

الهيئة العامة للطيران المدني
GENERAL CIVIL AVIATION AUTHORITY



Air Accident Investigation Sector

Accident

- Final Report -

AAIS Case N° AIFN/0015/2023

Severe Air Turbulence Encounter (TURB)

Operator: Emirates

Make and Model: Airbus A380-861

Nationality and Registration: The United Arab Emirates, A6-EEV

Place of Occurrence: Male flight information region (FIR)

State of Occurrence: Republic of Maldives

Date of Occurrence: 4 December 2023



Accident Brief

AAIS Report No.:	AIFN/0015/2023
Operator:	Emirates
Aircraft Type and Registration:	Airbus A380-861, A6-EEV
MSN:	150
Number and Type of Engines:	four, Engine Alliance GP7270
Date and Time (UTC):	4 December 2023
Location:	Male Flight Information Region (Republic of Maldives)
Type of Flight:	Commercial, Scheduled Passenger
Persons Onboard:	490
Injuries to Passengers and Crew:	Minor: 43, serious: 7
Other Injuries:	None
Nature of Damage:	Damage to the cabin

Investigation Objective

This Investigation is conducted pursuant to the United Arab Emirates Federal Act No. 20 of 1991, promulgating the Civil Aviation Law, Chapter VII- Aircraft Accidents, Article 48. It is in compliance with the Air Accident and Incident Investigation Regulation (AAIR), and in conformity with Annex 13 to the Convention on International Civil Aviation.

The sole objective of this Investigation is to prevent aircraft accidents and incidents. It is not the purpose of this activity to apportion blame or liability.

Investigation Process

The occurrence involved an Airbus A380-861, registration marks A6-EEV, and was notified to the Air Accident Investigation Sector (AAIS) of the United Arab Emirates by a phone call to the Duty Investigator (DI) Hotline Number +971 50 641 4667.

An Investigation team was formed in line with the *Annex 13* obligations of the United Arab Emirates being the State of Registry and State of the Operator. The Investigation was delegated to United Arab Emirates by the Republic of Maldives, in writing, as the latter being the State of Occurrence.

After the initial Investigation phase, the occurrence was classified as an 'Accident'.

The AAIS notified the Bureau of Enquiry and Analysis for Civil Aviation Safety (BEA) of France as of being the State of Manufacture and Design. The BEA assigned an accredited representative assisted by advisers from Airbus the aircraft manufacturer.

This Final Report is publicly available at:

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



Notes:

- ¹ Whenever the following words are mentioned in this Report with the first letter Capitalized, it shall mean:
- (Accident) – this investigated accident
 - (Aircraft) – the aircraft involved in this accident
 - (Augmenting Captain) – the captain who took over the copilot’s role in accordance with the Operator’s policy
 - (Cabin Supervisor) – the cabin supervisor of the cabin in the economy class during the flight
 - (Commander) – the commander of the flight
 - (Copilot) – the copilot of the flight
 - (Investigation) - the investigation into this accident
 - (Operator) – Emirates
 - (Purser) – the purser in-charge of the cabin during the flight
 - (Report) – this Final Report.
- ² Unless otherwise mentioned, all times in this Report are in coordinated universal times (UTC).
- ³ Photos and figures used in the text of this Report are taken from different sources and are adjusted from the original for the sole purpose to improve clarity of the Report. Modifications to images used in this Report are limited to cropping, magnification, file compression, or enhancement of color, brightness, contrast or insertion of text boxes, arrows or lines.



Abbreviations and Definitions

3D	Three-dimension
AAIS	The Air Accident Investigation Sector of the United Arab Emirates
ACMS	Aircraft condition monitoring system
AIFN	Accident/incident file number
AOA	Angle of attack
AP	Autopilot
A/THR	Autothrust
AUTO	Automatic
BEA	Bureau d'Enquêtes et d'Analyses of France
CAR	<i>Civil Aviation Regulations of the United Arab Emirates</i>
CB	Cumulonimbus
CG	Center of gravity
COA	Certificate of airworthiness
COR	Certificate of registration
CP	Control panel
CPDLC	Controller pilot datalink communication
CRC	Crew rest compartment
CSN	Cycles since new
CVR	Cockpit voice recorder
DAR	Data acquisition recorder
DFDR	Digital flight data recorder
EFIS CP	Electronic flight instrument system control panel
FCOM	<i>Flight crew operating manual</i>
FCTM	<i>Flight crew techniques manual</i>
FD	Flight director
FIR	Flight information region
FL	Flight level
FSB	Fasten seat belt
GMS	Ground medical support
IR	Infrared
M	Mach
MAC	Mean aerodynamic chord
MFD	Multi-function display
M_{Mo}	Maximum operating Mach
MSN	Manufacturer serial number
NCC	Network control centre
ND	Navigation system
NOTAM	Notice to airmen
OM	<i>Operations manual</i>



OFF	<i>Operational flight plan</i>
OMDB	Dubai International Airport
PA	Public announcement
PF	Pilot flying
PFR	Post flight report
PM	Pilot monitoring
PSU	passenger service unit
QRH	<i>Quick reference handbook</i>
SOP	Standard operating procedure
RDR	Radar
SURV	Surveillance
TAB	<i>Temporary Abnormal Behavior</i>
TSN	Time since new
TURB	Turbulence
SEP	Safety and emergency procedures
UAE	The United Arab Emirates
UTC	Coordinated universal time
VD	Vertical display
VMC	Visual meteorological conditions
V_{MO}	Maximum operating speed
VP	Vertical profile
VPNC	Vice President Network Control
WAFC	World Area Forecast Centers
WX	Weather
WXR	Weather radar
YPPH	Perth International Airport



Synopsis

On 4 December 2023, an Emirates Airbus A380-861 aircraft, registration A6-EEV, departed Perth International Airport (YPPH), Australia, for a scheduled passenger flight number EK421 to Dubai International Airport (OMDB), the United Arab Emirates. There were 490 people onboard: 3 flight crewmembers, 24 cabin crewmembers, and 463 passengers. While cruising at FL380 within the Male flight information region (FIR), Maldives, the Aircraft encountered moderate to severe air turbulence that lasted for approximately 50 seconds, including severe turbulence with vertical g-variation between -0.5g and +2.16g, which lasted for six seconds. The severe turbulence caused injuries to 50 occupants. Among the 50 injured persons (36 passengers and 14 cabin crew), seven suffered serious injuries, and 43 sustained minor injuries.

The Air Accident Investigation Sector determines that the Accident was caused by the Aircraft encountering severe turbulence associated with vertically developing convective activity in a tropical environment, where weak radar reflectivity and the characteristics of the weather radar presentation did not provide a prominent indication of the associated turbulence potential.

The Air Accident Investigation Sector identifies the following contributing factors to the Accident:

- (a) The presence of unrestrained passengers and cabin crewmembers during the turbulence encounter, resulting in injuries during significant vertical accelerations.
- (b) The short interval between the activation of the seat belt sign and the onset of severe turbulence limited the opportunity to complete full flight deck–cabin coordination and cabin securing actions under time-constrained conditions.

The AAIS issued one safety recommendation to the Operator, identifying an opportunity to enhance flight crew situational awareness during cruise in convective environments. It recommends that the Operator review existing guidance and training to consider incorporating additional advisory material on the complementary use of weather radar functionalities, supporting more comprehensive weather assessment while maintaining alignment with procedures and effective workload management.



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1. Factual Information

1.1 History of the Flight

On 4 December 2023, an Emirates Airbus A380-861 Aircraft, registration marks A6-EEV, operated a scheduled passenger long-range flight, EK421, from Perth International Airport (YPPH), Australia, to Dubai International Airport (OMDB), the United Arab Emirates.

The flight had 490 persons onboard, consisting of 3 flight crewmembers, 24 cabin crewmembers, and 463 passengers. Out of the 463 passengers, 70 were on the upper deck and 393 were in the main cabin on the lower deck. The passenger manifest listed 8 first-class passengers, 62 in business class, 391 in economy class, and 2 infants.

The flight crew consisted of the Commander, who was the pilot flying (PF) seated on the left seat, the Copilot as the pilot monitoring (PM), and the Augmenting Captain, who was occupying the third occupant seat in the flight deck behind the Commander and the Copilot.

All flight crewmembers reported that they were well-rested and fit for duty. As per the Commander's statement, he received the briefing package¹ ahead of time. Before the flight, in the preflight briefing, he discussed the *operational flight plan (OFP)* with the Copilot, the Augmenting Captain, and the cabin crew, including notice to airmen (NOTAM), weather, en-route, and all the flight preparation routines. He did not highlight any specific instances of severe turbulence conditions in flight since there was no such information indicated in the *OFP*. The Commander reviewed the available weather information using an application that depicted isolated convective activity along the route, but no significant or organized weather systems. Based on the information presented, and consistent with his prior experience operating this route, he assessed the conditions as typical for the region and not indicative of unusual or heightened turbulence risk.

The purser, who was in charge of business class, confirmed that the briefing did not mention the possibility of encountering severe turbulence. The Copilot stated that the flight crew did not expect to encounter severe turbulence. Before the flight, when the Copilot downloaded the flight plan, he also checked the weather conditions by using applications called SkyPath and Lido MPilot for that purpose.

The Aircraft departed from YPPH at 1428 UTC, with a smooth and uneventful takeoff. It climbed to FL340 for cruising, then climbed further to FL360 to continue its cruise.

For the flight, the weather (WX) push button was activated on the electronic flight instrument system control panel (EFIS CP). The Aircraft's weather radar (WXR) and turbulence (TURB) functions were set to active mode, displaying weather information on the navigation display (ND).

At 1911:17, while cruising at flight level (FL) 360 within Melbourne flight information region (FIR), the Aircraft initiated a weather-related deviation.

At 1951:06, the Aircraft climbed to FL380, reaching this altitude at about 1953:13 for the next cruise, within Melbourne FIR, just before reaching Colombo FIR.

¹ Briefing Package: A term used to describe the informative package of information the Operator provide to their crewmembers which includes the operational flight plan and the weather enroute.



At 2014:00, the Aircraft entered Colombo FIR from DADAR² waypoint.

At 2029:06, the Aircraft entered Male FIR from SUNAN waypoint.

Several minutes after passing SUNAN waypoint, the Copilot left the flight deck to take a rest and was replaced by the Augmenting Captain, who assumed the role of PM from the right seat. The Copilot stated that before he left the flight deck, there were no significant weather concerns. A few weather cells were present in the Male FIR, but these were located far from the Aircraft's route.

After a while, both flight crewmembers (the Commander and the Augmenting Captain) monitored the weather conditions. They observed an isolated cell about 30 to 40 nautical miles away at 10 to 11 o'clock position, showing as off-path weather on the radar. Another off-path weather return appeared ahead of the Aircraft. The Aircraft was flying in night visual meteorological conditions (VMC) with moonlight aiding visual identification of clouds below; the flight deck lights were dimmed to enhance the outside weather assessment. The flight crewmembers observed two weather formations to the left and ahead, both of which appeared well beneath the flight path. To assess the weather, the radar range was adjusted between 40 and 640 nautical miles. They confirmed there were no threats to the Aircraft, as the off-path radar returns showed none of the alerting colors (red, red speckles, amber, or magenta), displaying only black screens with small areas/spots of green instead. As the weather remained calm and turbulence was minimal, the Augmenting Captain decided to take a physiological break.

In accordance with the Operator's policy, a cabin crewmember was positioned in the jump seat in the flight deck before the Augmenting Captain left the flight deck. The Commander switched on the seat belt signs at about 2104:15. At that time, the weather radar ND range setting on both sides was set to 80 nautical miles.

About six and half hours into the flight, at 2105:00, while cruising at FL380 in Male FIR, about 35 nautical miles before reaching AQAXA waypoint at Mach 0.84, on a heading of 320 degrees, the Aircraft experienced a period of turbulence lasting about 36 seconds, with most severe turbulence with vertical g variation between -0.5g and +2.16g that lasted for six seconds (between 2105:04 and 2105:10), then moderate turbulence that lasted for 14 seconds (between 2105:10 and 2105:24), followed by light turbulence for another 16 seconds. (Figures 1 and 2 illustrate the geographical location of the Aircraft where the turbulence occurred).

During the turbulence, the loss of altitude varied from 320 feet above to 360 feet below FL380. The master caution triggered on both sides for 11 seconds, which was linked to the post flight report (PFR) message, OVERSPEED LOADS ANALYSIS REQUIRED. No other flight deck audio or visual warnings or alerts were triggered.

The turbulence encountered was mainly due to wind variations, with longitudinal winds fluctuating between a 31-knot headwind and a 39-knot tailwind, lateral winds shifting between 19-

² A waypoint is a specified geographical location used to define an area navigation route or the flight path of an aircraft employing area navigation [Source: www.skybrary.com]

knot from the right and 15-knot from the left, and vertical winds between an 11-knot downdraft and 46-knot updraft. The Aircraft experienced lateral g variation ranging from -0.17g to +0.08g.

