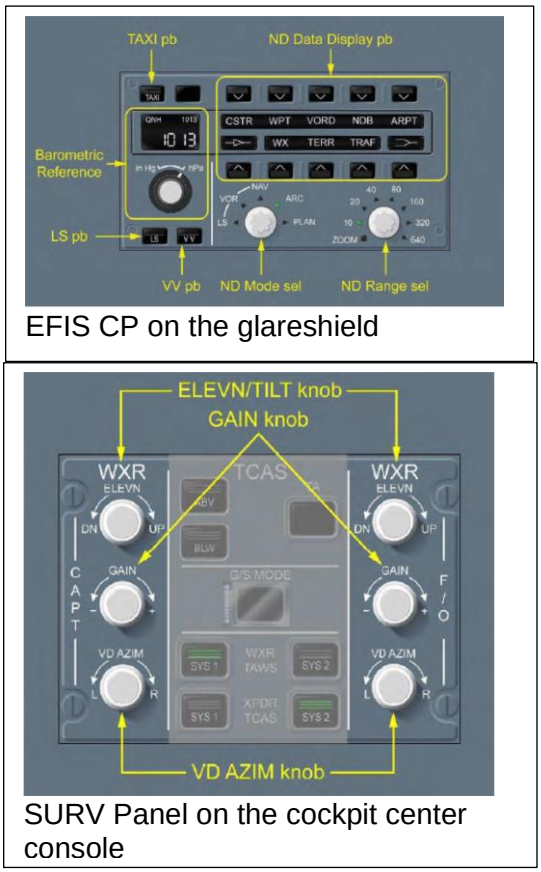

Figure 3. EFIS CP and SURV Panel [Source Airbus]

The WX display function enables the flight crew to view precipitation in different colors (green, yellow, and red) depending on the intensity of the precipitation. The colors of the weather display are the same on the VD and the ND. The weather echo appears with a color scale that goes from red (high reflectivity) to green (low reflectivity).

The turbulence detection (TURB) function is based on the Doppler effect[7] and detects wet turbulence in a volume of space ahead of the aircraft. This function is based on the movement of precipitation. The TURB detection function scans ±60 degrees in azimuth, between 0 ft and 60 000 ft MSL and up to 40 NM in front of the aircraft. The ND displays the areas of wet turbulence in magenta color. As noted in figure 4, the magenta within the white box (the white box is used for illustration purpose only) is on-path wet turbulence. The magenta that is hashed within the blue box (the blue box is used for illustration only) is off-path wet turbulence. The VD does not display areas of wet turbulence.

The TURB function does not detect clear air turbulence or dry turbulence.

Figure 4. TURB area indication (magenta) on ND
[Source: FCOM A380]

TURB detection is available when the WXR is operative and the flight crew sets the TURB button to AUTO on the SURV/CONTROLS page of the multifunction display unit.

For weather to be displayed on the ND, the WX pushbutton must be selected. The *FCOM* states that WXR message[8] TURB (in white with a black background) will appear on the lower right hand corner of the ND when the WXR turbulence detection function system has detected wet turbulence close to the aircraft and the flight crew has not selected WX pushbutton on the electronic flight instrument system (EFIS) control panel. There is no cockpit audio alert associated with the 'TURB' message. Some audio alerts can be triggered in case of predictive and reactive windshear.

The envelope associated with the 'TURB' message is:

- 20 NM on both sides of the aircraft heading
- ± 5 000 ft around the current aircraft altitude.

When the WXR is in automatic mode, it takes into account a vertical envelope along the vertical flight path of the aircraft and defines the applicable weather echo returns, displayed on the ND, on the aircraft flight path (on-path) or not (off-path).

The on-path weather that the aircraft will encounter (i.e. weather inside the envelope) appears on the ND in the conventional colors.

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[7] The Doppler effect is the change in frequency of a signal caused by relative motion between the source of the signal and the receiver.

[8] Reference *Flight crew operating manual (FCOM) DSC-34-20-30-10 P 12/18* section Aircraft Systems 34-Surveillance, WXR, System Description – Turbulence Detection (TURB) Function.

The off-path weather that is not on the aircraft trajectory (i.e. weather outside the envelope) appears on the ND in black parallel lines, with reduced intensity.

For aircraft altitude more than 29,000 feet above mean sea level (MSL), the following are the envelope boundaries:

- For lower envelope boundary
  - Flight altitude minus 4,000 ft or
  - 25,000 ft MSL if there is convective weather detected.
- For upper envelope boundary
  - Flight altitude plus 4,000 ft to a maximum of 60,000 ft.

During level flight, the on-path envelope extends from 4,000 ft above to 4,000 ft below the aircraft altitude. However, when the weather radar detects convective weather, the lower boundary is lowered to 25,000 ft around the convective weather. The upper boundary cannot be lower than 10,000 ft. Figure 4 illustrates level flight on-path and off-path envelope.

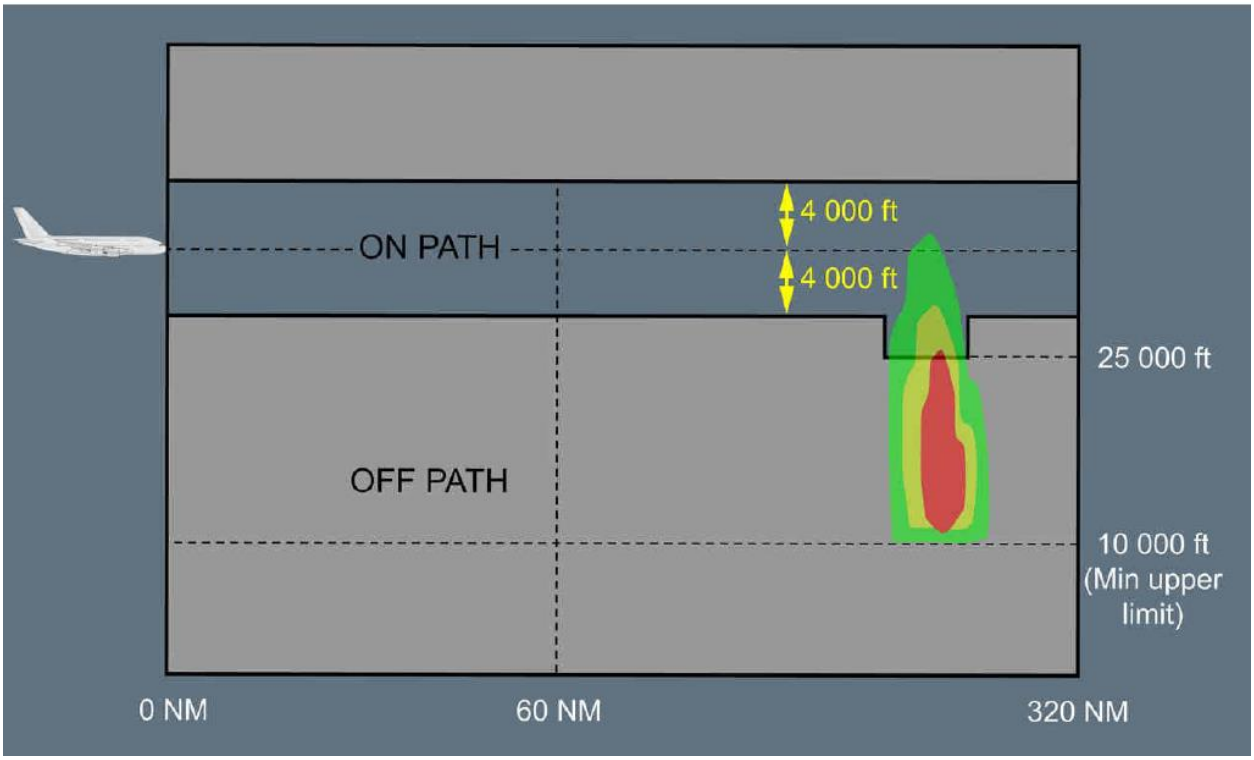


Figure 5. Level flight weather radar display envelope [Source: FCOM A380]

1.7 Meteorological Information

The Investigation confirmed that there were no significant meteorological information (SIGMET) warnings issued by the Indian meteorological office for the area over the Bay of Bengal. The Investigation was unable to obtain actual satellite imagery of the weather system close to 2153 when the turbulence occurred.

The significant weather chart from the OFP that was effective at 1800 on 10 July 2019 is illustrated in figure 6. The approximate area of the turbulence encounter is indicated by the red dot.

