Bundesstelle für
Flugunfalluntersuchung

German Federal Bureau of
Aircraft Accident Investigation

Investigation Report

Identification

Type of Occurrence:	Accident
Date:	2 March 2023
Location:	Seychelles Airspace
Aircraft:	Airplane
Manufacturer:	Airbus
Type:	A330-900
Injuries to persons:	6 passengers suffered serious, 15 passengers and one cabin crew member minor injuries
Damage:	Minor damage to aircraft
Other Damage:	None
State File Number:	BFU23-0102-2X

This investigation was conducted in accordance with the regulation (EU) No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation and the Federal German Law relating to the investigation of accidents and incidents associated with the operation of civil aircraft (*Flugunfall-Untersuchungs-Gesetz - FlUUG*) of 26 August 1998.

The sole objective of the investigation is to prevent future accidents and incidents. The investigation does not seek to ascertain blame or apportion legal liability for any claims that may arise.

This document is a translation of the German Investigation Report. Although every effort was made for the translation to be accurate, in the event of any discrepancies the original German document is the authentic version.

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Abbreviations

Glossary of Abbreviations

ACARS	Automatic Communications and Reporting System	
AFM	Airplane Flight Manual	Flight manual
ALTCRZ	Airbus Mode - Altitude Cruise	
AMSL	Above Mean Sea Level	über dem mittleren Meeresspiegel
AOA	Angle of Attack	Anstellwinkel
AOM	Airplane Operating Manual	Flugbetriebshandbuch
AP	Autopilot	automatische Flugregelungs- und Steueranlage
ARC	Airworthiness Review Certificate	Bescheinigung über die Prüfung der Lufttüchtigkeit
ATC	Air Traffic Control	Flugverkehrskontrolle
ATPL	Airline Transport Pilot Licence	Verkehrspilotenlizenz
BDSG	German Data Protection Act	Bundesdatenschutzgesetz
CA	Cabin Attendant	Flugbegleiter(-in)
CAMO	Continuing Airworthiness Management Organisation	Organisation für die Aufrechterhaltung der Lufttüchtigkeit
CAT	Clear Air Turbulence	Klarluftturbulenz
CB	Cumulonimbus	Cumulonimbus
CISM	Critical Incident Stress Management	
COP	Co-pilot	Copilot
CPL	Commercial Pilot Licence	Lizenz für Berufspiloten
CPDLC	Controller Pilot Data Link Communications	
CRM	Crew Resource Management	
CVR	Cockpit Voice Recorder	Stimmenrekorder
DFDR	Digital Flight Data Recorder	Flugdatenschreiber
DSGVO	General Data Protection Regulation	Datenschutz-Grundverordnung

EFB	Electronic Flight Bag	
EFIS	Electronic Flight Instrument System	
EMBD CB	Embedded Cumulonimbus	Eingelagerter Cumulonimbus
FCL	Flight Crew Licensing	Lizenzierung von Flugbesatzungen
FCN	Flight Support Notice	
FCOM	Flight Crew Operating Manual	Betriebshandbuch für Flugpersonal
F/CTL	Flight Controls	Flugsteuerung
FL	Flight Level	Flugfläche
FMS	Flight Management System	
FSN	Flight Support Notice	
ft	Feet	Fuß (1 Fuß = 0,3048 m)
ft/min	Feet per minute	Fuß pro Minute
g	acceleration due to Earth's gravity (9,81 m/s²)	Beschleunigung durch die Erdanziehungskraft (9,81 m/s²)
GDPR	General Data Protection Regulation	Datenschutz-Grundverordnung
GPS	Global Positioning System	Globales Positionsbestimmungssystem
GS	Ground Speed	Geschwindigkeit über Grund
HDG	Heading	Steuerkurs
IAS	Indicated Airspeed	Angezeigte Fluggeschwindigkeit
IATA	International Air Transport Association	
IFR	Instrument Flight Rules	Instrumentenflugregeln
IMC	Instrument Meteorological Conditions	Instrumentenwetterbedingungen
IR	Instrument Rating	Instrumentenflugberechtigung
ISI	In-Service Information	
ITCZ	Inter Tropical Convergence Zone	Intertropische Konvergenzzone
kt	knot(s)	Knoten (1 kt = 1,852 km/h)
LBA	Federal Aviation Office (Germany)	Luftfahrt-Bundesamt
LDMCR	Lower Deck Mobile Crew Rest	