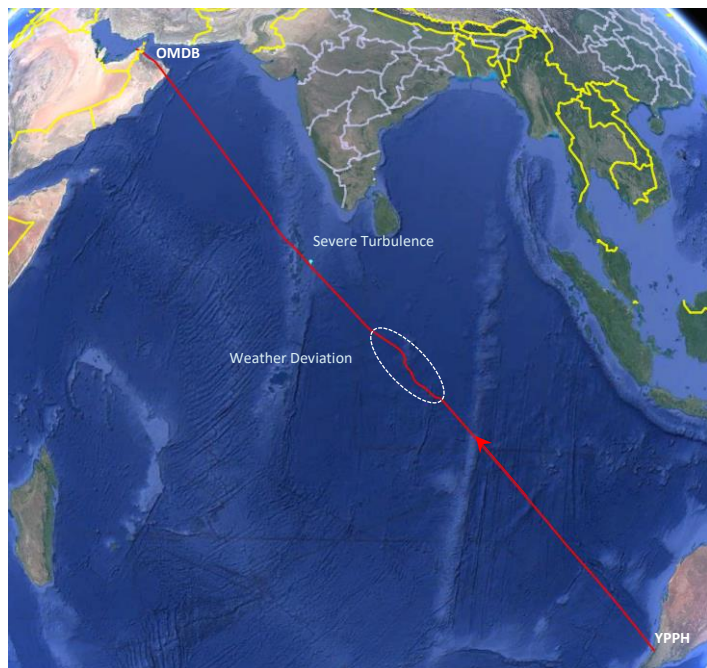


Figure 1. Flight path YPPH - OMDB

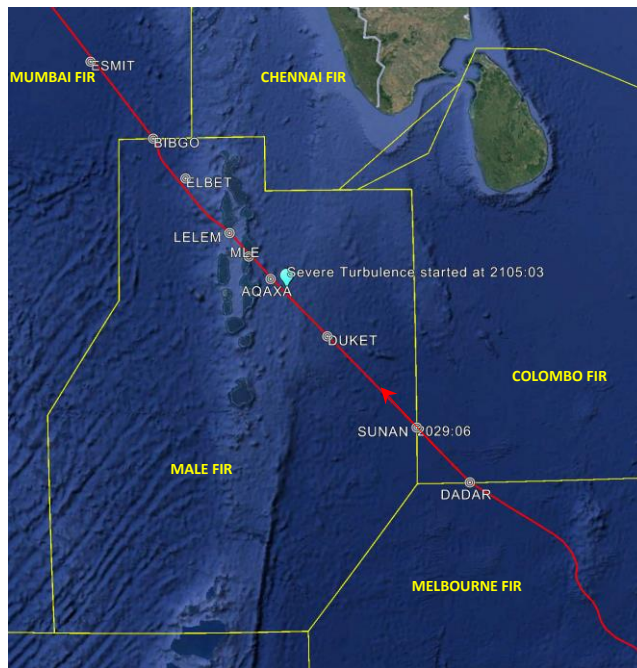


Figure 2. Flight path within Male FIR

As the airspeed increased, the speed brake lever automatically extended before reaching the maximum operating speed (V_{MO}), resulting in the deflection of the spoilers accordingly. The Mach speed fluctuated between 0.78 and 0.92, briefly exceeding the maximum operating Mach (M_{MO}) of 0.89 for less than one second, which was insufficient to trigger the overspeed warning. The (computed/calibrated) airspeed varied between 293 and 245 knots. The vertical speed varied between +1300 (climb) and -1300 feet/minute (descent).

Autopilot 2 (AP2), flight directors (FDs) 1 and 2, and autothrust (A/THR) were engaged prior to the event and remained engaged afterward.

The Commander followed the *quick reference handbook (QRH)* procedure for the overspeed while controlling the Aircraft alone at that moment, as he stated. He made a public announcement (PA) communication instructing the cabin crew to take their seats, following the onset of turbulence.

The Augmenting Captain contacted the Commander from the cabin to report the status of the cabin conditions and the serious injuries among passengers and cabin crewmembers.

Following the turbulence encounter, the Commander communicated with the cabin crew to evaluate the extent of the damage and any injuries. At the same time, the Copilot offered initial assistance to the cabin crew and passengers. A few minutes later, the Copilot returned to the flight deck to assume the PF's duties from the right seat, allowing the Commander to focus on addressing the aftermath of the severe turbulence encounter.

Meanwhile, the Augmenting Captain stayed in the cabin to assist the cabin crew with the cleanup, support injured cabin crewmembers and passengers, and relay regular updates on the situation to the Commander in the flight deck.



At 2145:58, the Aircraft exited Male FIR through BIBGO waypoint.

After consulting the flight crew and the Purser, considering the diagnosis of the doctors who were on board, and in coordination with the ground medical support and Operator's network control centre (NCC), the Commander decided to continue the flight to OMDB.

The Purser ensured that all available cabin crewmembers were assigned to operate the cabin doors for a safe landing. However, several pre-landing tasks could not be completed due to the diminished capacity caused by the focus on providing medical treatment.

At 0045:02 UTC, the Aircraft landed safely at OMDB.

1.2 Injuries to Persons

Table 1. Injuries to persons						
Injuries	Flight crew	Cabin crew	Other crew onboard	Passengers	Total Onboard	Others
Fatal	0	0	0	0	0	0
Serious	0	3	0	4	7	0
Minor	0	11	0	32	43	0
None	3	10	0	427	440	0
TOTAL	3	24	0	463	490	0

A total of 14 cabin crewmembers sustained injuries and were evaluated at either the airport medical center or the nearby hospitals. Among those injured, 3 cabin crewmembers sustained serious injuries and were hospitalized. The remaining injured cabin crewmembers admitted to the hospital have been discharged within 24 hours.

A total of 36 passengers were injured and received assessments at either the airport medical center or the nearby hospitals. All injured passengers have been discharged from the hospital within 24 hours, except for one who required surgery.

1.3 Damage to Aircraft

The Aircraft sustained damage to the cabin. This has resulted in the Aircraft going under maintenance after arrival at OMDB.

The flight deck was inspected, and no damage was identified.

An inspection of the cabin revealed extensive damage in various areas, particularly to the overhead bins, ceiling panels, and passenger service units (PSUs), which were cracked from impact. Additionally, some curtain rails above the aft economy class seats and in the upper deck galley had deformed chassis. A visual map illustrating the damage distribution and indicating the positions of crewmembers and injured passengers is given in Appendix B.

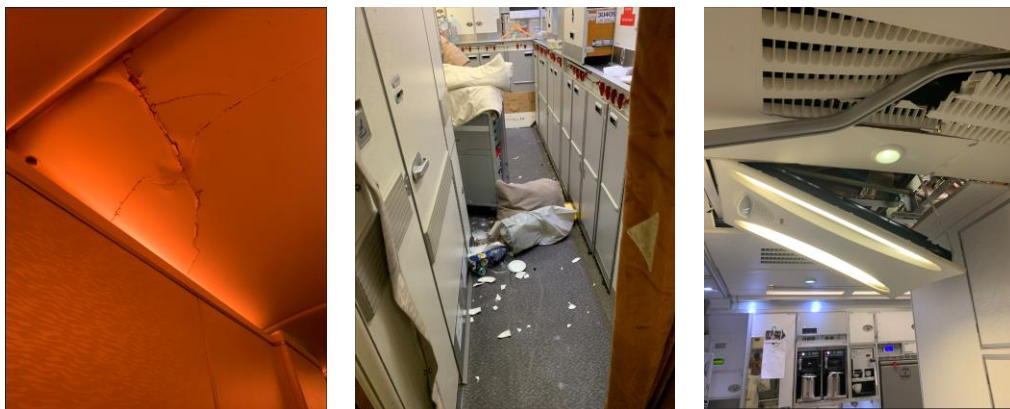


Figure 3. Some of the damages and scattered service equipment

1.4 Other Damage

There was no other damage.

1.5 Personnel Information

The flight and cabin crewmembers' rosters confirmed that all personnel complied with the rest period requirements of the *Civil Aviation Regulations (CARs)* of the United Arab Emirates.

The flight crewmembers possessed valid pilot licenses and medical certificates. Similarly, all cabin crewmembers possessed current licenses and medical certificates.

In compliance with the Operator's annual recurrent safety and emergency procedures (SEP) training, the flight and cabin crew attended the annual training on *duties to be undertaken in the event of encountering turbulence*.

1.6 Aircraft Information

The Airbus A380 is a four-engine, double-deck jetliner manufactured by Airbus Industries.

1.6.1 Aircraft data

Table 2 illustrates the general Aircraft information as of the date of the Accident.

Table 2. Aircraft data		
Manufacturer:	Airbus Industries	
Model:	A380-861	
MSN:	150	
Date of manufacture:	December 2013	
Nationality and registration:	A6-EEV	
Name of the Operator:	Emirates Airlines	
Certificate of airworthiness		
	Number:	UAE-COA-0230
	Issue date:	19 May 2014
Certificate of registration		



	Number: Issue date:	UAE-COR-0724 19 May 2014
Date of delivery		19 May 2014
Time since new (TSN) (hours)		37,845:43
Cycles since new (CSN)		4,133
Cycles since last service check		26

The Aircraft was configured with 14 seats in first class, 76 in business class, and 401 in economy class.

1.6.2 Aircraft systems

1.6.2.1 Fasten seatbelt

The flight crew is able to activate the fasten seat belt (FSB) signs throughout the Aircraft cabin using a three-position switch, ON/AUTO/OFF, located on the overhead control panel in the flight deck. For passengers, FASTEN SEAT BELT and RETURN TO SEAT signs are installed in overhead panels throughout the cabin, including in the lavatories, lounge areas, and showers. The cabin crew areas, such as the galleys and crew rest compartment (CRC), are also equipped with FSB signs.

When the switch is set to the ON position, the FASTEN SEAT BELT and RETURN TO SEAT signs illuminate continuously in the cabin after flashing for five seconds. This activation is accompanied by a single low-tone chime that sounds throughout the cabin, intended to alert both the cabin crew and passengers.

1.6.2.2 Weather radar

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

The Honeywell RDR-4000 model represents the latest generation of weather radar technology, featuring a three-dimensional (3D) volumetric buffer that continuously scans the entire airspace ahead of the aircraft. It provides comprehensive coverage from -80 to +80 degrees laterally, from ground level up to 60,000 feet (with a tilt angle ± 15 degrees), and extends to 320 nautical miles in front. The WXR may not be able to discriminate between on-path and off-path weather at ranges above 160 nautical miles due to the angle of the antenna beam width. The WXR could consider some off-path weather as on-path weather.

The WXR performs continuous 3D scanning ahead of the aircraft, storing all reflectivity data in a dynamic 3D memory. This memory is consistently refreshed with information from new scans, adjusting for aircraft movement. The system then retrieves reflectivity data from memory to create the chosen display views instantly, without needing specific antenna sweeps for each view.

Weather detection relies on the reflectivity of water droplets, with weather echoes displayed on the ND using a color scale that ranges from red, indicating high reflectivity, to green for lower reflectivity (figure 4). The intensity of radar echoes depends on factors like droplet size, composition, and quantity. For instance, a water droplet is about five times more reflective than an ice particle of the same size. The color scheme for the weather display was consistent on both the vertical display (VD) and the ND.

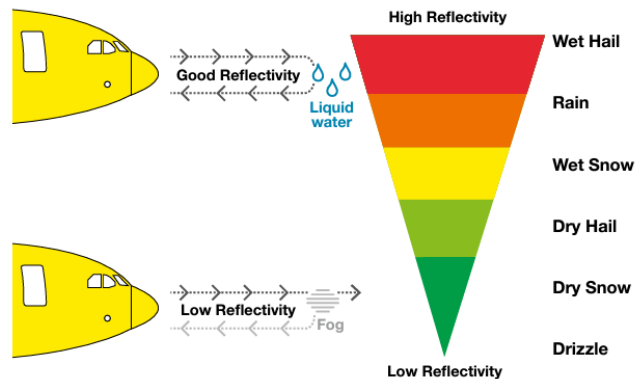


Figure 4. Weather radar principle

When activated in automatic mode, the WXR takes into account a vertical trajectory envelope, typically set at +/- 4,000 feet along the aircraft's vertical flight path, determined by the flight path angle. It then assesses whether the weather echo falls within this envelope (designated as 'ON PATH') or outside of it (classified as 'OFF PATH'), depending on the flight profile. Weather conditions along the aircraft's trajectory are indicated with solid colors, while more distant vertical echoes are represented with striped patterns, assisting pilots in deciding whether a weather avoidance maneuver or rerouting is required. (Figure 5)

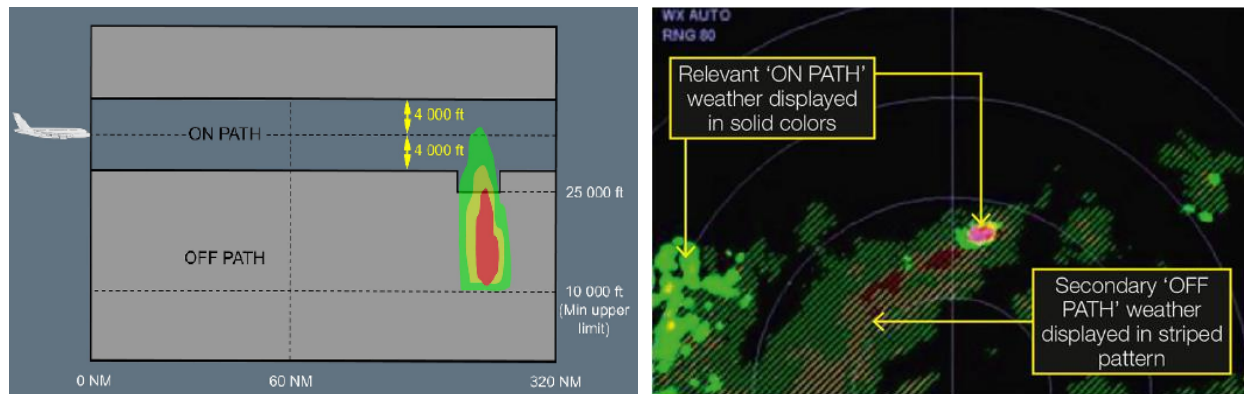


Figure 5. Weather radar system envelope

The WXR can additionally operate in manual mode (elevation mode ELEVN), serving as a tool for analyzing weather at user-selected altitudes, allowing for an assessment of the vertical expansion and structure of convective clouds.

As per the *flight crew operating manual (FCOM)*, the WXR has a weather (WX) display function, a turbulence (TURB) detection function, a weather ahead function, a predictive wind shear system (PWS) function, and a ground mapping function.

The WXR comes on: if at least one engine is running, and if the flight crew presses the WX pushbutton on at least one EFIS CP; and automatically in flight.

The flight deck's main flight display units allow the flight crew to view weather information on both the VD and the ND by pressing the WX pushbutton found on the EFIS CP (figures 6 and 7).



Figure 6. Weather radar rotating knobs [Source: FCOM-Surveillance Panel]

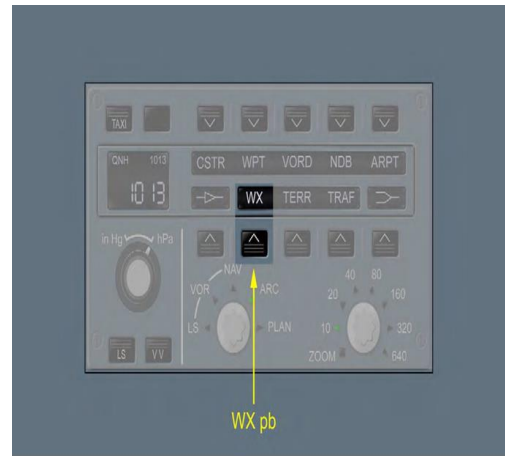


Figure 7. WX (weather) button on EFIS

The automatic (AUTO) mode was the default setting for the WXR, which, by design, would continuously scan a volume of space ahead of the aircraft and store the data in a 3D buffer. In general, WXR manual modes can be selected by a flight crew by pulling on the corresponding control knobs on the SURV panel (figures 6 and 7), allowing them to modify the sensitivity of the weather display on the ND.