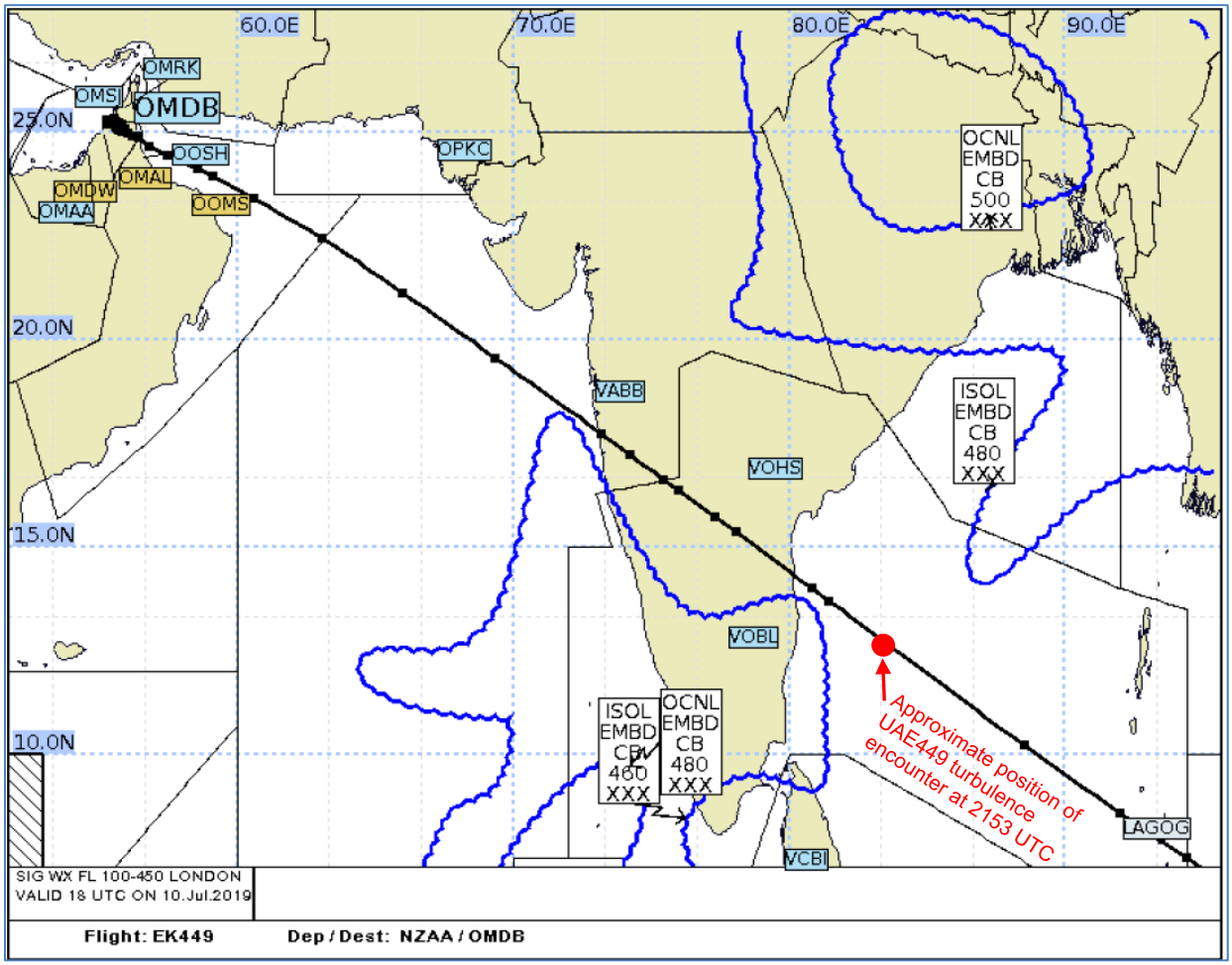


Figure 6. OFP significant weather chart at 1800 on 10 July 2019

The weather chart as illustrated in figure 7[9] was made available to the Investigation by Airbus and shows the significant weather for this area at 0000 UTC on 11 July 2019. The chart shows an area of convective activity with isolated embedded cumulonimbus (CB) and tops at FL460. It also indicates an easterly jet stream at FL490 with maximum wind speed of 120 kt and depth of FL420 to FL550. The large area of low level convergence was oriented generally north-south, slightly northeast-southwest, approximately 100 to 150 NM east of the southern portion of the Indian Sub-Continent. Within this area of convergence, multiple isolated and embedded CBs and multiple lines of CBs can be identified in the chart. The area of convergence was moving east at approximately 15 NM per hour.

Figure 7 indicates the area of the turbulence encounter, shown as a boxed red dot.

[9] Airbus recovered from free access website http://aviationwxchartsarchive.com/tool/brief-pack.

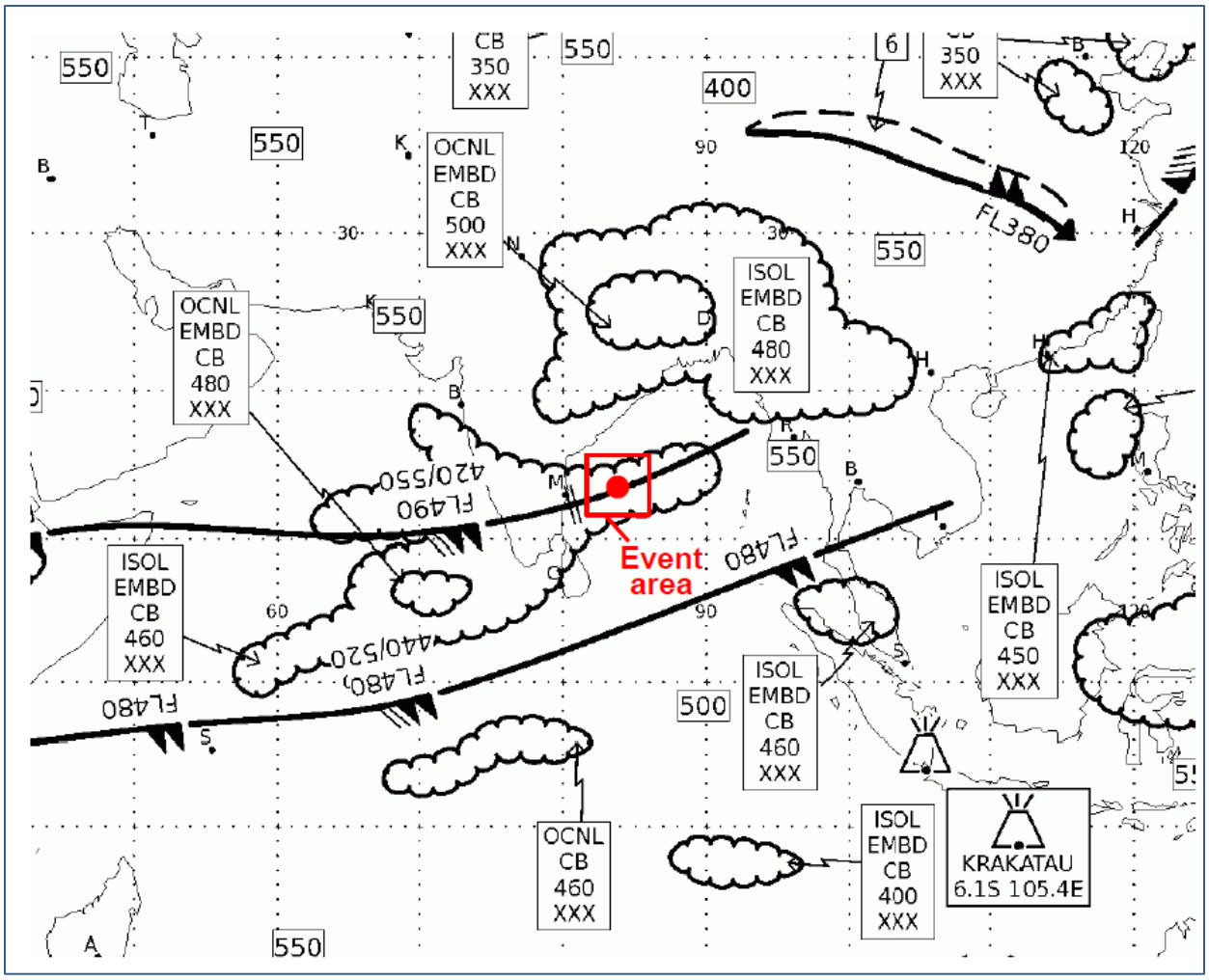


Figure 7. Forecasted significant weather chart at 0000 on11 July 2019 [Source: see footnote No.9]

1.8 Aids to Navigation

The Aircraft was equipped with the required navigational equipment. All ground and onboard navigation equipment were serviceable.

1.9 Communications

The flight crew stated that all Aircraft communications while in the flight information region were uneventful. For this phase of the cruise, over the Bay of Bengal, the flight crew stated that they were communicating with air traffic control through the Controller/Pilot Datalink Communication (CPDLC).

1.10 Aerodrome Information

Not applicable to this Investigation

1.11 Flight Recorders

The Aircraft was fitted with a flight data recorder (FDR) and a cockpit voice recorder (CVR). The FDR data was successfully downloaded and provided to the Aircraft manufacturer for analysis.

The Aircraft manufacturer stated that activation of the seat belt sign and weather data displayed on the navigation display (ND) are not recorded in FDR data. Flight data was also retrieved from the Aircraft's quick access recorder (QAR) and was used to determine when the seat belt switch was moved to the ON position.

Because the CVR records only the last two hours of the flight, the data from the turbulence encounter was overwritten and was not available to the Investigation.

The Aircraft manufacturer provided a report, which contained an analysis of the FDR data related to the turbulence encounter. The following is a summary of this analysis prior to and during the event:

- Between 2148:40 and 2152:16 (Appendix C of this Report):
    - The FDR data confirmed that the weather radar manual mode was not used to obtain a better assessment of the current weather situation.
    - The TURB alert message parameter was recorded on the FDR. Airbus analysis indicates that since the weather was already selected and displayed on the NDs, some magenta areas were permanently displayed on NDs during the time the TURB alert message parameter was permanently triggered.
- At 2148, the Captain's and Copilot's navigation displays (ND) were selected in 'ARC' mode with a range of 80 nautical miles (NM).
- Between 2148 and 2203, the Copilot's range was changed 10 times between 40 NM, 80 NM, 160 NM and 320NM.
- At 2153:25, the Aircraft entered an area of turbulence that ended at 2157:30. The strongest turbulence was encountered in the initial 20 seconds between 2153:25 and 2153:45.
- Significant wind variations were recorded in the FDR data at the start of the strongest disturbances. A significant tailwind decreased from 54 kt to 17 kt in five seconds. In the lateral axis, there were short bursts of left and right gusts varying between 29 kt and 40 kt.
- At 21:53:36, a significant tailwind decrease from 54 kt to 17 kt in 5 seconds was encountered leading the Mach number to increase from 0.837 to 0.903 in less than 6 seconds.
- Mach number reached MMO (0.89) +0.006 leading to an overspeed warning for three seconds between 2153:40 and 2153:43.
- The speed increase caused an automatic thrust adjustment commanded by the autothrust, and automatic speed brake deployment commanded by Flight Control

Laws. However, these automatic aircraft system actions were not sufficient to avoid a transient MMO exceedance.