LPC	Licence Proficiency Check	
MAC	Mean Aerodynamic Chord	Mittlere aerodynamische Flügeltiefe
METAR	Aviation Routine Weather Report	Routine Wettermeldung für die Luftfahrt
MFD	Multi-Function Display	
MLM	Maximum Landing Mass	Maximale Landemasse
MSA	Minimum Sector Altitude	Mindestsektorenhöhe über MSL
MSL	Mean Sea Level	Mittlerer Meeresspiegel
MTOM	Maximum T/O Mass	Maximale Startmasse
N_1	engine fan or LP compressor speed	
ND	Navigation Display	Bildschirm für die Navigation
NM	Nautical Mile(s)	Nautische Meile(n)
NOTAM	Notice to Airmen	Ergänzende Informationen zur AIP
OAT	Outside Air Temperature	Außentemperatur
OCC	Operational Control Center	
ODR	Operator Difference Requirements	
OM	Operations Manual	Betriebshandbuch
OPC	Operator Proficiency Check	
PA	Passenger Address	Durchsagesystem zur Information der Passagiere
PF	Pilot Flying	Steuerführender Pilot
PFD	Primary Flight Display	Hauptbildschirm
PIC	Pilot in Command	Verantwortlicher Luftfahrzeugführer
PM	Pilot Monitoring	Pilot, der den PF unterstützt
PWS	Predictive Windshear	Vorausschauende Windsherung
PSU	Passenger Service Units	
QNH	Altimeter pressure setting to indicate altitude AMSL	Höhenmesser-Druckeinstellung zur Anzeige der Höhe in AMSL
RTU	Receiver Transmitter Unit	
RXO	Specialist ophthalmological examinations required	Spezielle augenärztliche Untersuchung erforderlich

SCCM	Senior Cabin Crew Member	Leitendender/-e Flugbegleiter/-in
SEP	Safety and Emergency Procedures	Sicherheits- und Notfallverfahren
SIGMET	Information concerning en-route weather phenomena which may affect the safety of aircraft operations	Informationen bezüglich Wettererscheinungen auf der Flugstrecke, welche die Sicherheit des Flugbetriebs beeinträchtigen können
SIGWX	Significant Weather Chart	
SOP	Standard Operating Procedure	Standard-Betriebsverfahren
TAF	Terminal Aerodrome Forecast	Flugplatzwettervorhersage
TR	Type Rating	Musterberechtigung
TSD	Troubleshooting Data	Fehlerbehebung bei Daten
UTC	Universal Time Coordinated	Weltzeit, koordiniert
VD	Vertical Display	
VDL	Correction for defective distant vision	Korrektur für eine eingeschränkte Sehschärfe in der Ferne
VML	Correction for defective distant, intermediate and near vision	Korrektur für eine eingeschränkte Sehschärfe in der Ferne, der Zwischendistanz und der Nähe
VHF	Very High Frequency	Ultrakurzwelle
WAFC	World Area Forecast Centre	Meteorologisches Zentrum

Synopsis

The aircraft took off at Frankfurt/Main Airport, Germany, and landed at Sir Seewoosagur Ramgoolam International Airport, Mauritius. While the aircraft was in Seychelles airspace, at Flight Level (FL) 390, it encountered turbulence. Six passengers suffered severe, 15 passengers and one cabin crew member minor injuries, which were treated at hospital.