The turbulence (TURB) detection function detects wet turbulence in a volume of space ahead of the Aircraft. This function was based on the movement of precipitation, which requires a certain level of precipitation to operate effectively. The TURB detection is available if the WXR is operative and TURB button is set to AUTO on the SURV/CONTROLS page of the multi-function display (MFD). As per the design, the TURB detection function would scan ± 60 degrees in azimuth, between 0 and 60,000 feet mean sea level (MSL), and up to 60 nautical miles in front of the aircraft. The function did not detect clear air turbulence or dry turbulence. The ND and VD display the areas of (wet) turbulence in magenta. As illustrated in figure 8, the magenta within the blue box (which is for illustrative purposes only) indicates on-path (wet) turbulence, while the hashed magenta within the white box represents off-path (wet) turbulence.

The weather ahead function detects potential weather or turbulence hazards three minutes ahead of the aircraft and warns the flight crew by WEATHER AHEAD message on the ND.

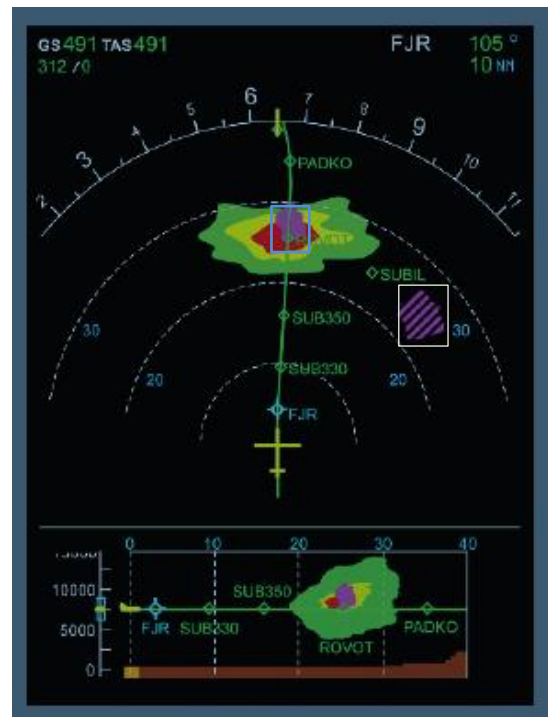


Figure 8. Illustration of TURB area indication (magenta) on VD and ND [Source: FCOM A380]



1.6.3 Post-Accident Aircraft maintenance inspection

The Aircraft encountered excessive load factors, necessitating inspections before the next flight. An “OVERSPEED LOAD ANALYSIS REQUIRED” warning was displayed on the Aircraft upon landing.

The initial *Load Analysis Report* identified 15 structural areas for a 'Phase I' inspection due to indications of 'High Loads'. Phase I inspection consisted of general visual inspections (GVIs) to detect primary damage and any related impact areas. These inspections also focused on 'key points', which are specific areas where load exceedances above limit values could reveal noticeable damage before critical damage might appear elsewhere.

Inspections were conducted on the fuselage sections, structural fittings, wings, ailerons, vertical and horizontal stabilizers, inboard elevators, pylons, nacelles, flaps, slats, and spoilers, with no issues identified. In the cargo holds, the aft cargo net was found torn, and five ceiling light lenses were damaged.

Following additional load analysis assessment of the Aircraft data by the Aircraft manufacturer, the manufacturer recommended further inspections. A more detailed examination was required for the aft fuselage section (tail cone), the horizontal stabilizer, including internal structural components (such as spars, fittings, and attachments), as well as the elevators and their internal structural elements.

The analysis indicated that load exceedance was detected in the wings, horizontal tailplane pivots, and fuselage section 19; consequently, the Aircraft manufacturer issued maintenance recommendations to the Operator, which were implemented subsequently.

1.7 Meteorological Information

The flight was initially planned to route south of Tropical Cyclone Michaung on the southeast coast of India. The forecast for the flight segment over Male FIR indicated the presence of cumulonimbus (CB) cells, which were expected to be associated with moderate/severe turbulence and icing.

The dispatch documents provided to the flight crew included significant weather (SIGWX) fixed time prognostic charts issued by World Area Forecast Centers (WAFAC) London of the Indian Ocean valid for 18:00 UTC, 4 December 2023 from FL 250 to FL 630, and for 00:00 UTC, 5 December 2023 from FL 250 to FL 630, as shown respectively in figures 9a and 9b.

According to figure 9a, the flight route was expected to traverse an area with isolated embedded CB clouds. These clouds had cloud tops reaching up to FL460, and occasional embedded CB with cloud tops reaching up to FL500 were anticipated between waypoints DUKET and ESMIT near the area where the severe turbulence was encountered.

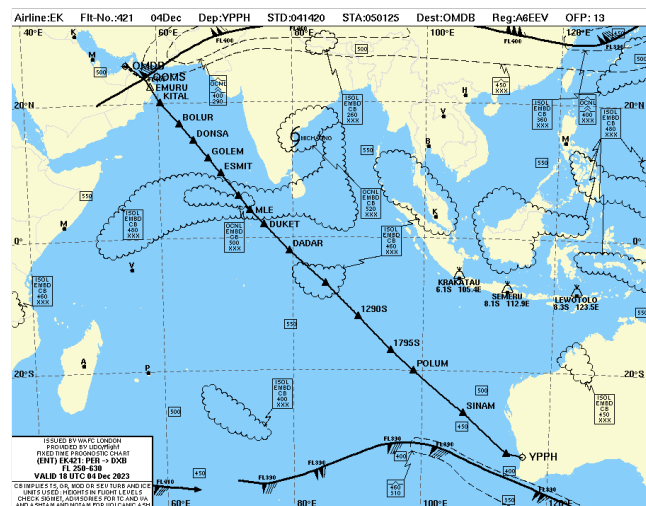


Figure 9a. Significant weather fixed time prognostic chart of the Indian Ocean valid for 18:00 UTC, 4 December 2023 from FL250 to FL630

According to figure 9b, the flight path was anticipated to pass through an area containing isolated embedded CB cloud, with cloud tops reaching up to FL460 expected between waypoints DUKET and MLE in the vicinity where severe turbulence was encountered.

The severe turbulence event occurred at 2105 UTC, a time that fell between the forecasted weather conditions shown in figures 9a and 9b. Therefore, the planned flight path was expected to pass through an area containing isolated embedded CB with a cloud top of FL460/480.

Furthermore, the Investigation was provided with historical satellite images at the event's time and location that show a developing cloud formation that grew larger over the two hours, from 1900 to 2100 UTC, preceding the turbulence encounter (figures 10a to 10d).

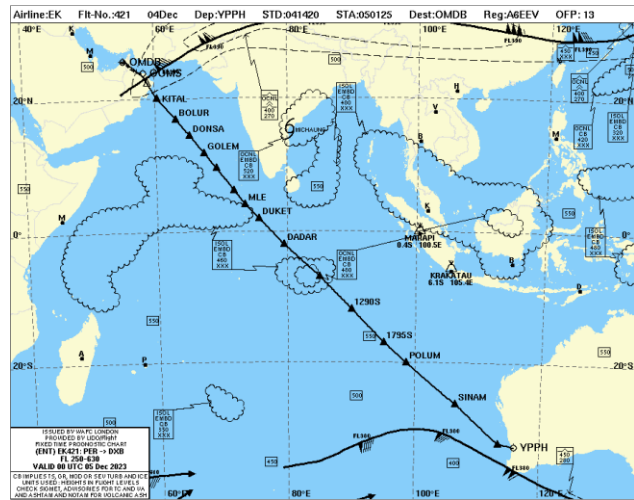


Figure 9b. Significant weather fixed time prognostic chart of the Indian Ocean valid for 0000 UTC, 5 Dec 2023 from FL250 to FL630

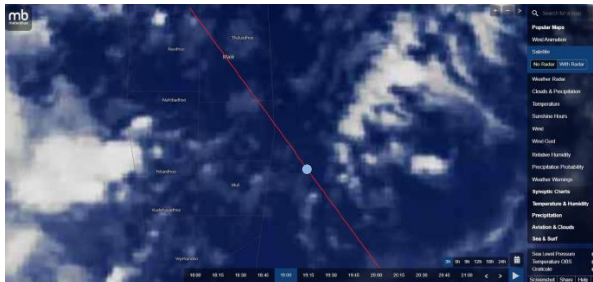


Figure 10a. Captured on 4 Dec. 2023 at 1900 UTC

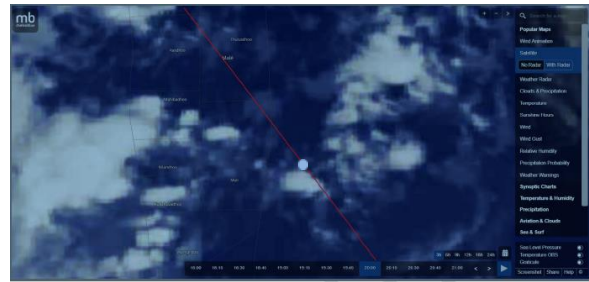


Figure 10b. Captured on 4 Dec. 2023 at 2000 UTC

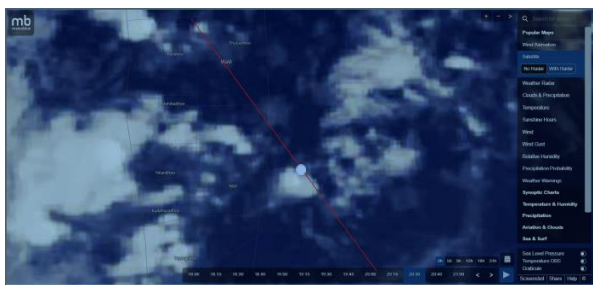


Figure 10c. Captured on 4 Dec. 2023 at 2030 UTC

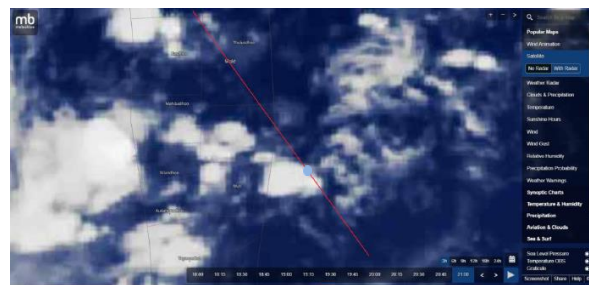
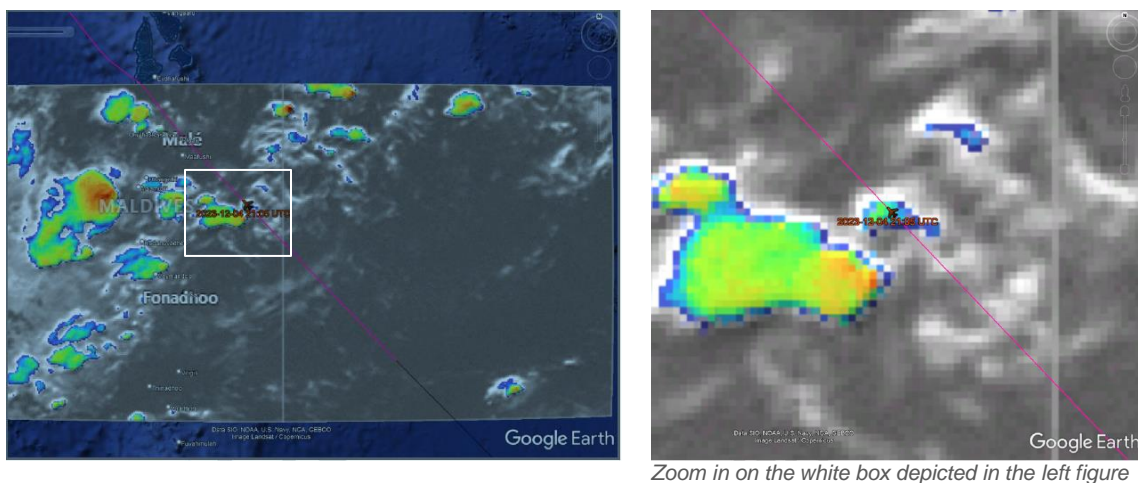


Figure 10d. Captured on 4th Dec 2023 at 2100 UTC

Note: the red line indicates the planned flight track, and the blue dot indicates the Aircraft position at the time of the severe turbulence event.

Figure 10. MeteoBlue satellite images of atmospheric conditions snapshots over two hours (1900 – 2100 UTC) in the area of the severe turbulence encounter

Through the Operator, the Aircraft manufacturer provided a satellite weather chart and stated that, at 2105 UTC, the Aircraft overflew a thunderstorm, when severe turbulence was encountered (figure 11).



Note. The magenta line illustrates the intended flight path as a visual reference, indicating the aircraft's northwest heading.

Figure 11. Satellite radar image at 2105 UTC

1.8 Aids to Navigation

The Aircraft was fitted with the required navigational equipment, and all ground and onboard navigation systems were fully operational.

1.9 Communications

All communications between air traffic control and the flight crew were normal, including during the flight in Male FIR.

Entering Male FIR, and as per the Commander and the Augmenting Captain's statements, the communication was made by means of controller pilot data link communications (CPDLC).

1.10 Aerodrome Information

Not applicable since the Accident took place in flight.

1.11 Flight Recorders

The Aircraft was equipped with a digital flight data recorder (DFDR) and a cockpit voice recorder (CVR) as described in table 3.

Table 3. Flight recorders information

Recorder	Manufacturer	Model	Serial Number	Date Received	Date Downloaded
DFDR	L3-Comms	2100-4045-00	000905076	7 December 2023	11 December 2023
CVR	L3-Comms	2100-1025-02	000596336	7 December 2023	11 December 2023



The DFDR was received in good condition and the downloaded data was relevant to the flight. In addition, the Investigation was also provided with the digital aircraft condition monitoring system - data acquisition recorder (ACMS DAR)³ data.