- The Aircraft encountered a significant downdraft of approximately 3,000 feet per minute soon followed by a significant updraft of about 3,000 feet per minute.
- For the duration of the turbulence:
    - Vertical load factor varied between -0.35 G and +1.65 G
    - Lateral load factor varied between -0.15 G and +0.10 G
    - Angle of attack varied between -1.0 degree and +5.5 degree.
    - Load Alleviation Function (LAF) activated more than 10 times during the turbulence event, contributing to reduce the fatigue and static loads on wing structure. The LAF activated for approximately 27 seconds.
    - Based on the ICAO turbulence classification in *Doc 4444 Procedures for Air Navigation Services – Air Traffic Management*, the Aircraft had encountered severe turbulence.
- The variations of load factor and angle of attack were fully consistent with the wind variations.
- Autopilot (AP) and Autothrust (A/THR) remained engaged during the entire turbulence period.

The Aircraft Post Flight Report (PFR) that was retrieved by the Operator from the Aircraft Onboard Memory Central Maintenance System (CMS), had recorded a fault code which stated OVERSPEED LOADS ANALYSIS REQUIRED. This was recorded in the CMS during the turbulence on 10 July 2019 at 2153 during the cruise phase. The flight crew made a technical log book entry for severe turbulence only, as they were not aware that the Aircraft experienced an overspeed.

Appendix B of this Report illustrates that the seat belt sign was switched ON by the Captain at approximately 2148, five minutes before the turbulence encounter. This Appendix also shows the turbulence g-loads the Aircraft encountered for about four minutes starting from 2153:25.

1.12 Wreckage and Impact Information

Not applicable to this Investigation as the Aircraft landed uneventfully at OMDB.

1.13 Medical and Pathological Information

There was no evidence that physiological factors or incapacitation had affected the performance of the flight crew.

1.14 Fire

There was no reported fire.

1.15 Survival Aspects

The severity of the injuries sustained by the passengers and cabin crewmembers as a result of the turbulence and impacting the Aircraft interior were considered to be non-life

threatening. The injuries were assessed via communication between the flight crew and the Operator's ground medical team. Based on this assessment a diversion was not considered to be necessary and the flight continued to OMDB where upon arrival, the injured persons onboard were medically attended to.

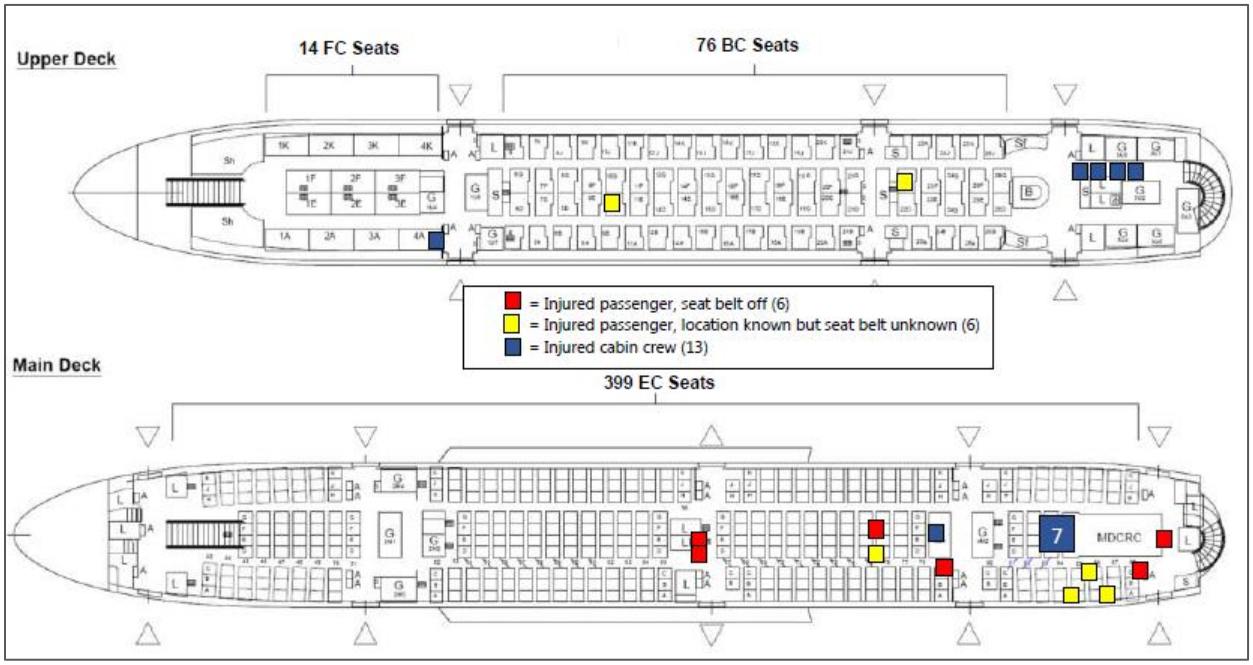


Figure 8. Location of the injured passengers and cabin crew [Source: Emirates]

Figure 8 illustrates a schematic of the Aircraft seating and the location of the passengers and cabin crewmembers injured during the turbulence encounter. The Investigation was unable to verify the location of two passengers, one each in business and economy class, and the lavatories where they sustained their injuries. The figure also shows the status of the passenger seat belt sign for the injured passengers.

During the post incident interviews, the Cabin Manager stated that he was not aware that the seat belt sign was ON five minutes before the turbulence encounter. He could not recollect if he had heard the chime when the seat belt sign was turned ON. The remaining 14 cabin crewmembers on duty during the turbulence encounter could neither recall seeing the seat belt sign ON nor hearing the seat belt chime when it was turned ON. Because the cabin crew did not observe the seat belt sign ON, no passenger announcement was made directing passengers to return to their seats and fasten their seatbelts, nor was any physical verification performed to check that passengers had their seatbelts fastened.

1.16 Tests and Research

Except for the Aircraft manufacturer's analysis of the environmental conditions and Aircraft performance during the turbulence encounter, no tests or research was carried out.

1.17 Organizational and Management Information

1.17.1 The Operator

1.17.1.1 Seat belt policy

The policy of the Operator, in accordance with the Operator's *Operations Manual* (*OM*), states that the seat belt sign must be switched ON and a seat belt is to be worn by all passengers under several conditions, which include, "in turbulent conditions or when turbulent conditions are expected", and "at the Commander's discretion or as required by abnormal or emergency procedures". The *OM* states that "whenever passenger seat belts are to be fastened, each person who is aged 2 years or more must wear a safety belt or be strapped in a child restrain device, which is acceptable to the Authority".

In July 2008, the Operator revised its policy. The automated audio announcement throughout all sections of the cabin to fasten seat belts when the seat belt sign was turned ON was discontinued. This policy change was accepted by the GCAA. The change followed a service delivery request to minimise the amount of cabin announcements especially during night flights in order to minimize disturbance to the first and business class passengers. Following this change, the updated standard operating procedure required that the cabin crew:

"

- perform fasten seat belt announcement only in economy cabin together with a physical walk through the cabin to ensure that passengers seat belts were fastened and;
- for the premium cabin, first and business class, to perform a physical walk through the cabin to ensure that passengers seat belts were fastened.
- passengers before takeoff briefing includes advising to keep their seat belts fastened at all times whilst seated during the flight."

1.17.1.2 Turbulence levels

As part of the Operator's annual flight and cabin crew recurrent training, theoretical and practical instructions include duties to be undertaken in the event of encountering turbulence.

The *OM* states that as part of the pre-flight briefing, the flight crew must inform the Cabin Manager and the rest of the cabin crew about expected areas of turbulence during the flight.

In accordance with the *OM* flight procedures for anticipated turbulence during flight, flight crews are instructed that if the weather conditions, cloud structure and route forecast indicate that turbulence is likely, the cabin crew shall be advised. For turbulence encounter that is imminent or unpredicted, the flight crew are required to switch the seat belt sign ON and advise passengers to return to, or remain in their seats, ensuring that their seat belts/harnesses are securely fastened. For cabin services, if the seat belt signs are switched ON during cruise due to turbulence, the flight crew are required to communicate with the Cabin Manager as to the level of cabin service that is appropriate.

For take-off, landing and during turbulence, in order to notify the Cabin Manager that an area of the cabin is secured, cabin crew are required to press the respective flight attendant panel AREA READY button on the flight attendant panel. After all areas are confirmed ready, the Cabin Manager is required to inform the flight crew that the cabin is ready by pressing the CABIN READY button. The CABIN READY signal confirms that all cabin crew, except the Cabin Manager are seated with lap belts and shoulder harnesses fastened.

Table 4 is a summary of the Operator's policy in regards to the level of flight turbulence encounters and relevant crew actions.