The accident which occurred in cruise flight during significant turbulences is due to the following direct causes:

- The weather radar captured a bank of clouds which was displayed in green on the Navigation Display (ND). The bank of clouds included an upwind and downwind region, which could not be recognised in its intensity by the flight crew and generated severe turbulence over a period of 10 s.
- The initiated change of heading about 20 NM ahead of the bank of clouds occurred too late so that the aircraft entered the top layer of clouds.
- Some passengers not wearing their seat belts, suffered injuries, some of them serious.

The investigation identified the following contributory factors:

- According to the co-pilots' statements the weather radar was set to the All WX mode and did not display turbulence on the ND.
- Due to the dynamic growth of the cloud area, its actual extent was only recognised shortly before entering the bank of clouds.
- The Initial Safety & Emergency Procedures Training the operator had conducted for flight and cabin crew members showed deficits in handling on-board systems, especially the on-board communications system.

1. Factual Information

1.1 History of the Flight

1.1.1 General

On the day of the occurrence, take-off occurred at Frankfurt/Main Airport, Germany. Under instrument flight rules, the flight led to Sir Seewoosagur Ramgoolam International Airport, Mauritius. The Flight Log listed a flight time of 11:02 hours. It was a scheduled passenger flight. On board were 3 pilots, 10 cabin crew members and 277 passengers.

1.1.2 Flight and Cabin Crew Members

At the time of the occurrence, co-pilot 1 (Senior First Officer - SFO) was Pilot Flying (PF) and sat in the left-hand seat. Co-pilot 2 (First Officer - FO) was Pilot Monitoring (PM) at the time. The Pilot In Command (PIC), the Senior Cabin Crew Member (SCCM) and four colleagues were in the Lower Deck Mobile Crew Rest (LDMCR).

1.1.3 Data Basis

The presentation of events is based on the Digital Flight Data Recorder (DFDR) and Cockpit Voice Recorder (CVR) data, statements of the flight and cabin crews and witnesses.

1.1.4 Occurrence Description

According to the flight crew, the weather radar was switched to ALL WX[1] shortly before line up on the runway. This should ensure that the weather radar was switched on during the entire flight.

At the time of occurrence, during cruise flight, autopilot No. 1 was active, both Flight Directors (FD) were switched on and the Modi ALTCRZ[2] (Altitude Cruise) and HDG[3] (Heading) were active. Autothrust (A/THR) was in Mode Mach, the engine levers were in Mode CLIMB and airspeed was selected to Managed MACH 0.82 Ma. At the cruise

1 According to the FCTM, the standard setting for the IntuVue RDR4000 is ALL display mode. For storm cell analysis, the flight crew switches to ON PATH or to manual ELEVN mode. When a weather threat is identified, the flight crew uses the functionalities of the ALL WX to assess the weather. Then they should select the display mode back to ALL.

2 Autopilot flying mode for vertical guidance.

3 Autopilot flying mode for lateral guidance.

level of FL 390, pitch angle was about +2.5° and the Angle of Attack (AOA)[4] about +2.6°.

According to the pilots' statements, during cruise flight they initially operated the weather radar in the Weather and Turbulence Mode. There were no reports of other pilots regarding unusual weather phenomena along the flight path. From the cockpit, they did not see any thunderbolts or cloud formations. According to co-pilot 1, he had had the weather App eWAS (Chapter 1.17.2) open on the Electronic Flight Bag during the flight and updated the weather data several times. For the occurrence location, the App had not depicted any banks of clouds and turbulences. According to the SIGWX[5] charts, south of the flight path there was a cloud area with embedded cumulonimbus clouds[6] (EMBD CB) (Chapter 1.7). The cumulonimbus clouds spread up to FL 460, according to the weather chart of 2 March 2023 at 0000 UTC.

The weather radar in mode ALL WX registered a bank of clouds about 80 to 160 NM ahead of the aircraft and depicted it on the ND in green. The bank of clouds rose beyond FL 390. Co-pilot 2 stated that he then used the weather radar in Manual Gain Mode and Manual ELEVN Mode. The selected flight level for detection was set between FL 300 and FL 390.