The CVR had a two-hour recording capacity and, for this flight, captured only the final two hours. As a result, the audio recording of the turbulence encounter was overwritten and unavailable for the Investigation.

The flight data indicated that the Aircraft was flying through weather deviations at FL360 during the cruise phase of the flight within Melbourne FIR, starting at 1911.

The Aircraft cruised at FL360 between 1736:35 and 1951:06 within Melbourne FIR, and the weather radar was employed in various modes across both the left and right sides. The following radar settings and adjustments were recorded as follows (see also Appendix A):

- In general, the weather radar was set on automatic (AUTO) mode as the default configuration.
- Elevation (ELEVN) settings:

The elevation slice was manually adjusted several times on the right side, between 21,000 and 35,000 feet, enabling targeted scanning of atmospheric layers below the Aircraft's altitude.

The left side remained in AUTO mode, holding a default elevation at the Aircraft's cruise level (36,000 feet), with only a single, brief manual intervention noted (lasting approximately one second).
- Gain (GAIN) settings:

On the left side, GAIN was initially in MANUAL mode before switching to AUTO. In AUTO mode, the system maintained a consistent gain level of 85%, consistent with manufacturer defaults for calibrated reflectivity representation.

On the right side, GAIN was manually adjusted several times, enabling fine-tuning display sensitivity while scanning different altitude layers.
- Tilt (TILT) settings:

The right-side tilt remained in AUTO mode throughout the segment, maintaining a 0° angle (relative to level flight) and was never switched to manual.

On the left side, the TILT was manually adjusted three times, reaching a maximum of 1.75° nose-down, allowing the crew to investigate potential lower-altitude weather reflectivity.
- Azimuth (AZIM) settings:

The right-side azimuth was manually adjusted multiple times between 19:06:54 and 19:50:01, reaching a maximum deflection of 78 degrees to the left, enabling to scanning of lateral weather systems outside the default forward cone.

³ Aircraft condition monitoring system - data acquisition recorder (ACMS DAR) is a component of the ACMS, which is used to collect, monitor, and record aircraft performance and operational data for maintenance, safety, and performance analysis.



The left-side azimuth remained fixed at 0 degrees, indicating no lateral scanning was performed on that side.

At 1951:07, the Aircraft commenced its climb to FL380, levelling off at 1953:13. At 1953:36, the Aircraft ended flying weather deviation while still within Melbourne FIR.

The Aircraft reached and levelled off at FL380 at 1953:13. Between 1953:13 and 2105:00 (when the turbulence started), while maintaining FL380, the WXR on both sides remained in automatic mode for ELEVN, TILT, GAIN, and AZIM settings (see also Appendix A). The only exception occurred at 1958:39, when the right-side GAIN mode was briefly switched to manual for about one second, adjusting the gain from 90% to 50%, before being reverted to AUTO at 19:58:40. In AUTO mode, the system then displayed a gain value of 100%.

Throughout this period, the AUTO ELEVN settings on both sides remained at 38,000 feet, with TILT at 0 degrees and AZIM at 0 degrees on both sides. The left-side GAIN setting showed 85%, although the mode remained in AUTO. The navigation display (ND) range settings on both sides were adjusted multiple times, varying between 80 and 640 nautical miles.

At 2014:00, the Aircraft entered Colombo FIR through the DADAR waypoint.

At 2029:06, the Aircraft entered Male FIR from Colombo FIR through the SUNAN waypoint.

At 2045:18, the Commander changed the weather radar ND range from 640 to 80 nautical miles.

At 2101:03, the pilot on the right seat (Augmenting Captain) changed the weather radar ND range from 160 to 80 nautical miles.

At 21:04:55, few seconds before the turbulence, the Aircraft was on a cruise phase at FL380 with a gross weight of 416.78 tons, longitudinal center of gravity (CG) of 41.0% mean aerodynamic chord (MAC), and AP2, FDs 1 and 2 were engaged in ALT / NAV modes, along with an engaged A/THR.

Between 2105:00 and 2105:50, the Aircraft entered a turbulence area, characterized by the following parameters:

- The pitch angle varied between -1.8 and +4.2 degrees
- The roll angle varied between 4.9 to the right and 5.3 degrees to the left
- The vertical acceleration (load factor) varied between -0.5g and +2.16g
- The lateral acceleration (load factor) varied between -0.17g and +0.08g
- The minimum/maximum value of the left angle of attack (AoA1): -1.8/+9.0 degrees
- The minimum/maximum value of the right angle of attack (AoA2): -1.1/+9.0 degrees.
- The Mach number varied between 0.92 and 0.78. Mach number exceeded the maximum operating Mach (M_{MO}) of 0.89 for less than one second, which did not trigger the overspeed warning.

The computed/calibrated airspeed (CAS) varied between 293 and 245 knots

- The standard altitude varied between 38,195 and 37,515 feet
- Vertical speed varied between +1,020 and -1,300 feet/minute



- The longitudinal wind varied between 31 knots headwind and 39 knots tailwind
- The lateral wind varied between 19 knots from the right and 15 knots from the left
- The vertical wind varied between 11 knots downdraft and 46 knots updraft
- At 21:05:05 UTC, speed brakes were selected for 11 seconds and spoilers deflected accordingly
- At 21:05:06 UTC, the master caution triggered on both sides for 11 seconds. This master caution is linked to the PFR message OVERSPEED LOADS ANALYSIS REQUIRED
- The autopilot remained engaged throughout the entire period of the turbulence.

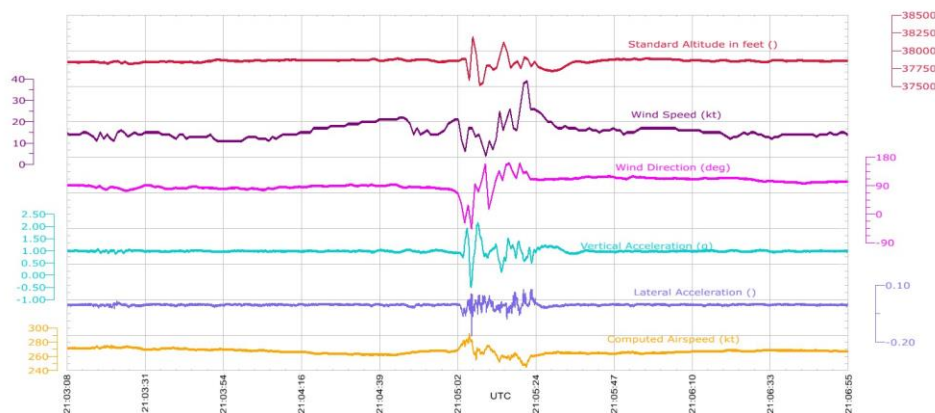


Figure 12. Vertical and lateral g variation, altitude, airspeed, and wind conditions during turbulence

Figure 12 depicts the vertical and lateral g variation, altitude, airspeed, and wind conditions before, during, and after the severe turbulence.

1.12 Wreckage and Impact Information

The Aircraft was intact.

1.13 Medical and Pathological Information

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

1.14 Fire

There were no signs of fire.

1.15 Survival Aspects

Before encountering the turbulence, the cabin supervisor in economy class observed the seatbelt sign being illuminated and announced a turbulence warning over the PA. Some cabin crewmembers began securing the cabin. However, some of the cabin crew on duty in the upper deck could not remember seeing the seatbelt signs illuminated or hearing the chime when it was activated. At that time, no service was being provided, except for the nearly finished “We Care”



service in economy class, offering juice and water. Meanwhile, the Purser was on break in the crew rest bunk. The short interval of about 48 seconds between seat belt sign activation and the onset of severe turbulence limited the opportunity for communication between the Commander and the cabin supervisor regarding cabin service considerations.

During the turbulence, one cabin crewmember was stationed at the crew workstation in the forward cabin on the main deck. Another crewmember was in the flight deck, while eight others were in the crew rest compartment, with some stating that they had not fastened their seatbelts while there. The turbulence mainly affected the aft economy class cabin, along with the aft galley and bar lounge area on the upper deck.

The Copilot, who was resting in the bunk, hit his head on the ceiling despite wearing a seat belt. Meanwhile, the Augmenting Captain, who was in the first-class corridor, quickly laid on the floor and secured himself between seats, managing to avoid injury.

Following the onset of turbulence, the Commander made an announcement instructing the cabin crew to take their seats, enabling several crewmembers to secure themselves quickly. In total, 14 cabin crewmembers and 36 passengers sustained injuries ranging from minor to serious during the turbulence event.

After the Purser left the crew rest compartment, he began collecting information and evaluating the extent of the damage and injuries. A PA was issued in the cabin to ask if there were any medical professionals onboard. In response, two doctors and two nurses, including an emergency room nurse, volunteered to assist with providing medical support.

With the cabin crew and the onboard medical professionals providing first aid, the Commander communicated with the ground medical support (GMS) for assistance. The injuries sustained by passengers and cabin crew were deemed non-life-threatening. After thoroughly assessing the damage and injuries onboard, and with the agreement of GMS and the Operator's Vice President Network Control (VPNC), the Commander decided to proceed with the flight to OMDB.

Upon arrival, medical teams were on standby for the Aircraft, and several cabin crewmembers and passengers were transported to the airport clinic and local hospitals. Representatives from the Operator's group safety team, service delivery, and flight operations greeted the flight and cabin crew upon arrival. All injured cabin crewmembers and passengers received the required medical treatment.

1.16 Tests and Research

No tests or research were required to be conducted for the Investigation.

1.17 Organizational and Management Information

1.17.1 The Operator - general

Emirates was founded in March 1985 and was granted air operator certificate (AOC) No. AC-0001 issued by the General Civil Aviation Authority of the United Arab Emirates (GCAA).

The Operator's fleet consisted of about 250 aircraft comprising Boeing 777 and Airbus A380 types.

1.17.2 Training

All required training for the pilots as per the regulatory requirements, was described in the *operations manual – part D (OM-D)*.



Based on the A380 initial and conversion training, and line flying under supervision (LIFUS) training, the weather radar study guide describes as follows:

- Consider the height of a storm cell when planning avoidance.
- Avoid overflying a cell if its top is at or above 25,000 feet because turbulence may be stronger than expected.
- For flight above a convective cloud, apply a vertical margin of at least 5,000 feet from the identified area of greatest threat.

The study guide provides more detailed information and is intended to be used in conjunction with the full suite of training materials, including the *OM-A*, *FCTM*, *FCOM*, *QRH*, *OM-E*, and guidance from training instructors.

1.17.3 **Operations manual – part A (OM-A) policies**

The Operator's policies concerning flying through areas of thunderstorm activity, seatbelts, and PA, as outlined in the *OM-A*, include the following provisions:

“8.3.8.2 Thunderstorms

Although a flight through areas of thunderstorm activity should be avoided wherever possible, provided that the recommended techniques are employed, such flight may be carried out where no alternative course of action is possible.

Maximum use of weather radar shall be made to identify and assist in avoiding thunderstorm activity and turbulence. Strong weather radar echoes shall be avoided by at least 10 NM at or below FL200, and by at least 20 NM above FL200.”

“8.3.11.1 Crew

Crew members shall be at their assigned crew stations and fully secured by means of seatbelt and shoulder harness during:

...

c. Whenever deemed necessary by the Commander (e.g., during turbulence or under other abnormal/non-normal conditions).

During all other phases of the flight, Flight Crew members shall keep their seat belt fastened while at their stations in the flight deck.

Females who occupy the flight deck jump seats do not need to use the lower strap to secure themselves for taxi, take-off, landing and during turbulence.”

“8.3.11.2 Passengers

All Emirates aeroplanes are equipped with a seat and seat belt for each passenger. Passengers shall fasten their seat belts when the seat belt sign is illuminated.

The seat belt shall be fastened tight and low. A child aged 2 years and above, shall be secured in their own seat for take-off, landing and during turbulence.”

“8.3.11.3 Use of the Fasten Seat Belt Sign

The seat belt sign shall be on during:

...

c. Whenever deemed necessary by the Commander (e.g., during turbulence or anticipated turbulence).”

“14.1.3 How to Present Information in the PA

Other than for delays, routine announcements from the flight deck should be restricted to:

- The welcoming and farewell addresses



- Emergencies
- Abnormal situations
- When turbulence is encountered or expected”

1.17.4 **Operations manual – part E (OM-E) policies**

The Operator’s policies concerning flying through areas of thunderstorm activity, seatbelts, and turbulence, as outlined in the *OM-E*, include the following provisions:

“1.7.3.1 Purser

During turbulence, in the absence of any instructions from the Flight Crew, the Purser shall be authorised to discontinue non safety related duties, advise the Flight Crew of the level of turbulence being experienced and the need for the seat belt sign to be switched on.”

“3.11.5.1 Use of Seat Belts/Harnesses by Cabin Crew and Passengers

• Cabin Crew

During taxi, take-off and landing and whenever the Captain considers it necessary in the interest of safety (e.g. during turbulence or under other abnormal conditions), Cabin Crew must be seated on a jump seat with the lap belt and shoulder harness secured.

• Passengers

All aircraft are equipped with a seat and seat belt for each passenger.

Passengers must fasten their seat belts when the seat belt sign is illuminated. The seat belt must be fastened tight and low.

Note: A child aged two years and above, shall occupy and be secured in their own seat for take-off, landing and during turbulence.”

“4.3.1 Pre-flight

As part of the pre-flight briefing, Flight Crew must inform the Purser and the rest of the Cabin Crew about expected areas of turbulence during the flight.

In-Flight – Flight Crew

When turbulence is expected during the flight, the Flight Crew must advise the Cabin Crew how much time is available to secure the cabin, the level of turbulence and the expected duration.

In-Flight – Purser to ensure that:

- Cabin Crew have secured all passengers.
- If required, Cabin Crew are also secured.
- Pass Cabin Ready check to the Flight Crew.
- The turbulence PA should also be made when the seat belt sign remains illuminated for an extended period of time or when passengers are observed not complying with the illuminated seat belt sign.”

“4.3.3 Levels of Turbulence

The following levels of turbulence can be encountered during a flight:

1. Light Turbulence.
2. Moderate Turbulence.
3. Severe Turbulence.

All three levels of turbulence can either be anticipated (time available to secure) or unanticipated (no time available to secure).