Table 4. Flight turbulence level and crew actions

Level	Light	Moderate	Severe
Definition	Momentarily causes slight, rapid and rhythmic movements without change in aircraft altitude or attitude.	Causes rapid bumps or jolts. Moderate changes in aircraft altitude or attitude may occur but the aircraft remains in positive control as all times.	Causes abrupt changes in the aircraft altitude and attitude. Aircraft may be out of control for short periods.
Flight crew actions - Anticipated	- advise the purser when turbulence is expected and to ensure that the passengers are secured in their seats; - Switch the seat belt sign ON; - At the discretion of the Captain, to advise the purser the level of cabin service.	- advise the purser when turbulence is expected, to cease all cabin service, secure the galleys and for cabin crew to be seated; - Switch the seat belt sign ON; - Report turbulence to flight dispatch; - Record severe turbulence in the aircraft technical log.	
Flight crew actions - Unanticipated	- Switch the seat belt sign ON - At the discretion of the Captain, communicate with the purser the level of cabin service.	- Switch the seat belt sign ON; - Make a passenger announcement for cabin crew to take seats immediately; - Report turbulence to flight dispatch; - Record severe turbulence in the aircraft technical log.	
Cabin crew actions	- For economy class, make a passenger announcement to RTS and FSB. Ensure passengers in the lavatory RTS. Ensure all passengers and infants are seated and FSB. - In first and business class, individually inform passengers to RTS and FSB. - Secure the galleys and galley equipment; - Cabin crew will pass their area ready check to the purser - The purser will communicate to the Captain that 'Cabin Ready'	Anticipated moderate or severe turbulence: - For economy class, make a passenger announcement to RTS and FSB. Ensure passengers in the lavatory RTS. Ensure all passengers and infants are seated and FSB. - In first and business class, individually inform passengers to RTS and FSB. - Secure the galleys and galley equipment; - All cabin crew shall be seated on their jump seats with seat and shoulder belts fastened; - Cabin crew will pass their area ready check to the purser - The purser will communicate to the Captain that 'Cabin Ready'.	

		Unanticipated moderate or severe turbulence: - If possible, make a passenger announcement to RTS and FSB. - Secure hot liquids, galleys and galley equipment; - All cabin crew to be seated immediately on any seat and FSB and those on jump seats to fasten seat and shoulder belts.

1.17.1.3 Adverse weather operation

For adverse weather, the *Flight Crew Operating Manual* (*FCOM*) states that the flight crew should monitor the weather, by selecting long and also short ND ranges, in order to determine the best trajectory to avoid areas of adverse weather. In order to avoid thunderstorms, the *FCOM* recommends the pilot monitoring (PM) to select a range of 160 NM on the ND and the pilot flying (PF) a range of 80 NM.

To avoid a large thunderstorm, or 'area of greatest threat', flight crew are instructed to decide at least 40 NM away from the thunderstorm what action to take to avoid any identified "area of greatest threat" keeping a distance of at least 20 NM from the weather. When in doubt, the flight crew are required to use lateral deviation over vertical deviation. Figure 9 illustrates the margins and distances.

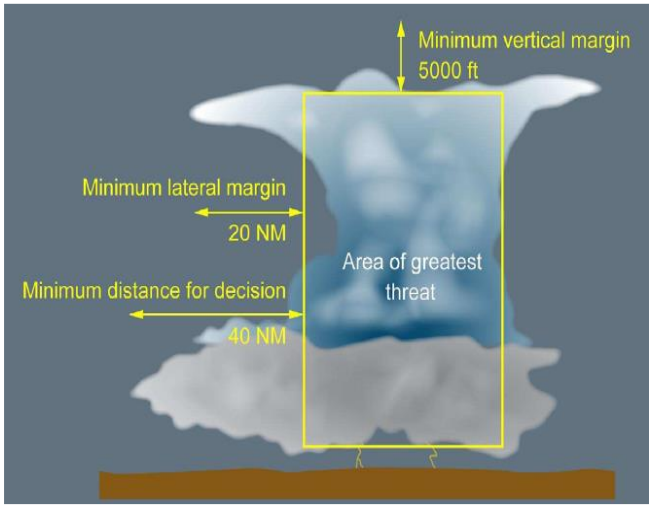


Figure 9. Summary of margins and distances [Source: FCTM A380]

The *Flight Crew Techniques Manual* (*FCTM*) states that to avoid the 'Blind Alley' effect and to correctly detect the weather, the flight crew should use a combination of both low and high ND ranges. A high ND range provides the flight crew with a long-term vision, for strategic anticipation. The 'Blind Alley' effect occurs when the use of a low ND range hides weather on the flight path. As a result, the use of two different ND ranges on PF and PM sides provides enhanced awareness of the situation.

In order to analyze the WXR returns with increased precision, the *FCOM* procedure *PRO-SUP-91-30 WEATHER RADAR* and *FCTM* recommendation to cope with adverse weather states that the flight crew can use manual gain as this mode adjusts the sensitivity of the weather display on the ND. As a result, the weather signal will appear either stronger (increased gain) or weaker (decreased gain).

As part of the pilots training and FCOM procedure, it is stated to avoid:

- Areas of severe turbulence by flying the aircraft above, or around, these areas.
- All yellow, red, or magenta areas by at least 20 NM.
- Single magenta areas of turbulence that are not associated with heavy precipitation, by at least 5 NM.

- Penetrating a cell.
- Clearing its top by less than 5,000 ft vertically, because turbulence may occur at the top of the clouds.
- Overflying a cell if its top is at or above 25,000 ft, because turbulence may be stronger than expected.
- Flying under a thunderstorm or convective cloud, because of possible windshears, microbursts, severe turbulence, or hail.

When the WXR is in AUTO mode, the *FCTM* states that off-path weather is displayed on the ND with black parallel lines. In such cases, and If the ND displays off-path weather with yellow, red or magenta color, the flight crew are required to perform a detailed analysis of the corresponding convective cell.

For operations in convective weather, the *FCTM* alerts pilots that for weather detection, frequent lightning may indicate an area with high probability of severe turbulence.

The FCTM states that flight crew must be aware that radar top may not be the visible top of the convective cloud, and that convective cloud and associated areas of threat (e.g. turbulence) may significantly extend above the radar top as illustrated in figure 10.

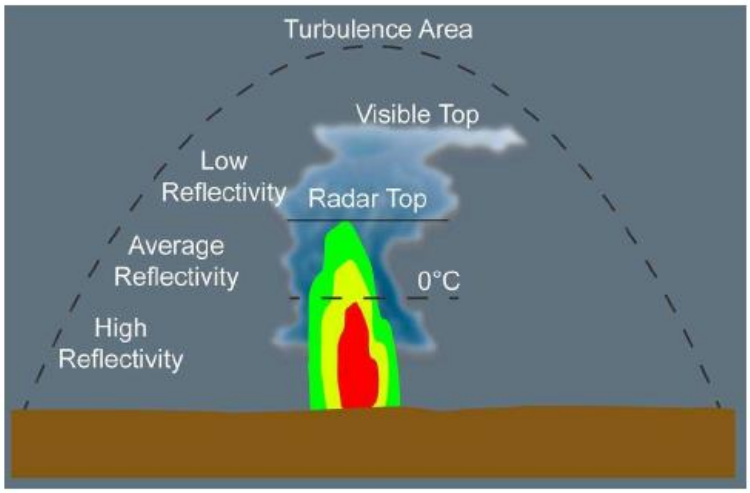


Figure 10. Turbulence area above the 'visible top' [Source FCTM A380]

The Operator's flight procedures policy in the operating manual *OM-A* states that the flight crew must report to air traffic control as soon as possible whenever there is moderate and severe turbulence, and particularly when a 300 ft or more deviation occurs, giving position, altitude, wind velocity and direction.

Flight crew training consisted of an eLearning turbulence presentation; operations manual policy for thunderstorm avoidance; recurrent training 'flight in turbulence'; weather radar batch-6 presentation for the Airbus A380; Honeywell weather radar differences; and severe turbulence events during line operational evaluation (LOE).

For updated weather information enroute, the Operator stated that flight crew were able to contact air traffic control to get the latest SIGMET and pilot reports. In addition, they could request weather updates from the Operator's flight dispatch throughout the flight using the Aircraft Communication Addressing and Reporting System (ACARS), or alternatively by contacting flight dispatch via voice communication using Satphone. The Operator stated that pilots were unable to get updated weather information on the electronic flight bag (EFB) during flight.

The FCOM *Abnormal and Emergency Procedures* for *Overspeed Prevention* provides the operating techniques when the aircraft encounters significant speed variations close to maximum operating Mach (MMO). This procedure requires keeping the autopilot and autothrust

ON, reducing the selected speed and if the speed trend approaches MMO, using the speed brakes as required.

1.18 Additional Information

1.18.1 Operator's cabin service unit handholds

On the Operator's A380 aircraft, the Investigation reviewed the location of the handholds in the lavatory, wet and dry galleys, cabin work stations, lounge areas and crew rest compartment.

Lavatories for people of determination had multiple handholds at different heights, which were easily reachable in all circumstances.

Other lavatories had either one or two handholds. The orientation in lavatories with a single handhold, was either horizontal or vertical, and those with two were oriented one horizontal and the other vertical. The handles were placed on the lavatory wall and within reachable distance and height only for a person who was seated on the toilet. None of the lavatories had handholds adjacent to the lavatory wash sink. In some lavatories, if the occupant was using the wash sink, the installed handhold was behind their back.

The wet galleys had handholds that were mostly placed close to the top of galley units and sometimes between the upper storage doors. These handles were of the same colour as the surrounding structure of the galley. The number of handholds on the wet galley units depended on the size of each unit. The small units had one handhold and the larger units had either two or three handholds. Most of the handholds were above the galley counter tops and at a height above the heads of the cabin crew. One galley vertical wall adjacent to the cabin aisle had a slot cutout which acted as a handhold. The size of the handholds and slot, would allow for a single hand only

The dry galleys and work stations had no handholds.

Most of lounge areas had handhold. The shower had a single handhold adjacent to the shower seat.

Each of the nine cabin crew rest bed compartments, which were located in the aft section of the cabin, had a single seat belt which restrained the wearer at the waist. There was no handhold any of the bed compartments. The interior walls were made of fiber glass reinforced plastic.

Figure 11 illustrates samples of the A380 cabin handholds.