The DFDR only records the left Primary Flight Display (PFD) Weather Radar setting, and not the right PFD side. The Co-pilot 2 stated that he was aware that they were flying in the area of the Intertropical Convergence Zone (ITCZ) and he was therefore watchful regarding special weather phenomena. According to the DFDR data, the weather radar was in Mode WX+T during cruise flight and the modes changed several times between ALL WX and ELEVN.

According to the flight crew's statements and the ADS-B Exchange[7] data, an Airbus A350 was on a similar route and flying ahead of them. It was at 2,000 ft above their altitude with a lateral distance of about 5 NM. Both pilots saw on the ND that the other aircraft ahead of them changed the heading to the right (south). At the time, VHF radio

4 The angle of attack values in the text are the arithmetic mean of the two angle of attack values the DFDR had recorded.

5 Forecasts of significant en-route weather phenomena shall be prepared as SIGWX forecasts four times a day by a WAFC and shall be valid for fixed valid times at 24 hours after the time (0000, 0600, 1200 and 1800 UTC) of the synoptic data on which the forecasts were based. The dissemination of each forecast shall be completed as soon as technically feasible but not later than 9 hours after standard time of observation (ICAO Annex 3).

6 Heavy and dense cloud, with a considerable vertical extent, in the form of a mountain or huge towers (World Meteorological Organization).

7 ADSBexchange.com offers a high fidelity, stable, and secure flight tracking service based on the world's largest independent unfiltered ADS-B receiver network.

contact with air traffic control did not exist, to promptly request a direction change clearance without delay. Communications occurred via Controller Pilot Data Link Communications (CPDLC).

About 20 NM before reaching the bank of clouds, the flight crew asked the responsible air traffic control unit via CPDLC about an avoidance course. The flight crew stated that they did not wait for the air traffic control unit's clearance but turned right (southern heading) in order to avoid the approaching bank of clouds. At the time, the aircraft was at FL 390, near the position UVESO[8].

During the turn, the aircraft entered a cloud layer, according to the flight crew and witnesses' (passengers) statements. It was observed that the strobe lights[9] were reflected by clouds. The flight crew observed ice crystals on the cockpit window.

At about 0020 UTC, slight turbulences began. The aircraft was at FL 390 in Seychelles airspace (Airway UM 665, southern flight direction between waypoint UVESO and ANKOR[10], 1 NM right (Parallel Offset) of the flight path above ground). It was night and the SCCM had dimmed the lights in the cabin. At the time, there was no service and most of the passengers were in their seats and slept.

The flight crew switched on the seat belt signs. There was no passenger announcement. A few seconds later, the turbulences intensified and within about 10 seconds had become so intense that loose objects were flying around the cabin and galley; some passengers were lifted out of their seats.

Over a time period of 10 s, the DFDR recorded acceleration values between +1,75 g[11] and -0,7 g. The aircraft reached an airspeed of 0.856 Ma. The maximum permitted Mach number[12] of 0.86 was not exceeded. At the time, autopilot No. 1 was active. During the occurrence, the vertical wind component was largely directed upwards.

The aircraft climbed up to FL 393. Autopilot No. 1 commanded a pitch down from +4.5° to -1.0° to counteract this uncontrolled altitude deviation.

Then the aircraft entered a strong downdraft with a vertical wind speed of about 40 kt[13]. Vertical acceleration dropped to -0.7 g and the altitude decreased slightly. The AOA

8 Latitude 07° 00' 00.00" S; Longitude 048° 39' 35.75" E.

9 Positioned near the trailing edge of the wing tips.

10 Latitude 10° 00' 00.00" S; Longitude 050° 34' 50.00" E.

11 The gravitational force equivalent, or, more commonly, g-force, is a measurement of the type of force per unit mass - typically acceleration - that causes a perception of weight, with a g-force of 1 g (not gram in mass measurement) equal to the conventional value of gravitational acceleration on Earth.