Cabin Crew should always use correct terminology when communicating turbulent conditions to the Flight Crew or other Crew Members.”



“4.3.4.1 Light Turbulence

	Anticipated Light Turbulence	Unanticipated Light Turbulence
Flight Crew Actions	<ol style="list-style-type: none"> 1. Advise the Purser when turbulence is expected, and to ensure that the passengers are secured in their seats. 2. Switch on the seat belt sign. 3. Should communication with Purser regarding what level of cabin service is appropriate e.g. can hot beverages be served to passengers. 	<ol style="list-style-type: none"> 1. Switch on the seat belt sign. 2. Should communication with Purser regarding what level of cabin service is appropriate e.g. can hot beverages be served to passengers.

“4.3.4 Moderate and Severe Turbulence

	Anticipated Moderate and Severe Turbulence	Unanticipated Moderate and Severe Turbulence
Flight Crew Actions	<ol style="list-style-type: none"> 1. Advise the Purser when turbulence is expected, to cease all cabin service, stow carts, secure the cabin and advise Cabin Crew to be seated. (Cargo aircraft only: the supernumerary shall be informed) 2. Switch on the seat belt sign. 3. Report turbulence encounter to Flight Dispatch. 4. Severe turbulence encounter must be recorded in the technical log and an aircraft inspection should be requested. 	<ol style="list-style-type: none"> 1. Switch on the seat belt sign. 2. Make a PA: “Cabin Crew take your seats now”. (Cargo aircraft only: the supernumerary shall be informed). 3. Report turbulence encounter to Flight Dispatch. 4. Severe turbulence encounter must be recorded in the technical log and an aircraft inspection should be requested.
Cabin Crew actions	<p>If time available to secure:</p> <ul style="list-style-type: none"> • Clear the cabin of all service carts (if applicable) • In Economy Class, make the turbulence PA. • If possible, send the turbulence message from the CMT to all the seats. • Lock all lavatories/shower SPAs once they are vacant. • Secure all cabins as per Safety Area of Responsibility ensuring all passengers are seated with their seat belts fastened. • Infants must be removed from bassinets and secured on the adult’s lap or in an approved 	<ul style="list-style-type: none"> • If applicable, tilt and wedge carts and apply brakes. • Stow any liquids that are on top of the cart, either in the cart or on the floor. • Sit down immediately on any seat available and fasten seat belt or on a jump seat with seat belt and shoulder harness fastened or sit on the floor secured to a seat structure. • If possible, make the turbulence PA in all classes.



	<p>car seat. Baby bassinet should be removed and stowed.</p> <ul style="list-style-type: none"> • Cabin crew shall be seated on their jump seat with seat belt and shoulder harness fastened. 	
Cabin Secure As Par Aircraft Type	<ol style="list-style-type: none"> 1. Cabin crew shall pass their Area Ready check to the Purser/Cabin Supervisor. 2. The Purser shall pass the Cabin Ready check to the Flight Crew. 	
Cabin Crew Action After Passing Cabin Secure Check	<ul style="list-style-type: none"> • Cabin Crew shall remain seated and secured until contacted by the Flight Crew, either by an interphone call to the Purser, a PA: "Cabin Crew cleared for duties" or when the seat belt is switched off. <p>Note: Instruct passengers attempting to access the lavatory to return back to their seat and fasten seat belt.</p>	
Post Turbulence Management	<ul style="list-style-type: none"> • Check colleagues (Flight Crew, Cabin Crew and CSAs). • Check passengers. • Check and unlock lavatories. • Secure galleys. • Render First Aid where necessary. • Individually report to Purser/Cabin Supervisor, passenger/crew injuries and/or cabin damage. • Purser to report passenger/crew injuries and/or cabin damage to Flight Crew. • Purser to liaise with Flight Crew about resuming cabin service. 	

Note: Unexpected moderate or severe turbulence may occur suddenly and presents an immediate hazard to passengers and Cabin Crew. The Flight Crew may not initially have time to switch on the seat belt sign, communicate with the Cabin Crew or make a PA. In these situations, Cabin Crew must use their judgement to protect themselves and others.

It is possible that the forward section of the aircraft will experience less turbulent conditions than the aft section of the aircraft. The Flight Crew may not be aware of the level of turbulence throughout the cabin. Therefore it is important that Cabin Crew communicate their experiences with each other and keep the Flight Crew informed of the conditions in the cabin."

1.17.5 *Flight crew techniques manual (FCTM) – Weather Radar*

As per the *FCTM* under *Weather Radar – General – Weather Radar Principle* subsection, it states:

"...

Due to the fact that convective clouds can have a large vertical expansion, their reflectivity depends on the altitude. The quantity of liquid water in the atmosphere decreases with the altitude. Therefore, the reflectivity of a convective cloud decreases with altitude.

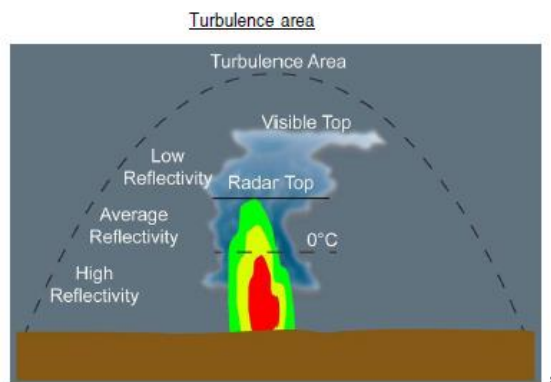
The upper detection limit of the weather radar is referred to as the radar top.

The flight crew must be aware of both the following:

- The radar top may not be the visible top of the convective cloud.
- The convective cloud and associated areas of threat (e.g. turbulence) may significantly extend above the radar top.



...



As per the *FCTM – Use of Weather Radar – General Information on Modes*, both the PF and PM can independently manage their own weather radar display. It also states:

“The AUTO mode is the default mode of the weather radar. The AUTO mode is adapted and optimized for all flight phases. The flight crew can temporarily use the manual modes if needed, depending on the operational context.

...

By default, TURB (turbulence) mode should be in AUTO. The flight crew can temporarily turn off the TURB function to better differentiate precipitations from wet turbulence when ND displays a lot of visual information.”

Range Management subsection states:

“... at a long distance, ahead of the aircraft the accuracy of the weather echo is low due to the both of the following:

- The increase of width in the weather radar beam
- Signal attenuation.

Therefore, the accuracy of the weather echo is higher for short-distance weather.”

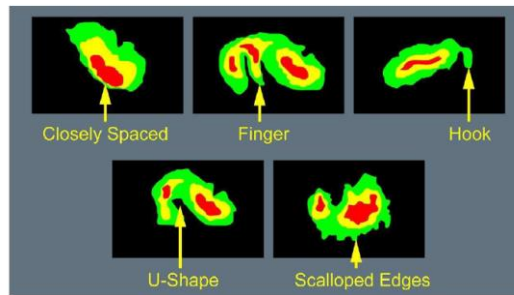
To interpret the weather on the ND and VD, under the *Interpretation of the Weather Displayed on the ND and the VD* subsection, it states:

“The reflectivity of a convective cloud does not always correspond to its danger. The following two cases are examples:

- When there is a high percentage of humidity in the atmosphere, thermal convection may generate clouds that are full of water. These clouds have a high reflectivity, but are not often dangerous.
- Specific converging winds may produce large-scale uplifts of dry air (e.g. in equatorial overland areas). These convective clouds may be very dangerous, but due to low reflectivity, they can be more difficult to detect.

The analysis of shapes combined to colors (instead of colors only) provides a more reliable indication on the severity of a convective cloud. Different colors next to one another usually indicate zones of severe turbulence. Some specific shapes (such as the ones displayed below) are also good indicators of severe hail and are usually associated with strong vertical drafts. Shapes that quickly change also indicate significant weather activity.

Typical Weather Shapes



In order to analyze the weather echo with increased precision, the flight crew can use manual gain. Manual gain mode adjusts the sensitivity of the weather display on the ND. Therefore, the weather echo will appear either stronger (increased gain) or weaker (decreased gain).

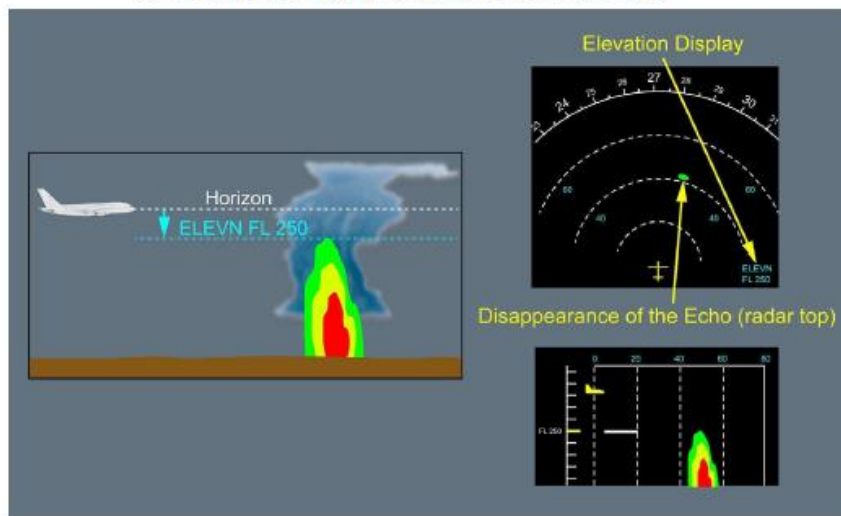
...”

To analyze the weather radar echo with greater precision, under the *Use of the Manual Elevn Mode for the Analysis of Vertical Expansion* subsection, it states:

“In order to analyze a detected convective cloud, the flight crew should assess its vertical expansion. The flight crew should use the VD to assess this expansion and to interpret the corresponding altitude (or flight level) of the convective cloud displayed on the left side of the VD.

In addition, the flight crew can use the manual ELEVN mode to assess with increased precision the expansion of the convective cloud on the ND.

Assessment of the Vertical Expansion of a Convective Cloud



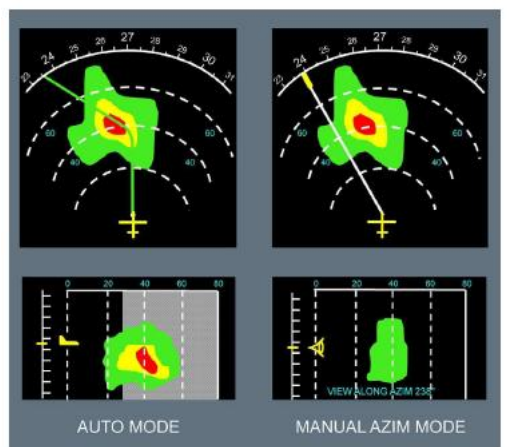
For using the azimuth mode, under the *Use of the Manual AZIM Mode for Avoidance Planning* subsection, it states:

“To assess the general weather conditions in the case of a course change, the flight crew can use the manual AZIM mode. In manual AZIM mode, the VD displays a vertical view along the selected course.

Note: The weather radar automatically reverts to the AUTO mode after 30 s, if the flight crew does not select any AZIM value.



Manual Azim Mode



As per the *FCTM* under *Operations in Convective Weather* subsection, it states:

“OPERATIONS IN CONVECTIVE WEATHER

The flight crew should apply the following operational recommendations in convective weather conditions. These recommendations are applicable in addition to basic knowledge of meteorology and of operation in adverse weather conditions.

- Weather detection:
 - Always consider that a convective cloud may be dangerous, even if the weather echo is weak. Remember that the weather radar detects only water droplets.
 - Frequent lightning may indicate an area with high probability of severe turbulence.
 - Remember that the TURB function detects areas of wet turbulence only.
- Avoidance decision:
 - Establish an “area of greatest threat” based on the location and shape of the strongest weather radar echoes, and on the meteorological knowledge of the flight crew. This “area of greatest threat” corresponds to the zone where the flight crew estimates that the weather conditions are too dangerous to fly in.
 - Initiate your avoidance maneuver as early as possible. As the aircraft gets nearer to the convective weather zone, the information from the weather radar often becomes partial.

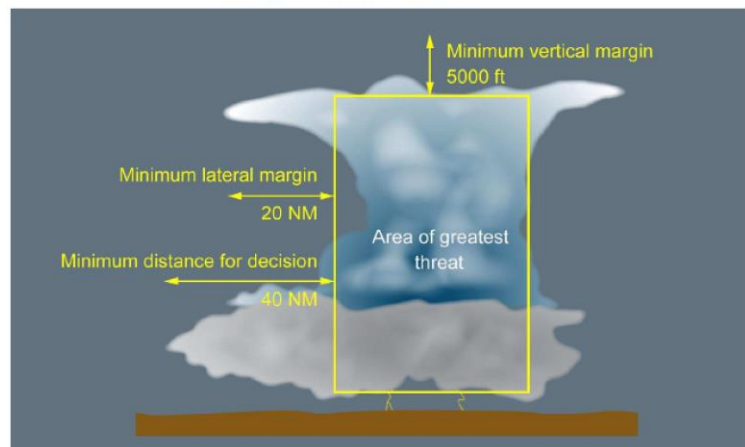
Consider a minimum distance of 40 NM from the convective cloud to make the decision for avoidance maneuver.
- Avoidance technique:
 - If possible, perform lateral avoidance instead of vertical avoidance. Vertical avoidance is in general not recommended, particularly at high altitude, due to the reduction of buffet and performance margins. In addition, some convective clouds may have a significant and unpredictable build-up speed....
 - Lateral avoidance:
 - If possible, deviate upwind instead of downwind. Usually, there is less turbulence and hail upwind of a convective cloud.
 - If possible, avoid the identified “area of greatest threat” by at least 20 NM.
 - Apply an additional margin if the convective clouds are very dynamic.
 - Vertical avoidance:
 - Avoid flying below a convective cloud, even in visual conditions, due to possible severe turbulence, windshear, microbursts, lightning strikes



and hail. If an aircraft must fly below a convective cloud, the flight crew should take into account all indications (visual judgement, weather radar, weather report, pilot's report, etc.) before they take the final decision.

- For flight above a convective cloud, apply a vertical margin of 5 000 ft from the identified "area of greatest threat".

Summary of the margins and distances



1.17.6 Quick reference handbook (QRH) – Procedures during severe turbulence⁴

As per the QRH – *Abnormal Procedures – Severe Turbulence*, the following procedures need to be implemented by the flight crew:

“ ...