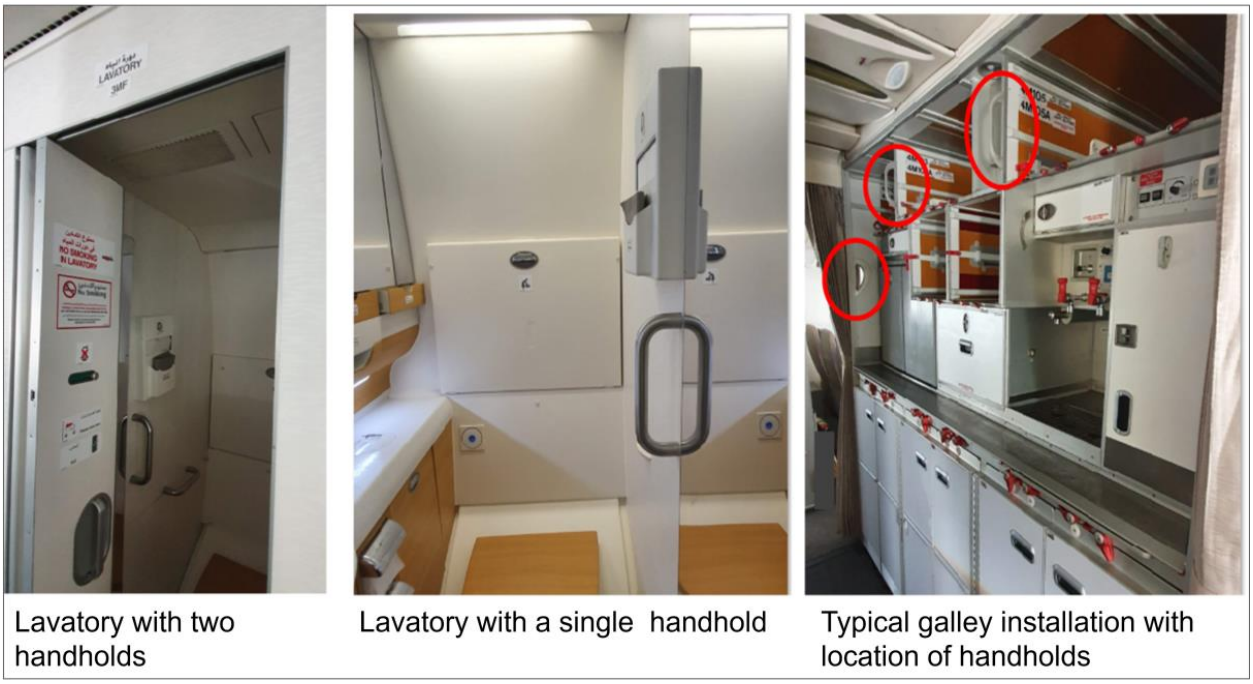


Figure 11. Examples of the A380 cabin handholds

1.19 Useful or Effective Investigation Techniques

The Investigation was conducted in accordance with the Legislation and *Civil Aviation Regulations* of the United Arab Emirates, in accordance with the AAIS approved policies and procedures, and the Standards and Recommended practices of Annex 13 to Chicago Convention.

2. Analysis

2.1 General

The flight and cabin crewmembers were appropriately licensed and medically fit to operate the flight.

The Aircraft was maintained in accordance with the maintenance program approved by the General Civil Aviation Authority of the United Arab Emirates, and there were no technical anomalies prior to the turbulence. The Aircraft systems and engines performed as designed.

2.2 Flight planning

For the flight from Auckland to Dubai, the OFP provided to the flight crew contained the significant enroute weather charts which were effective from 1800 on 10 July 2019. The planned flight route took the Aircraft over the Bay of Bengal just north of a large area with forecasted cumulonimbus clouds.

Because it was monsoon season, convective clouds such as embedded CBs and squalls are normally expected over the Bay of Bengal at this time of year. However, because the Commander for the flight did not consider the weather enroute to be a threat to the planned flight based on the pre-departure weather package, there were no changes made to the flight plan.

The augmenting flight crew, who operated the Aircraft during the turbulence encounter, were aware of an area of significant weather activity based on the following; the OFP significant weather chart, the handover from the outgoing flight crew with information that other flights were requesting deviations; the evidence of lightning approximately every 30 seconds; the visibility of the cloud tops; and the squall lines that they had reported. After discussion between the operating Captain and Copilot, their decision was to continue along the planned route and not request a deviation, as the weather activity was painting off-path on the navigation display (ND).

According to the significant weather chart (provided to the Investigation and not available to the flight crew) effective at 00:00 on 11 July 2019, two hours after the turbulence encounter, the forecast showed that the large area of adverse weather was still active with isolated embedded cumulonimbus clouds and was moving north-east at 15 kt with cloud tops at 46,000 ft.

The flight planning for long-range flights will always be challenging. Significant weather forecasts may change after an aircraft departs. For UAE449, the reliability of the weather forecast would have decreased over the duration of the flight time, especially as the forecast available to the flight crew was produced approximately 16 hours before the Aircraft neared waypoint IDASO. Thus, in planning a long-range flight that has adverse weather forecast some 13 hours into the flight, there should be consideration in minimizing the risk of exposure to adverse weather conditions.

As turbulence associated with cumulonimbus clouds extends beyond the cloud itself, consideration should be given for weather avoidance especially when the planned route is in an area where cumulonimbus clouds have developed.

The Investigation recommends that the Operator review, and enhance, flight planning taking into consideration known historical geographical locations that are affected by seasonal enroute significant weather and meteorological conditions.

2.3 Flight crew performance

The flight crew members stated that before entering the Bay of Bengal, the flight was uneventful with no significant weather. During the cruise phase with the Aircraft at FL400, approximately 12.5 hours into the flight, there was a planned change of flight crew in line with normal flight procedures. During the handover, the outgoing flight crew had briefed the incoming crew about an area of threat and that other flights were deviating from course to avoid the weather.

Being aware of the threat as the Aircraft approached waypoint IDASO, the operating flight crew became more attentive to the weather and made the necessary range adjustments to the weather radar by selecting long and short ranges. In order to have a better view of the lightning that was present during the night flight, the cockpit lights were also dimmed.

Because the Operator does not facilitate updated enroute weather information on the flight crew electronic flight bag, flight crews are instructed to contact air traffic control for the latest significant weather and pilot reports, as well as the Operator's flight dispatch for weather updates. As the operating flight crew assessed that they would safely pass the unsettled weather, they continued the flight along the planned route without requesting updated weather information.

Therefore, apart from the flight plan's significant weather charts, the only other reference for the existing weather ahead was the echo returns from the weather radar system. The decision to not request additional weather information was influenced by the weather radar system which was showing that the weather as off-path, indicating that the weather system threat was below the Aircraft by at least 5,000 ft.

For operations in convective weather, the *FCTM* alerts pilots that for weather detection, frequent lightning may indicate an area with a high probability of severe turbulence. The flight crew did not consider that there was a significant threat to the operation of the Aircraft along the planned flight route as they stated that the weather radar did not show any indication on the ND that there was precipitation. Consequently, they made the decision not to deviate from the planned route. They were cognizant that a decision to deviate around an adverse weather system is normally taken before the aircraft comes within 40 NM from a convective cloud and that any avoidance away from the identified area of greatest threat was to be taken by at least 20 NM, and that lateral deviation instead of vertical deviation was preferred.

With the Aircraft within five minutes of the turbulence encounter, the FDR data indicates that some wet turbulence were detected ahead of the Aircraft within the envelope of WXR turbulence detection function. The detected wet area was displayed in the form of magenta on both NDs. At around the same time, the Captain turned the seat belt sign ON at about 2148. This was approximately 40 NM before the turbulence encounter.

In accordance with the flight crew procedures, pilots are required to avoid all areas showing yellow, red or magenta by at least 20 NM, and any single magenta areas of turbulence that are not associated with heavy precipitation, by at least 5 NM. For UAE449, it is possible that the wet turbulence detected was within the envelope of detection but 20 NM off to one side of the flight path, and hence no deviation was required.

Between both flight crewmembers previous flying experience on the A380, they would have transited off-path weather that resulted in light or no turbulence. Thus, because the Aircraft was in clear air, they did not anticipate that the Aircraft would have encountered any turbulence as they stated that were "downwind of the CBs", had just passed the second squall line and that there was no precipitation indicated on weather radar along the flight path.

When the turbulence started at 2153, the flight crew correctly executed the *FCOM Abnormal and Emergency Procedures* for *Overspeed Prevention* and kept the autopilot and autothrust engaged. The Copilot deployed the speed brakes and reduced the selected speed, however unknown to the flight crew, the maximum operating Mach number (MMO) was momentarily exceeded. The Aircraft post flight report confirmed that there was an OVERSPEED warning triggered which the flight crew was not aware of.

The severity of the turbulence encounter was not immediately known to the flight crew but was quickly classified as severe when the cabin crew reports of injuries and cabin damage were received. When the cabin crew reported the need to contact the Operator's medical ground support, the flight crew became busy, so no notification was sent to air traffic control advising that the Aircraft had experienced severe turbulence.

The *FCOM* describes severe turbulence stating that it causes large and abrupt changes in altitude and/or attitude, usually causes large variations in airspeed, pushes passengers and crewmembers against their seat belts, and causes loose objects to move around the aircraft.

The Investigation believes that the threat of adverse weather containing a large area of convective activity with embedded cumulonimbus clouds should always be thoroughly reviewed. The flight crew did not identify that there was a threat to the Aircraft by staying on the planned route, but were aware that other pilots were requesting deviation around the weather as well as the high lightning activity as they approached waypoint IDASO. To aid their decision making process, they could have been better informed had they used the WXR manual mode as per *FCOM PROSUP- 91-30 WEATHER RADAR* procedure, communicated with air traffic control, and/or the Operator's flight dispatch, and obtained the current updated weather information and pilot reports.