- Seat belts: ON
- Maximum turbulence speed: 300kts/.85 Mach
- Minimum turbulence speed: Green Dot⁵
- Adjust speed as necessary for comfort.
- Autopilot: Keep ON
- Cabin and cockpit (loose equipment): Secure
The flight and cabin crewmembers must secure all loose equipment.
Be prepared to use the speed brake, if necessary.

If excessive thrust variations:

- Auto Thrust: OFF
- Descend to or below optimum altitude: Consider ALT.”

⁴ Severe turbulence is characterized by large, abrupt changes in attitude and altitude with large variations in airspeed. There may be brief periods where effective control of the aircraft is impossible. Loose objects may move around the cabin and damage to aircraft structures may occur. [Source: www.skybrary.com]

⁵ Green Dot Speed is defined as: the engine-out operating speed in clean configuration. It provides an estimate of the speed for best lift-to-drag ratio. [source: www.skybrary.com]

1.18 Additional Information

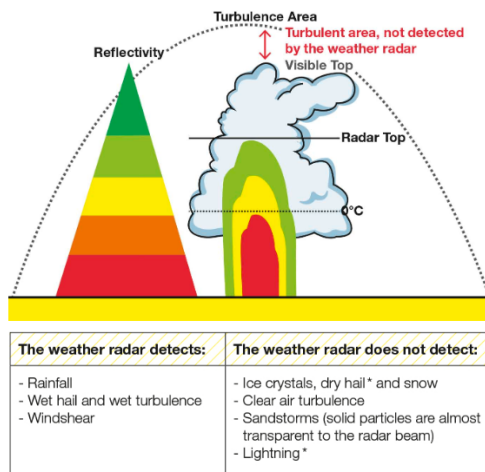
1.18.1 Airbus Safety First – Optimum Use of Weather Radar

In the article "Optimum Use of Weather Radar" by Airbus Safety First #22, it is noted, under the section on *weather radar limitations*, that:

“One of the weather radar limitations is that it indicates only the presence of liquid water. The consequence is that a thunderstorm does not have the same reflectivity over its altitude range because the quantity of liquid water in the atmosphere decreases with the altitude (fig.4). Yet, the convective cloud and associated threats may extend significantly above the upper detection limit of the weather radar (called ‘radar top’). This means that reflectivity is not directly proportional to the level of risk that may be encountered: a convective cloud may be dangerous, even if the radar echo is weak.

This is particularly true for equatorial overland regions where converging winds produce large scale uplifts of dry air. The resulting weather cells have much less reflectivity than mid-latitude convective cells. However, turbulence in or above such clouds may have a higher intensity than indicated by the image on the weather radar display. On the other hand, air close to the sea can be very humid. In this case, thermal convection will produce clouds that are full of water: these clouds will have a high reflectivity but may not necessarily be a high threat.

Consequently, limitations of weather radars must be well understood and complemented by basic meteorological knowledge of the crew and, where possible, visual observation.”



(fig.4) Reflective image of a cumulonimbus

* The latest generations of weather radars offer hail and lightning prediction functions (see the following sections).

This article is provided as a general reference, covering a wide range of weather radar systems installed across Airbus aircraft, from older legacy models to modern, advanced units. The guidance is intentionally broad and not specific to any one radar type. For accurate operational use, always refer to the aircraft’s weather radar manual and the manufacturer’s specific instructions. This article should be viewed as supplementary information only.

1.18.2 Technical information of Honeywell RDR-4000 weather radar performance

The investigation reviewed information regarding the performance of the Honeywell RDR-4000 radar. Airbus *In-Service Information (ISI)* 34.71.00016, dated 3 July 2023, documented reports of reduced radar sensitivity at ranges between 80 and 160 nautical miles, which could lead to an underestimation or late display of weather returns. In response, Airbus issued a *Temporary Abnormal Behavior (TAB)* operational recommendation advising crews to consider all displayed



weather information and be alert to the possibility of late display, particularly in areas of expected convection.

The identified root cause involved the misclassification of certain atmospheric returns as ground clutter, which were consequently filtered out in WX mode. Honeywell confirmed this affected all RDR-4000 systems. Corrective software updates are under development.

Furthermore, this operational context of potential late or weak returns must be considered alongside the more fundamental limitation described in Section 1.18.1: the inherent challenge of detecting weakly reflective, high-altitude convection over water, a documented limitation of weather radar technology that remains a key consideration for flight crew.

1.19 Useful or Effective Investigation Techniques

This Investigation was conducted in accordance with the Air Accident and Incident Investigation Regulation of the United Arab Emirates, and the AAIS-approved policies and procedures, and in conformity with the Standards and Recommended Practices of Annex 13 to the Chicago Convention.



2. Analysis

2.1 General

The Investigation collected data from multiple sources to determine the causes and contributing factors of this Accident.

This analysis examines flight planning, weather deviations, weather radar use, flight crew performance, convective cloud development, satellite imagery, and cabin preparedness in relation to the occurrence. It also addresses safety considerations identified during the Investigation, including those not directly contributing to the Accident.

2.2 Flight Planning

The *operational flight plan (OFP)* for the flight from Perth to Dubai included en-route weather charts, effective from 1200 UTC on 4 December 2023 to 0000 UTC on 5 December 2023. The planned route proceeded northwest across the Indian Ocean, including a segment in the vicinity of the Maldives where isolated CB activity was forecast.

A standard preflight briefing was conducted in accordance with the Operator's procedures. During the briefing, the flight crew reviewed the forecast meteorological information contained in the OFP. Although wind shear was discussed, it was assessed as not indicative of significant turbulence along the planned route. Based on the available forecast data, the crew did not identify any weather phenomena expected to adversely affect the flight.

In preparing for the flight, the flight crew reviewed the fixed-time prognostic charts included in the OFP (figures 9a and 9b) and conducted weather checks using various applications the day before the flight. The convective activity forecast near the Maldives was assessed as isolated and not expected to significantly affect the route at the estimated time of overflight. Established weather avoidance procedures were available should deviation become necessary.

Both the Commander and Augmenting Captain had prior experience operating this route and were aware that crossings of the Indian Ocean can involve convective activity, including the formation of CB clouds and turbulence activity. In line with standard practice, they planned to use onboard weather radar to monitor and manage any convective weather encountered en route. Severe turbulence was not specifically discussed during the briefing, consistent with the forecast information reviewed at that time. It was noted, however, that seat belt signs would be activated, and passengers instructed to return to their seats and fasten their seatbelts whenever the Commander deemed necessary.

The Investigation concludes that the flight preparation and briefing were conducted in accordance with the Operator's standard operating procedures and were consistent with the forecast meteorological information available at the time.

2.3 Weather Radar Functionality

While cruising within Melbourne FIR, the Aircraft performed a weather-related deviation at FL360, which continued during a climb to FL380. Once leveled at FL380, the Aircraft resumed its planned route. The weather deviations were based on both weather radar returns and visual observations. The flight data indicates that the flight crew actively monitored the weather conditions, utilizing various weather radar ranges and manual adjustments such as elevation, gain, and azimuth, before and during the deviations. These actions were consistent with normal system operation and indicate appropriate use of available radar functions. Post-flight, an

engineering inspection of the weather radar, carried out under the supervision of the Aircraft manufacturer, confirmed that the system was operating correctly.

The fixed-time prognostic charts valid for 1800 UTC on 4 December 2023 and 0000 UTC on 5 December 2023 (figures 9a and 9b) indicated isolated embedded CB clouds along the planned route. The timing and location of the route deviation were consistent with the forecast isolated CB activity within the Melbourne FIR. Additionally, a MeteoBlue satellite image (figure 13), captured on 4 December at 1915 UTC, showed atmospheric conditions at the time, with the Aircraft's position at 1911 UTC marked for reference.



Figure 13. MeteoBlue satellite image of atmospheric conditions, 4 December 2023 at 1915 UTC in the area where the Aircraft flew

2.4 Severe Turbulence Encounter

Following the weather-related deviation within Melbourne FIR, the Aircraft returned to its originally planned route. Subsequently, while cruising within Male FIR, the Copilot took a rest and was replaced by the Augmenting Captain in the right seat.

While cruising at FL380 within Male FIR under clear, moonlit skies, the flight crew noticed weather cells ahead and to the left, both visually and on the radar. As stated by the Commander and Augmenting Captain, at a certain position, the weather radar showed a small spot about 40 nautical miles ahead at 11 o'clock position, which remained off-path. Based on this assessment, they continued along the planned route under smooth cruise conditions. They also monitored the weather for a while, assessing that it did not present an immediate threat to the Aircraft. Consequently, the Augmenting Captain took a physiological break. Before leaving the flight deck, a cabin crewmember was seated in the jump seat in the flight deck, in accordance with the Operator's policy. According to the statements of both flight crewmembers, the severe turbulence occurred less than a minute after the Augmenting Captain left the flight deck.

During the severe turbulence encounter, the flight data indicated rapid and significant vertical wind fluctuations consistent with severe turbulence, including a 6-second period of the most severe turbulence. This extreme turbulence occurred shortly after the onset of light turbulence, followed by 14 seconds of less intense severe turbulence and 8 seconds of moderate turbulence. Throughout the most severe period, vertical acceleration (g variation) ranged between -0.5g and +2.16g, while lateral acceleration varied between -0.17g and +0.08g. These caused significant variations in the Aircraft's attitude and a sudden increase in airspeed. The Aircraft's flight control and protection systems responded automatically, preventing structural exceedance. The airspeed briefly exceeded the maximum operating Mach (M_{MO}) of 0.89 for less than one second before returning within limits. The autopilot remained engaged, and the Aircraft remained controllable throughout the turbulence encounter.



2.5 The Use of Weather Radar

The Honeywell RDR-4000 weather radar system, as documented in the *FCOM* and *FCTM*, is designed with an AUTO mode that employs automated threat prioritization and display logic to reduce clutter and highlight primary threats. This design prioritizes on-path weather within a $\pm 4,000$ -foot vertical envelope. The system's operational characteristics in certain environments are documented in manufacturer guidance and in Airbus Safety First publication (#22, "Optimum Use of Weather Radar"), which notes that reflectivity is not directly proportional to risk, and that convective clouds in equatorial regions may produce weak radar returns despite potentially significant turbulence.

The Aircraft's weather radar system, the most recent upgrade from the manufacturer, was standard across the Operator's entire A380 fleet. This system features both AUTO and MANUAL modes, allowing pilots to tailor radar performance to operational conditions. The flight crews were trained on its functionality and radar symbology via eLearning modules.

During this flight, both weather radar (WXR) and turbulence detection (TURB) were active in accordance with SOP. Flight data confirmed that the flight crew used both AUTO and MANUAL modes before and during a weather deviation while operating in the Melbourne FIR at FL360. In AUTO mode, the radar provided continuous on-path, altitude-relevant weather detection. The flight crew varied the ND range between 40 and 640 nautical miles to enhance situational awareness.

As convective weather developed along the flight path, the flight crew switched to MANUAL mode to adjust elevation, tilt, gain, and azimuth, allowing for a more detailed assessment of the storm's structure and vertical extent. This supported a tactical deviation from the planned route. The maneuver was consistent with SOP and operational best practices and resulted in only light turbulence.

Later, while cruising at FL380 in the Male FIR, the Aircraft encountered severe turbulence. Prior to this, radar returns were visible but categorized as off-path, outside the $\pm 4,000$ feet vertical envelope centered on the Aircraft's altitude, used by the radar to define on-path weather threats above FL250. In AUTO mode, such returns are displayed without emphasis and may not generate alerts unless operational thresholds are met.

As per the system design described in the manufacturer's documentation, the weather radar continuously captures volumetric weather data across the full forward scan volume and distinguishes between on-path and off-path weather returns for display. In AUTO mode, weather outside the on-path envelope is shown as secondary or off-path and may be de-emphasized unless it reaches thresholds of operational relevance, such as strong reflectivity or notable vertical development, to reduce clutter and focus attention on hazards along the flight path. This filtering logic may influence how high-altitude or weakly reflective convective activity is visually emphasized in AUTO mode, particularly in tropical regions where such activity is common, the type noted in the Airbus Safety First article as being typical of equatorial environments.

Although AUTO mode provides streamlined protection during cruise, it incorporates mode-specific characteristics that differ from MANUAL mode functionality, as follows:

- AUTO mode does not allow pilot-selectable vertical cross-sections of specific storm cells: In AUTO mode, the vertical profile (VP), an automatic feature available on A380 displays, shows a vertical representation of weather along the aircraft's flight path. It is not a profile of a specific storm cell selected by the pilot, but rather a "tunnel view" of what lies directly ahead. For detailed analysis, the vertical display



(VD) can be used in MANUAL mode to create a vertical cross-section of a storm at a manually selected azimuth.

- Pilot-selectable lateral sector scanning is not available in AUTO mode. Azimuth remains forward-oriented, and VD activation is only possible in MANUAL mode.
- Restricted pilot-selectable elevation control: AUTO mode prioritizes the display of weather within a $\pm 4,000$ -foot vertical envelope relative to the aircraft's altitude above FL250, with no option to select specific layers unless in MANUAL mode. Pilot adjustment of tilt is not available unless MANUAL mode is selected.
- High or weakly reflective convective tops may not be prominently depicted in AUTO mode: Returns not meeting thresholds of operational relevance may not be prominently displayed.

MANUAL mode enables full control over tilt, gain, elevation, azimuth, and VD. This allows the crew to scan specific altitude bands, assess storm structure, and view vertical cross-sections of weather aligned with the aircraft's heading or at a selected azimuth. According to the Honeywell IntuVue RDR-4000 Pilot's Manual, "Manual mode can be used to reveal the vertical extent of the storm. Note that moisture must be present to detect turbulence." This confirms that VD is available in MANUAL mode and is particularly useful for assessing storm height and vertical development.

During this segment, the flight crew observed cloud formations below the Aircraft near the 11 o'clock position under moonlit conditions and assessed sufficient vertical clearance. Based on visual cues and AUTO mode returns, they concluded that no immediate on-path threat existed. Both pilots actively adjusted the ND range between 80 and 640 NM. The Commander's last range change (left side) from 640 to 80 nautical miles occurred when the Aircraft was at approximately 165 nautical miles before the turbulence encounter, while the Augmenting Captain (right side) made similar adjustments closer to the event, about 34.2 nautical miles. These actions aligned with standard enroute procedures. No additional vertical storm assessment using pilot-selectable radar functions was performed during this segment.

Unlike in the earlier weather avoidance segment, where pilot-selectable radar inputs were used, no such inputs were applied during this phase.

The Investigation determined that the radar's AUTO mode prioritizes weather within the projected flight path and may de-emphasize off-path or weakly reflective convective activity. During this segment, the flight crew assessed the weather based on the automated presentation and visual observations. The available data do not allow a determination of how alternative radar use may have influenced the flight crew's weather assessment. This occurrence highlights that radar threat presentation may not fully represent the vertical development or associated turbulence potential of high-altitude convection in tropical environments.

The Aircraft ultimately encountered severe turbulence while flying in proximity to radar returns categorized as off-path. No turbulence alerts were triggered, and no strong precipitation-based radar returns were evident. This was not a radar malfunction but a limitation of Doppler-based turbulence detection, which requires significant motion within precipitation to generate alerts.

Satellite imagery obtained during the Investigation shows a developing cloud formation that grew larger over the two hours prior to the occurrence, and figure 10d indicates the Aircraft may have been within or just above a vertically developing convective cloud. Even with moonlight, nighttime visual estimation of vertical separation is inherently unreliable and may have affected the reliability of the flight crew's visual assessment of vertical clearance above the convective tops. Convective clouds in equatorial regions often produce weak radar reflectivity at altitude due to



drier upper-level air and limited precipitation, yet turbulence risk remains high. Weak or off-path radar returns in such regions may reduce the apparent prominence of associated hazards.

The A380 documentation did not provide explicit guidance on overflying off-path returns. However, the Operator's *FCTM* and training materials advised avoiding storm cells with tops at or above 25,000 feet and maintaining at least 5,000 feet vertical separation. At FL380, the on-path radar envelope spanned between FL340 and FL420; returns outside this range were displayed as off-path in accordance with system logic.

Moreover, the radar top reflects the highest altitude where precipitation is detected, not the actual storm top, which may extend higher due to weakly reflective convection. Convective activity and turbulence can reach altitudes above radar-detectable levels.

In this occurrence, the severe turbulence was consistent with convective activity characterized by weak radar reflectivity. The combination of limited reflectivity, nighttime visual limitations, and the inherent characteristics of weather radar may have influenced the extent of weather information available to the flight crew.

This occurrence illustrates the interaction between automated radar presentation, tropical convective characteristics, and operational interpretation.

2.6 Flight Crew Performance

During cruise at FL380 within the Male FIR, the flight crew assessed the weather ahead as non-threatening and continued on their planned route prior to encountering severe turbulence. The weather radar remained in AUTO mode. Both pilots actively adjusted the ND range settings between 80 and 640 nautical miles, indicating ongoing monitoring of the weather environment. Pilot-selectable radar functions were available but not utilized during this phase. The flight crew's weather assessment was therefore based on the information presented by the radar in its automated configuration, supplemented by visual observations.

The Commander, who occupied the left seat, used only the ND range function during this phase, with the final setting adjusted to 80 nautical miles when the Aircraft was at about 165 nautical miles before the turbulence encounter.

The Copilot, acting as the pilot monitoring (PM) until about 20 minutes before the turbulence, during this phase, made a single adjustment to the manual gain setting (from 90% to 100%) approximately 557 nautical miles prior to the event. He also cycled through various ND ranges before leaving the flight deck for rest.

The Augmenting Captain, who replaced the Copilot in the right seat, adjusted the ND range from 640 to 320 nautical miles, and then down to 80 nautical miles in the minutes leading up to the turbulence encounter. Following this assessment, the Augmenting Captain temporarily left the flight deck for a physiological break, and shortly thereafter, the severe turbulence occurred.

The available manual functions of the weather radar were not utilized during this phase; accordingly, the weather assessment was based on AUTO mode presentation supplemented by visual observation.

Requesting updated weather information from air traffic control or the Operator's NCC was not required by SOP. Based on the operational picture available at the time, including onboard radar indications and visual observations, the flight crew did not perceive a need to seek additional information. While real-time datalink weather was not available on the flight deck, there is no indication that its absence influenced the flight crew's assessment or decision-making in the prevailing circumstances.



The operational context, characterized by off-path, non-alerting returns and visual cloud tops below the Aircraft, did not prompt a transition from AUTO mode to other radar configurations. The use of AUTO mode was consistent with normal operational practice. However, the available data do not allow a determination of whether the use of MANUAL mode in this occurrence would have provided additional or actionable information, or whether it would have influenced the flight crew's assessment or decisions.

The Investigation determined that the combined effect of weather radar system characteristics, the prevailing meteorological conditions, and the operational use of the radar during this phase may have influenced the extent of vertical weather characterization available to the flight crew.

No evidence was identified that the absence of flight deck Wi-Fi connectivity influenced the crew's decision-making.

2.7 The CB Clouds and Satellite Image

Turbulence associated with CB clouds is not limited to the interior of the cloud itself. It is common for turbulence to occur near or above the cloud, and several past cases of severe turbulence have been attributed to vertical turbulence above the cloud, where updrafts and downdrafts can extend thousands of feet above the cloud tops. Weather radar displays precipitation-sized hydrometeors, and does not detect turbulence directly or dry atmospheric motion. It may not display convective activity with limited hydrometeor content, particularly near cloud tops.

The MeteoBlue satellite image (figure 13), captured during a previous weather deviation when the Aircraft was laterally off course from the *OFP* planned route, shows the Aircraft flying over a white dense mass of clouds. This satellite image showed a dense cloud mass broadly similar in appearance to the cloud formations later during the severe turbulence encounter. Such cloud formations may produce limited radar reflectivity depending on water content, precipitation structure, and cloud top characteristics.

According to an analysis by the UAE National Center of Meteorology (NCM) based on MeteoBlue satellite image, there is a possibility that a developing CB cloud could have been associated with severe turbulence. However, the cloud pattern in this instance does not strongly indicate a "severe" CB. To determine the altitude of this cloud, the grey scale applied to create the image would need to be known.

The satellite captures infrared (IR) temperature data, which is then transformed into cloud formations through a grey scale. By obtaining a temperature value from the brightest white area of the cloud, its altitude could be estimated. However, since the temperature value for the brightest part of the cloud was not provided by MeteoBlue, the altitude of the cloud cannot be determined from this image.

According to the NCM meteorologists, who reviewed satellite images not included in this Report, the quality and resolution of the NCM's weather satellite imagery were lower than those of the MeteoBlue images. The NCM stated, with limited confidence, that a pixel within the reported turbulence area appeared to align with a cloud top altitude of around 50,000 feet. If this estimate is accurate, it would suggest an isolated CB cloud. SIGMETs are typically not issued for isolated CB clouds, as pilots can usually identify them visually. This may be consistent with the absence of a SIGMET.

Based on the available information, it cannot be definitively determined whether the Aircraft entered the top of a convective cloud. The NCM meteorologist's analysis was inconclusive,



noting that the MeteoBlue images lacked sufficient detail to confirm the cloud top altitude and did not clearly indicate a “severe” CB cloud, although it remained a possibility. Furthermore, NCM's analysis of its own imagery suggests, with low confidence, that an isolated CB cloud in the vicinity of the encounter might have reached a cloud top altitude of up to 50,000 feet above mean sea level (AMSL).

The NCM meteorologist discussed the potential extent of vertical turbulence above a convective cloud, highlighting that there are no established guidelines for determining the maximum altitude at which such turbulence may occur. However, he pointed out that in strong tropical convection, vertical motions may extend significantly above typical cruise altitudes. In this Accident, the severe turbulence occurred southeast of Male, within the tropical region near the Equator.

The NCM advised that wind patterns in and around a CB cloud are always unique, and since the atmosphere is never identical, each situation is distinct. He explained that significant vertical motions may extend above the visible cloud top, sometimes in areas with limited or diffuse cloud structure.

Due to the distinctiveness of each situation, it is difficult to provide a clear "rule of thumb" for such phenomena. Generally, vertical winds above a CB cloud in the tropical regions tend to be stronger than those above a CB cloud in mid-latitudes or further north, due to the altitude of the tropopause. In poleward latitudes, the drier air and the capping effect of the lower tropopause limit the penetration of CB-associated winds beyond the visible cloud, especially in fully developed CB clouds. However, in tropical regions, the tropopause is much higher, often reaching altitudes of up to 60,000 feet, which allows a CB cloud with substantial energy to extend well above the typical cruising altitude of commercial aircraft.

2.8 Cabin Preparedness

The cabin crew was informed about the potential for turbulence during the flight and instructed that seatbelts be fastened at all times. Passengers were also reminded of this during the welcome announcement.

The seat belt signs were turned on about 48 seconds prior to the turbulence encounter. The Commander stated that turbulence was not anticipated; the seatbelt sign was activated as a precaution. Although severe turbulence was not anticipated, the activation of the seatbelt signs reflects a precautionary action to perceived convective activity. This was intended to ensure passenger safety, even though the Operator's policy allows cabin crew to continue service during light turbulence.

Communication with the Cabin Supervisor to coordinate cabin securing was not established following the seat belt sign activation. The short time interval, coupled with the assessment of no immediate threat, likely influenced the sequence of actions. The existing *OM-E* procedure for unanticipated light turbulence used the term 'should' for this communication, which may have contributed to variability in its interpretation under time-sensitive conditions.

The short time interval between seat belt sign activation and the turbulence encounter limited the opportunity for cabin securing and coordination. The turbulence was neither expected to occur imminently nor forecasted to be moderate or severe, and radar indications did not suggest an immediate threat requiring urgent coordination.

At the time of the turbulence encounter, most cabin crewmembers, aside from one in the flight deck and another seated in the upper deck forward jump seat, were standing in the galleys,



cabin aisles, or near the lavatories. Some were resting in the crew rest compartment and had not yet secured themselves with seatbelts.

After the seat belt signs were turned on prior to the turbulence, the cabin supervisor in economy class made an announcement about the turbulence, and some cabin crewmembers began securing the cabin. However, due to the brief time between the signs' activation and the onset of severe turbulence, the cabin securing process had only just started. As a result, not all passengers were checked to ensure their seatbelts were fastened.

Of the 36 passengers who sustained injuries, five were in the lavatories and 31 were seated. The Operator's post-event analysis confirmed that 22 of the injured seated passengers were not wearing seatbelts at the time. Given the injury mechanisms associated with vertical accelerations, it is likely that unrestrained occupants were more susceptible to injury.

The absence of communication between the flight crew and cabin crew is assessed to be associated with the limited time available between activation of the sign and the turbulence encounter, together with the absence of indications requiring immediate action. Passenger seatbelt use is recognized as a mitigating factor in turbulence-related injuries. Pre-flight safety briefings via video, printed safety cards, and verbal announcements clearly advised passengers to remain seated with seatbelts fastened whenever possible, even when the seatbelt sign is off.

Fourteen cabin crew members were injured, including three with serious injuries and 11 with minor injuries. Among them, five were in the aft cabin, two in the mid cabin, and seven in the forward cabin. In the aft section, two were located in the galley, while three were resting in the crew rest compartment.

The turbulence encounter generated significant variations of vertical g-loads, resulting in unrestrained occupants being lifted off from their seats or feet and impacting the cabin ceiling or interior furnishings, causing injuries and damages. The Aircraft movements were most significant in the aft section of the economy cabin, the upper deck aft galley, and the bar lounge area.

The injury data indicate that seatbelt use was an important mitigating factor in the severity of injuries sustained. Passenger adherence to safety instructions, including the Commander's announcement, cabin crew briefings, and pre-departure demonstrations, may have contributed to this outcome.

The Operator's *operations manual – part E (OM-E)* contained procedures regarding communication between the flight crew and the Purser during unanticipated turbulence. However, the guidance for light turbulence was not sufficiently specific. The procedure stated that the Purser should be informed when turbulence is anticipated, and that the level of cabin service “should” be discussed. This wording allowed for variability in interpretation, with the crew potentially interpreting communication during light turbulence as optional.

Notably, the flight and cabin crew adhered to the procedures for unanticipated moderate and severe turbulence during and after the event. Following the turbulence encounter, the Commander conducted an initial damage and injury assessment, while the Copilot assisted the cabin crew and passengers before taking over flying duties. The Augmenting Captain assisted with cabin clean-up and provided ongoing updates to the flight deck. Meanwhile, the Purser coordinated assistance to injured passengers and crew, including enlisting onboard medical professionals.

Industry experience suggests that continuous seatbelt sign illumination may reduce long-term passenger compliance, which may influence operational decisions regarding its use.



The Commander decided to proceed to OMDB as the destination. The Purser ensured the landing procedures, although some pre-landing tasks were not completed due to prioritizing medical assistance.



3. Conclusions

3.1 General

From the evidence available, the following findings, causes, and contributing factors were made 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.** Are statements of all significant conditions, events, or circumstances in this Accident. The findings are significant steps in this Accident sequence but they are not always causal or indicate deficiencies.
- **Causes.** Are actions, omissions, events, conditions, or a combination thereof, which led to this Accident.
- **Contributing factors.** Are 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 certificated, equipped, and maintained in accordance with *Civil Aviation Regulations* of the United Arab Emirates.
- (b) The Aircraft was airworthy at the time of dispatch, and there was no indication of any defects or malfunctions that could have contributed to the Accident.
- (c) No defects or technical anomalies were reported in the Aircraft systems and equipment, including the weather radar system before, during, or after the severe turbulence encounter.
- (d) The Aircraft's protection systems functioned as designed and prevented structural exceedance, although M_{MO} was briefly exceeded for less than one second.
- (e) The Aircraft encountered severe turbulence with vertical accelerations ranging from $-0.5g$ to $+2.16g$, lasting for 6 seconds, shortly after the onset of light turbulence.
- (f) Throughout the turbulence, the Aircraft's autopilot and autothrust remained engaged, and the Aircraft remained controllable.

3.2.2 Findings relevant to the flight crew

- (a) All flight crewmembers possessed the necessary licenses and ratings 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 completed their annual recurrent safety and emergency procedures (SEP) training, which covered the required actions to be taken in the event of turbulence.
- (d) While cruising at FL380 within Male FIR prior to the severe turbulence, the flight crew assessed the weather ahead, based on the information available at that time, as not requiring deviation.
- (e) The Commander was the pilot flying (PF), and the Copilot was the pilot monitoring (PM). About 20 minutes before the severe turbulence, the Copilot was replaced by the Augmenting Captain and assumed the role of PM.