The Investigation recommends that the Operator reiterate to pilots the threat of adverse weather conditions, and taking timely avoidance decision based on weather charts, weather radar echo returns and alerts, and taking into consideration other information including updated weather information and pilot reports, when available.

The Investigation recommends that the Operator enhance the ability of pilots to access updated weather information through the electronic flight bag and/or updates from flight dispatch.

2.4 Aircraft performance

For the different flight phases, including cruise at FL400, the Aircraft was flown in the correct configuration and attitude with the autopilot and autothrust engaged.

Five minutes before the start of the turbulence encounter at 2153:25, the Aircraft had a tailwind component of approximately 55 kt and a right crosswind component of 40 kt. The airspeed was maintained at the target of 0.84 Mach.

At the beginning of the turbulence encounter, the FDR data indicated significant wind variations. The tailwind component reduced suddenly to about 17 kt. and in the lateral axis there where short bursts of left and right crosswind component gusts varying between 29 kt. and 40 kt. Severe turbulence occurred within the initial 20 seconds, from 2153:25 until 2153:45. This caused variations in the Aircraft attitude, altitude and a sudden airspeed increase, which momentarily exceeded MMO. The Aircraft systems responded in order to avoid the overspeed, however even with the autothrust reducing the engine thrust and the automatic deployment of the speedbrakes, there was an exceedance of the MMO speed that resulted in an overspeed warning lasting three seconds.

During the turbulence, as designed, the load alleviation function (LAF) had automatically engaged for about 27 seconds in order to reduce the fatigue and static loads on the wings. During this time, there were 10 symmetrical deflections of the ailerons and/or the outer spoilers upwards.

Based on the Airbus analysis, the turbulence encounter resulted in the Aircraft and occupants experiencing significant variations of vertical and lateral load factor and angle of attack, which were consistent with the adverse wind variations.

The Investigation concludes that throughout the severe turbulence encounter, the Aircraft autopilot and autothrust remained engaged, and the Aircraft remained controllable. The Aircraft systems, as designed, automatically responded to sudden flight variations in order to avoid the overspeed. However, due to the sharp longitudinal wind variation, the thrust adjustment and the automatic speed brakes deployment were not sufficient to avoid the transient MMO exceedance and Mach number reached MMO +0.006 leading to an overspeed warning.

2.5 Aircraft weather radar

The weather radar fitted to the Aircraft was of the latest modification status systems available from the Aircraft manufacturer and was standard across the Operator's fleet of A380 aircraft. The A380 weather radar incorporates several automated functions with manual intervention by the flight crew.

Pilots are made aware through eLearning of the capabilities of the weather radar as well as the meaning of the different colors displayed on the ND. The flight crew were aware that the weather radar was unable to detect clear air turbulence (CAT) because the air does not contain any precipitation.

For UAE449, in accordance with standard operating procedures, the weather radar and TURB functions were in AUTO mode and the WX push button was pushed which allowed weather information to be seen on the ND. The TURB function of the weather radar detects areas of wet turbulence up to 40 NM ahead of the aircraft, which is shown in magenta.

Before the turbulence encounter, between 2148 and 2152, the FDR data recorded that the TURB alert parameter message was triggered (see Appendix C of this Report). This meant that wet turbulence was displayed as magenta area/s on both flight crew's navigation displays within an envelope that was 20 NM on both sides of the aircraft heading, 40 NM ahead and ± 5 000 ft around the current aircraft altitude.

The weather radar display on the ND of green, yellow and red areas are not recorded in FDR or cannot be deduced from indirect recorded parameters as done for magenta areas. As a result, the Aircraft manufacturer was not able to identify at the time of the event the area of greatest threat and the actual vertical and lateral margin between this area and the UAE449 Aircraft trajectory.

With the Aircraft approximately 40 NM away from the turbulence, the flight crew had both applied the procedure of changing the range on the ND and the gain on the weather radar. However, the FDR data indicated that the weather radar (WXR) manual mode/s on the SURV panel was not used within the five minutes immediately before the turbulence encounter. The *FCOM* procedure requires using the WXR manual mode temporarily "in order to monitor thunderstorm development and to obtain the best cell echo". In accordance with the *FCTM* training to avoid the 'Blind Alley' effect, the FDR data also indicated that the range setting of ND for both pilots was adjusted between long range and short range. Even though the FDR data indicated that there was adjustment of the Copilot's ND range, other than the Captain's 80 NM setting, the data did not confirm any other settings were made (see Appendix C of this Report).

The Investigation believes that the detection of wet turbulence requires further explanation and guidance in the *FCOM* and *FCTM* by the Aircraft Manufacturer so that there is clear understanding and actions required by pilots. Knowing the capabilities and limitations of the weather radar installed on the aircraft is essential as well as being familiar with the techniques to optimize the use of the weather radar.

As the decision by the flight on what action is required is based on when the flight crew observes the magenta and then processing this information, in case the flight crew fails to observe the magenta from the onset, means that there is a greater possibility that the aircraft will be affected by wet turbulence. For an aircraft in cruise, the distance covered in one minute is approximately 8 NM, thus the Investigation believes that without any aural cockpit alerting system for when wet turbulence is detected within the 40 NM envelope, reduces the time for the flight crew to make an appropriate decision.

In addition, similar to the recording of the TURB alert parameter, the Aircraft Manufacturer is encouraged to facilitate the recording of other adverse weather precipitation information as displayed on the NDs so that flight data detected and captured by the weather radar can be used to enhance pilot training.

The Investigation concludes that the Aircraft weather radar was operating as designed. However, because the flight crew did not observe the magenta area/s on the navigation display, they limited their use of the weather radar by adjusting the gain and did not effectively use of the manual modes to enhance the echo returns. This would have assisted them in their assessment of the thunderstorm especially as they had reported prior to the turbulence “thunderstorm squall line in area, but no avoidance was required as weather was below aircraft and off-path”.

The Investigation recommends that the Operator reiterate to pilots the importance of using the full capability of the weather radar to better analyze adverse weather situations.

The Investigation recommends that the Aircraft Manufacturer enhance the explanation and guidance in the *FCOM* and *FCTM* of the detection of wet turbulence so that there is clear understanding and actions required by pilots.

The Investigation recommends that the Aircraft Manufacturer enhance the cockpit alerting system to include when wet turbulence is detected by the weather radar turbulence function.

The Investigation recommends that the Aircraft Manufacturer facilitate the flight data recording of adverse weather precipitation detected by the weather radar as displayed on the NDs so that this information can be used to enhance pilot training.

2.6 Cabin readiness

In order to maintain a good understanding of any flight, the preflight briefing by the flight and cabin crew is the initial phase when any forecast weather and the possible effects on flight conditions are briefed together. The flight crew will normally inform the cabin crew of any expected turbulence events and provide the estimated flight times and locations of possible turbulence. For UAE449 this was done during the preflight briefing.

Prior to the turbulence, there were 15 cabin crewmembers on duty serving the 378 passengers. Of these cabin crew, one was in the cockpit, seven were serving 78 first and business class passengers in the upper deck, and seven were serving the 300 economy class passengers in the main deck.

When the operating Captain turned the seat belt sign ON at about 2148, the Aircraft was almost 13 hours into the flight. At this time, passenger cabin service was minimal and no serving trolleys were in the cabins.

The flight crew's intention of switching the seat belt sign ON, was for the passengers to return to their seats and fasten their seat belts. However, this was not verbally communicated to the Cabin Manager. The flight crew did not anticipate that the cabin service would have been affected, thus, the cabin crew continued their normal duties. Except for the cabin crewmember in the cockpit and the one seated in the upper deck forward jump seat, the remaining 13 cabin crew on duty were standing either in the galleys, cabin or near the lavatories.

None of the 15 cabin crewmembers who were on duty could recollect either seeing the seat belt sign coming ON or hearing the chime when the seat belt sign was switched ON. Because of this lack of awareness, there was no cabin readiness performed for the upper and main passenger decks as required when the seat belt sign is switched ON.

It was only during the turbulence encounter that the Cabin Manager made a passenger announcement (PA) for all cabin crew and passengers to take their seats and to fasten their seat belts. At this time, it was too late as several persons onboard had already suffered injuries.

The severity of the wind variations resulted in significant vertical g-loads between minus 0.35G and positive 1.65G. As a result, several unrestrained passengers and cabin crewmembers were lifted off their feet and impacted the cabin ceiling causing injuries and damages. The Aircraft movements were more significant in the aft cabin and aft galleys for both the upper as well as the main cabin which resulted in several galley equipment being tossed on the galley floor.

For the status of the passenger's seat belts, it is most likely that the majority of passengers had complied with keeping their seat belts fastened for their own personal safety, as the number of injured passengers, especially in the aft cabin, would otherwise had increased. Passengers who had their seat belts fastened, were either aware of the seat belt sign coming ON or had paid attention to the Commander's and cabin crew passenger address before takeoff communication of keeping their seat belts fastened whilst seated.

Of the 14 passengers who were injured, two were in the lavatories and 12 were seated. Based on the post turbulence analysis done by the Operator, as well as the cabin crew report, of the 12 injured passengers, it was confirmed that six injured passengers did not have their seat belts fastened. Due to the severity of the turbulence, it is most likely that the remaining six injured passengers did not have their seat belts fastened.

Of the 13 cabin crew who suffered minor injuries, 12 were in the aft cabin and one was in the forward cabin. Of the 12 cabin crew in the aft cabin, five were in the galleys and seven were resting in crew rest compartment with their seat belts fastened.

Turbulence levels stated in the Operator's *operations manual* (*OM)* are light, moderate and severe. Because there was uncertainty by the flight crew if there was going to be turbulence or not, the existing weather conditions, prompted them to make the correct decision and turn the seat belt sign ON. This action by the flight crew was in anticipation in case if there was turbulence to have the passengers seated with the seat belts fastened. However, as required by the Operator's policy, what the flight crew were anticipating was not informed to the Cabin Manager.

For an aircraft like the A380 with close to 500 passengers, during a long-range flight when there are less cabin crew on duty due to planned rest cycles, it may not be possible for the available cabin crew to stop cabin services, stow galley equipment, and visually verify that each passenger has seated with their seat belts fastened if there is not sufficient notice from the flight

crew. Because the automated audio announcement throughout the cabin to fasten seat belt feature when the seat belt sign was turned ON was progressively discontinued from all of the Operator's aircraft starting from 2008, ensuring timely notification and communication from the flight crew to the cabin crew becomes even more critical.

The Investigation concludes that there were missed opportunities that started five minutes before the severe turbulence encounter to have the cabin ready before the turbulence encounter. The cabin crew lacked the awareness of the seat belt sign status even though the flight crew had turned the seat belt sign ON. The possible threat of associated turbulence because of the thunderstorms that was observed by the flight crew was not communicated to the Cabin Manager. It is possible that during many flights, there will be times when the seat belt sign will be switched ON more than once for anticipated turbulence. Especially during long-range flights, it is possible that the cabin crew may become less alert thus missing the seat belt chime sounds and the flashing of the seat belt sign.

There is always a risk of persons onboard suffering injuries because of turbulence especially if the cabin is not ready. When turbulence is expected during the flight, the flight crew should turn ON the seat belt sign and advise the cabin crew on how much time is available to secure the cabin, the level of turbulence and the expected duration. Thereafter, it is the duty of the cabin crew to ensure that all passengers and cabin crew are safe, and galleys are secured. To complete the feedback, the Cabin Manager should then notify the flight crew that the cabin is ready.

The Investigation recommends that the Operator improve the communication procedure between the flight crew and the cabin crew when the seat belt sign is turned ON.

The Investigation recommends that the Operator review the benefit of having automated passenger announcement when the seat belt sign is turned ON.

2.7 Cabin safety during turbulence

The sound of the low tone chime when the seat belt sign is turned ON is intended to attract the attention of the cabin crew and passengers. However, if they fail to hear this chime, then it is possible that they may not notice that the seat belt sign has been switched ON. The Investigation could not test how audible the chime is in flight, especially when the cabin crew are busy in the galleys. However, the fact that not one cabin crew member out of 15 who were carrying out their duties in the cabin did not hear the chime is notable.

There are areas in the A380 cabin where there are handholds for the safety of passengers and cabin crew in the event of a turbulence encounter. These areas include the wet galley units, lavatories, lounge areas and showers.

Except for lavatories specifically for people of determination, there was no handhold standardization between the lavatory handholds in terms of numbers and orientation as some lavatories had one handhold and others had two with the handholds oriented either horizontally or vertically. If a person was standing and facing the sink, there was no handhold in easy reach in case of turbulence.

The location of most of the handholds in the wet galleys meant that the cabin crew would have to stretch their arms above their heads to reach for the handholds. If the adjacent service doors were open, then these handholds were not easily accessible. The color of all the handholds was the same as the surrounding structure and during unanticipated turbulence it would not be easy to locate these handholds.

The dry galleys and work stations had no handholds. In case of unanticipated turbulence, the cabin crew will be challenged to find a suitable place to secure themselves.

Most of the lounge areas had handholds which were suitably fitted at specific locations within easy reach of passengers.

The shower had a single handhold adjacent to the shower seat. In case of unanticipated turbulence, there were no handholds to safeguard the passenger if the person is facing the water nozzle in the shower or if the person is exiting or entering the shower.

During the severe turbulence encounter of UAE449, seven of the nine cabin crew in the cabin crew rest compartment sustained minor injuries when their heads struck the upper part of the compartment. The cabin crew had their seat belts fastened but this did not prevent them from impacting the ceiling of the bed compartment.

The cabin crew rest compartment with nine separated bed compartments was located in the aft section of the cabin, which is the area that normally suffers most oscillations during turbulence. Access to the bed compartment is by kneeling. There was no protection to safeguard the cabin crew, as the interior plastic panels are not cushioned with padding material to prevent cabin crew injury should they contact the sidewalls during entry or egress, or due to turbulence. In case of turbulence, besides the waist seat belt, there was no handhold in any of the bed compartments, which meant that the cabin crew would have to brace themselves using their hands against the interior walls.

The Investigation recommends that the Operator implement the following changes;

(a) Improve the audibility in the passenger cabin of the seat belt chime;

(b) Standardize and improve the accessibility of the lavatory handholds, the accessibility and identification of handholds in the wet and dry galleys and the accessibility of the handholds in the showers.

(c) Implement measures to mitigate the risk of crew members suffering head injuries during turbulence while resting in the crew rest compartment.

3. Conclusions

3.1 General

From the available evidence, the following findings, causes, and contributing factors were determined with respect to this Accident. These shall not be read as apportioning blame or liability to any particular organization, or individual.

To serve the objective of this Investigation, the following sections are included in the Conclusions heading:

- **Findings.** Statements of all significant conditions, events or circumstances in this Accident. The findings are significant steps in the Accident sequence but they are not always causal nor do they indicate deficiencies.
- **Causes.** Actions, omissions, events, conditions, or a combination thereof, which led to the Accident.
- **Contributing factors.** Actions, omissions, events, conditions, or a combination thereof, which, if eliminated, avoided or absent, would have reduced the probability of the Accident occurring, or mitigated the severity of the consequences of the Accident. The identification of contributing factors does not imply the assignment of fault or the determination of administrative, civil or criminal liability.

3.2 Findings

3.2.1 Findings relevant to the Aircraft

(a) The Aircraft was certified, equipped, and maintained in accordance with the *Civil Aviation Regulations* of the United Arab Emirates.

(b) The Aircraft was airworthy when dispatched for the flight, and there was no evidence of any defect or malfunction that could have contributed to the Accident.

(c) The weather radar fitted to the Aircraft was of the latest modification status available from the Aircraft manufacturer.

(d) The Aircraft systems responded in order to avoid the overspeed but there were three transient exceedances of the MMO speed.

(e) During the turbulence, the Aircraft autopilot and autothrust remained engaged, and the Aircraft remained controllable.

3.2.2 Findings relevant to the flight crew

(a) The flight crew were licensed and qualified for the flight in accordance with the *Civil Aviation Regulations* of the United Arab Emirates.

(b) They were medically fit and rested for the flight.

(c) The flight crew had attended the annual recurrent safety and emergency procedures (SEP) training, which included actions required in the event of encountering turbulence.

3.2.3 Findings relevant to the cabin crew

(a) The cabin crew were licensed and qualified for the flight in accordance with the *Civil Aviation Regulations* of the United Arab Emirates.

(b) They were medically fit and rested for the flight.

(c) The cabin crew had attended the annual recurrent SEP training, which included actions required in the event of encountering turbulence.

(d) None of the 15 cabin crewmembers who were on duty could recollect either seeing the seat belt sign coming ON or hearing the chime when the seat belt sign was switched ON.

(e) No cabin readiness for turbulence was performed for the upper and main passenger deck as required when the seat belt sign is switched ON.

(f) During the turbulence, the Cabin Manager made a passenger announcement (PA) for all cabin crew and passengers to take their seats and to fasten their seat belts.

3.2.4 Findings relevant to flight operations

(a) The flight was conducted in accordance with the Operator's operational procedures.

(b) The operating flight crew did not contact either air traffic control nor the Operator's flight dispatch for updated weather information and pilot reports.

(c) Within five minutes before the turbulence encounter, the FDR data indicated that the magenta areas were permanently detected and displayed ahead of the Aircraft within the following envelope: 40 NM ahead, 20 NM on both side of current aircraft heading, +/-5000 ft of current aircraft altitude.

(d) Within five minutes before the turbulence encounter, the FDR data indicated that the weather radar (WXR) manual mode/s was not selected on the SURV panel.

(e) The flight crew turned the seat belt sign ON five minutes before the turbulence encounter at approximately 2148, the same time the wet turbulence magenta areas started to be displayed on NDs.

(f) Most of the on duty cabin crew were standing when the turbulence was encountered.

(g) No communication was established between the flight crew and the Cabin Manager/cabin crew after the seat belt sign was turned ON, which was not in accordance with the Operator's policy.

(h) At 2153:25 UTC (Indian local time 0323), approximately 13 hours into the flight, the Aircraft encountered different levels of turbulence that lasted until 2157:30. Severe turbulence was encountered within the initial 20 seconds.

(i) When the airspeed started to increase, the flight crew correctly executed the *FCOM Abnormal and Emergency Procedures for Overspeed Prevention* and kept the autopilot and autothrust ON, and deployed the speedbrakes.

(j) The flight crew did not observe that there was a speed exceedance by +0.006 Mach.

(k) The flight crew initially classified the turbulence as moderate and then changed to severe because of the injuries and cabin damage.

(l) The flight crew did not notify air traffic control that the Aircraft had experienced severe turbulence.

3.2.5 Findings relevant to the Operator

(a) The significant weather charts in the OFP were valid from 1800 on 10 July 2019 for flight levels FL100 to FL450. The charts forecasted a large area of convective activity with isolated embedded cumulonimbus over the Bay of Bengal.

(b) The planned flight routing included taking the Aircraft over the Bay of Bengal just north of a large area with forecasted cumulonimbus clouds.

(c) The Operator does not provide updated enroute weather information to flight crew through use of the electronic flight bag.

3.2.6 Survivability

(a) All injuries suffered by persons onboard were non-life threatening.