3.2.3 Findings relevant to the cabin crew

- (a) All cabin crewmembers possessed the necessary licenses 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 crewmembers had completed their annual recurrent SEP training, which covered the necessary actions to take in the event of turbulence.
- (d) Before the severe turbulence was encountered, when the seatbelt signs were turned on, the cabin supervisor in economy class made a public announcement (PA) about the turbulence, and some cabin crewmembers began securing the cabin.
- (e) Some of the cabin crew on duty could not remember seeing the seatbelt signs illuminated or hearing the chime when it was activated.

3.2.4 Findings relevant to flight operations

- (a) No evidence of non-compliance with the Operator's documented procedures was identified.
- (b) While cruising at FL360 within the Melbourne FIR, the flight crew conducted weather-related deviations, using AUTO mode for on-path monitoring and adjusting range for situational awareness. Additional pilot-selectable radar functions were also utilized to assess the surrounding weather.
- (c) During the cruise at FL380 in Male FIR prior to the event, the weather radar was operated in AUTO mode with adjustments made to the ND range. Other available pilot-selectable radar functions were not utilized during this phase.
- (d) Radar returns were present ahead of the Aircraft, but were displayed as off-path due to being located outside the $\pm 4,000$ -foot vertical corridor centered on the Aircraft's altitude.
- (e) The radar did not issue a turbulence alert prior to the encounter, consistent with the absence of sufficient hydrometeors required for Doppler-based turbulence detection in TURB mode.
- (f) About 48 seconds before the severe turbulence encounter, the Commander activated the seat belt signs.
- (g) Most of the on-duty cabin crew were standing or seated without their seat belt fastened when the turbulence was encountered.



- (h) Following the activation of the seat belt sign, communication between the flight deck and the cabin supervisor to coordinate the securing of the cabin was not completed prior to the onset of turbulence.
- (i) The flight crew observed that there was a brief exceedance to the maximum operating Mach number (M_{MO}).
- (j) After assessing the damage and injuries, the Commander, in coordination with the medical support and network control center (NCC), decided to continue to the destination.

3.2.5 Findings relevant to the Operator

- (a) The significant weather fixed time prognostic charts, valid for flight levels ranging from FL 250 to FL 630, for the 18:00 UTC of 4 December 2023 and for 00:00 UTC of 5 December 2023, forecasted areas of convective activity with isolated embedded cumulonimbus (CB) clouds over the Maldives.
- (b) The Aircraft's documentation did not provide specific guidance on avoidance criteria for off-path weather. The Operator's *FCTM* recommended avoiding storm cells with tops at or above 25,000 feet and maintaining at least 5,000 feet of vertical separation.

3.2.6 Findings relevant to survivability

- (a) Several unrestrained passengers, along with unrestrained and standing-up cabin crewmembers, were lifted off their seats and feet, striking the cabin ceiling and resulting in injuries and damage.
- (b) Among the 36 injured passengers, 4 sustained serious injuries, whereas 3 out of the 14 injured crewmembers sustained serious injuries.
- (c) The turbulence mainly affected the aft cabin.

3.3 Cause

The Air Accident Investigation Sector determines that the Accident was caused by the Aircraft encountering severe turbulence associated with vertically developing convective activity in a tropical environment, where weak radar reflectivity and the characteristics of the weather radar presentation did not provide a prominent indication of the associated turbulence potential.

3.4 Contributing Factors

The Air Accident Investigation Sector identifies the following contributing factors to the Accident:

- (a) The presence of unrestrained passengers and cabin crewmembers during the turbulence encounter, resulting in injuries during significant vertical accelerations.
- (b) The short interval between the activation of the seat belt sign and the onset of severe turbulence limited the opportunity to complete full flight deck–cabin coordination and cabin securing actions under time-constrained conditions.



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 outlined all safety issues identified during the Investigation that were subsequently addressed by the concerned entities.

4.2 Safety Actions Taken

The Operator undertook the following corrective safety measures following the Accident in response to its internal safety investigation:

- (a) A working group was formed to assess policies and procedures related to seatbelt sign usage, cabin securing procedures, passenger announcements, and service levels, incorporating a review of industry best practices. These ongoing safety actions aim to prevent and reduce the risk of damage and injuries resulting from inflight turbulence.
- (b) Pilots have been provided with an upgraded LIDO mPilot version that offers a more comprehensive and accurate display of forecasted weather, incorporating the International Air Transport Association (IATA) Turbulence Aware tool.
- (c) Wi-Fi extenders are being installed across both the Boeing and Airbus fleets to improve inflight internet connectivity in the flight deck, facilitating real-time weather updates. The installation on all Boeing aircraft was complete, while the A380 installation is ongoing.
- (d) The procedures regarding communication between the flight crew and the cabin crew during anticipated and unanticipated light turbulence in the Operator's *operations manual – part E* have been updated to state 'Shall' instead of 'Should' to avoid any misunderstanding.

4.3 Safety Recommendation

Emirates:

SR13/2026

The Investigation identified a safety enhancement opportunity, not directly associated with the causes of the Accident, related to the use and interpretation of weather radar information during cruise in convective environments.

Therefore, it is recommended that the Operator consider reviewing existing guidance and training provisions to determine whether additional advisory material on the complementary use of available weather radar functionalities could further support flight crew situational awareness and strategic weather assessment.

Such enhancements may include clarifying considerations for integrating different radar operating modes, where appropriate, while maintaining alignment with standard operating procedures and effective workload management during cruise operations.



This Final Report is issued by:

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Appendix A. Weather Radar Manual Modes and Values at FL360 and FL380

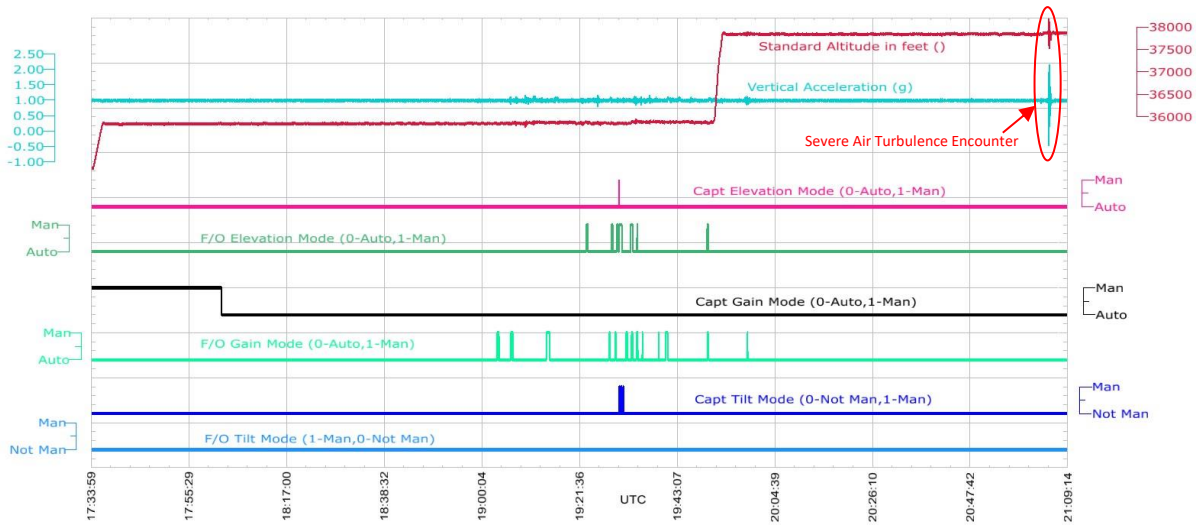


Figure A-1. Weather Radar Modes at FL360 and FL380

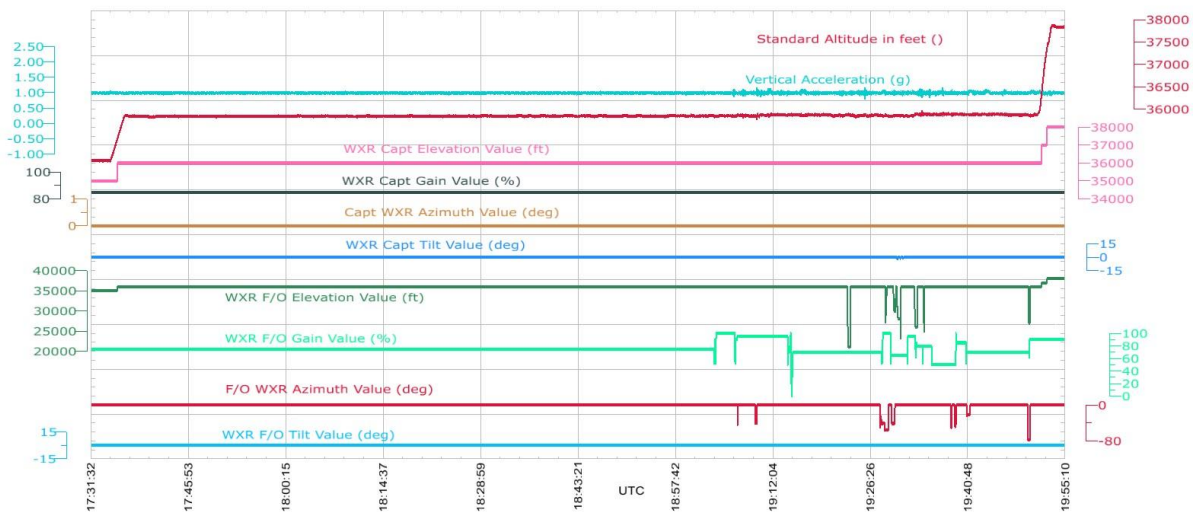


Figure A-2. Weather Radar Values at FL360

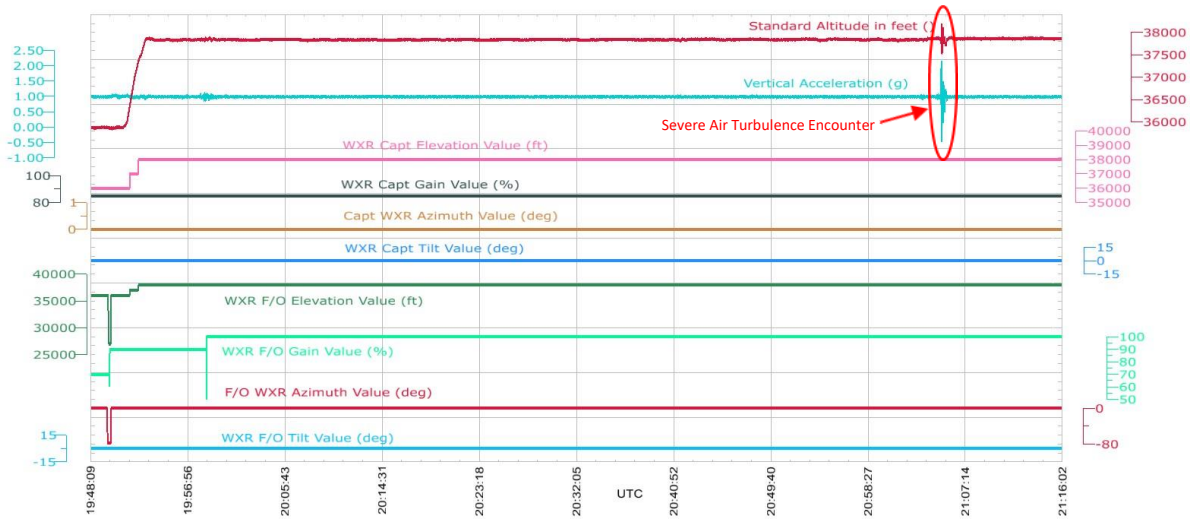
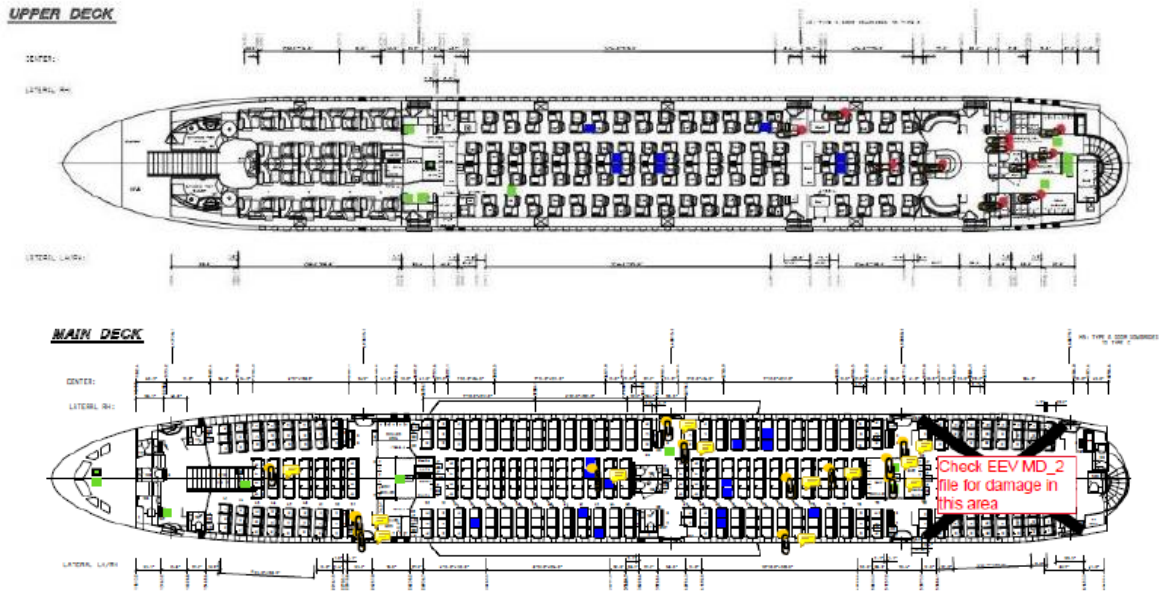


Figure A-3. Weather Radar Values at FL380



Appendix B. Location of Injured Persons and Damages



- ▣ Flight Crew
- Cabin Crew
- Injured passenger, seatbelt off
- Injured passenger, seatbelt unknown
- Upper deck damage
- Main deck damage