(b) Several unrestrained passengers and cabin crewmembers were lifted off their feet and impacted the cabin ceiling causing injuries and damages.

(c) The effects of the turbulence encounter were more significant in the aft cabins.

(d) Amongst the fourteen passengers who were injured, one suffered a serious injury.

(e) Seven of the nine cabin crewmembers in the cabin crew rest compartment sustained minor injuries when their heads hit the plastic lining of the upper part of the compartment.

(f) The four cabin crew in the upper deck aft galley were lifted off their feet and impacted the ceiling during the turbulence.

(g) The galley units' handholds are not easily reachable in case of unanticipated turbulence.

3.3 Causes

The Air Accident Investigation Sector determines that the cause of the Accident was the severe turbulence acceleration forces in clear air imposed on the Aircraft as it flew in an area affected by convective activity resulting in several unsecured passengers and cabin crewmembers forcefully impacting cabin furnishings.

3.4 Contributing Factors

The Investigation determines that the following were contributory factors to the Accident:

(a) The flight was planned north of an area with forecasted convective activity containing embedded cumulonimbus clouds.

(b) The flight crew did not request updated weather information from air traffic control or pilot reports as the Aircraft approached the area affected by the convective activity over the Bay of Bengal.

(c) The wet turbulence area/s displayed in magenta on the navigation display did not prompt the flight crew to use the WXR best capabilities by using WXR manual

mode, enabling a more accurate assessment of the distance margin with the area of greatest threat.

(d) After turning the seat belt sign ON, the flight crew did not communicate with the Cabin Manager to secure the passenger cabins before the onset of the turbulence.

(e) The Cabin Manager and other on duty cabin crewmembers were not aware that the fasten seat belt sign had been switched ON in spite of the fasten seat belt sign flashing for five seconds and fasten seat belt chime sounding.

4. Safety Recommendations

4.1 General

The safety recommendations listed in this Report are proposed according to paragraph 6.8 of *Annex 13 to the Convention on International Civil Aviation*, and are based on the conclusions listed in part 3 of this Report. The Air Accident Investigation Sector (AAIS) expects that all safety issues identified by the Investigation will be addressed by the receiving States and organizations.

4.2 Safety Actions Taken

4.2.1 Safety actions taken by Emirates

(a) Section 2.3 of this Report, it was recommended to the Operator the following:

"The Investigation recommends that the Operator reiterate to pilots the threat of adverse weather conditions, and taking timely avoidance decision based on weather charts, weather radar echo returns and alerts, and taking into consideration other information including updated weather information and pilot reports, when available."

In response, the Operator has taken the following safety action:

> "Between August and December 2019 a combination of articles and briefings from Fleet and Training for the Recurrent Training Ground School (RTGS – now called the ACTT)
>
> Training Review Committee (TRC) developed a learning module for flight crew on 5th September 2019 that includes the Weather Radar Differences Course for both the Boeing 777 and Airbus A380. This module is ongoing in eLearning since 15th January 2019."

(b) Section 2.3 of this Report, it was recommended to the Operator the following:

"The Investigation recommends that the Operator enhance the ability of pilots to access updated weather information through the electronic flight bag and/or updates from flight dispatch."

In response, the Operator has taken the following safety action:

> "Emirates are currently evaluating this functionality and there is on-going work to provide real time weather and turbulence data once on-board connectivity is established."

(c) Section 2.5 of this Report, it was recommended to the Operator the following:

"The Investigation recommends that the Operator reiterate to pilots the importance of using the full capability of the weather radar to better analyze adverse weather situations.

In response, the Operator has taken the following safety action:

> "This forms part of the Weather Radar Differences Course that is currently ongoing. Airbus updated the FCOM on the 23rd Jan 2020 to reflect the Weather Radar changes in Batch 6 and to provide guidance to the crew. Based on the FCOM changes, a video was created on e-learning for the crew."

(d) Section 2.6 of this Report, it was recommended to the Operator the following:

"The Investigation recommends that the Operator improve the communication procedure between the flight crew and the cabin crew when the seat belt sign is turned ON."

In response, the Operator has taken the following safety action:

> "Training Review Committee (TRC) developed a learning module for flight and cabin crew on 5th September 2019 that includes a discussion on enhancing communications between the flight and cabin crew when dealing with the use of the seatbelt sign. This module is ongoing in eLearning since 15th January 2019. Additionally, a Turbulence Awareness Campaign was conducted for all crews during November 2019 at the EGHQ."

(e) Section 2.6 of this Report, it was recommended to the Operator the following:

"The Investigation recommends that the Operator review the benefit of having automated passenger announcement when the seat belt sign is turned ON."

In response, the Operator has taken the following safety action:

> "The seatbelt sign announcement has been revised with the addition of 14 languages from February 2020.
>
> The IFE has the seatbelt awareness message as part of the passenger communication strategy… [the Operator presented a slide of the message on the IFE with the message 'We are experiencing turbulence. Please fasten your seat belt, infants must be removed from bassinets and toilets should not be used at this time']"

(f) Section 2.7 of this Report, it was recommended to the Operator the following:

"The Investigation recommends that the Operator improve the audibility in the passenger cabin of the seat belt chime."

In response, the Operator has taken the following safety action:

> "The volume of the seatbelt chime has been increased on the A380 as of 19th September 2019."

4.3 Final Report Safety Recommendations

4.3.1 Safety recommendations addressed to Emirates

Emirates is recommended to:

SR75/2020

Review, and enhance, flight planning taking into consideration known historical geographical locations that are affected by seasonal enroute significant weather and meteorological conditions.

SR76/2020

Standardize and improve the accessibility of the lavatory handholds, the accessibility and identification of handholds in the wet and dry galleys and the accessibility of the handholds in the showers.

SR77/2020

Implement measures to mitigate the risk of crew members suffering head injuries during turbulence while resting in the crew rest compartment.

4.3.2 Safety recommendations addressed to Airbus

Airbus is recommended to:

SR78/2020

Enhance the explanation and guidance in the *FCOM* and *FCTM* of the detection of wet turbulence so that there is clear understanding and actions required by pilots.

SR79/2020

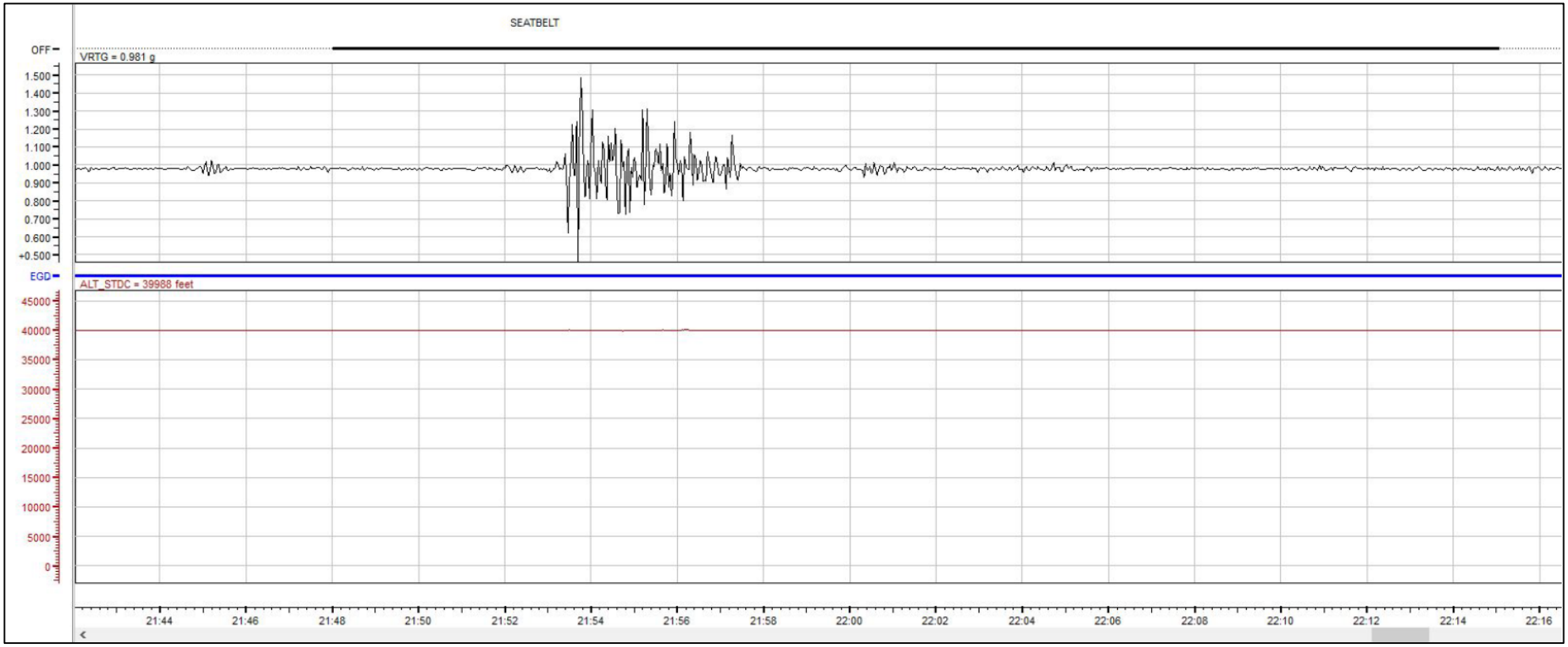
Enhance the cockpit alerting system to include when wet turbulence is detected by the weather radar turbulence function.

SR80/2020

Facilitate the flight data recording of adverse weather precipitation detected by the weather radar as displayed on the navigation display so that this information can be used to enhance pilot training.

Appendix A – Cockpit layout [Source Airbus]

Appendix B – Seat belt sign status and g-loads [Source Emirates]



Appendix C – FDR Data related the weather radar [Source Airbus]