12 Maximum Mach Number - MMO

13 This value was taken from the analysis report of the aircraft manufacturer.

decreased to -3.3°. Autopilot No. 1 commanded a pitch up to counteract this uncontrolled altitude deviation. This increase in pitch in combination with the slight updraft resulted in a vertical acceleration of up to +1.75 g. The AOA increased to a maximum of +5°.

At 0020:03 UTC, autopilot No. 1 was deactivated.[14] The engine thrust levers remained in the CLIMB position. During the occurrence, the Autothrottle Computer (A/THR) was still active. The engine parameter N_1[15] oscillated between 72% and 85%. The AUTO FLT AP OFF[16] warning was triggered in combination with a Master Warning and an aural warning (Cavalry Charge). During the deactivation of autopilot No. 1, the AOA α_{prot}[17] value was at about +4.7° and the High Angle of Attack Protection was active for a short time. Co-pilot 1 stabilised the flight path using sidestick inputs.

At 0020:04 UTC, the sidestick of co-pilot 1 was in the neutral position ($\alpha < \alpha_{prot}$ for at least 0.5 s) and the High Angle of Attack Protection was deactivated. About 8 s later, autopilot No. 1 was activated again in the modes ALTCRZ and HDG.

After they had entered severe turbulence, the flight crew instructed[18] the cabin crew via intercom: ”Cabin crew be seated“. In the further course of the flight, there were no more turbulences.

Co-pilot 1 attempted to contact the PIC, who was in the Lower Deck Mobile Crew Rest, by service interphone. This was not possible. To establish contact, three specific buttons had to be pressed in succession.

Six passengers, some of whom were not wearing their seat belts, suffered serious injuries. A few passengers were lifted out of their seats and impacted the area of the Passenger Service Units (PSU) at the overhead bins above them. One flight attendant in the aft galley hurt her ankle.

About eight minutes after the occurrence, the SCCM asked via intercom doctors or medical personnel on board to report to the cabin crew. Some doctors were on board and supported the cabin crew with giving first aid to the injured passengers and cabin crew members. The flight and cabin crew members in the Lower Deck Mobile Crew

14 DFDR parameter

15 In an axial flow jet engine, N_1 refers to the rotational speed of the low speed spool which consists of the fan, the low-pressure compressor and the low-pressure turbine, all of which are connected by a concentric shaft (SKYbrary).

16 The autopilot disconnects at α_{prot} value plus 1 degree.

17 Explanation in Chapter 1.6.8 Angle of Attack Protection

18 According to the procedure SEP Manual Rev. 2.1, Chapter 2.21 Extreme Weather Conditions, 2.21.3 Turbulence.

Rest were also asked for help. The passengers with serious injuries were medically treated in the business class. This was seen as advantageous as more space was available and the passengers could lay on the flat seats of the business class.

At 0047 UTC, the PIC addressed the passengers via the intercom. She explained the situation and which medical measures had been taken.

The flight crew decided to continue the flight to Sir Seewoosagur Ramgoolam International Airport. The pilots re-established VHF communication with the air traffic control centre and informed them and the other aircraft ahead about the turbulence they had experienced. They were given priority for landing due to the injured people on board.

At about 0232 UTC, the aircraft touched down on runway 14.

The documentation compiled by the operator and hospital listed 15 passengers and one cabin crew member with minor injuries. Six passengers were diagnosed with serious injuries[19]. The injured persons were treated medically.

At once, the operator sent a Critical Incident Stress Management[20] Team as support for the flight and cabin crew and a Special Assistance Team (SAT) to assist the passengers.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Total in aircraft	Other
Fatal				
Serious		6	6	
Minor	1	15	16	
None	12	256		
Total	13	277	290	

1.3 Damage to Aircraft

The cabin showed various damage. Detailed descriptions are part of Chapter 1.12.1 Damage in the Cabin Area

19 Definition of Regulation (EU) No. 996/2010, Article 2.

20 Critical Incident Stress Management (CISM) consists of targeted stress management measures that can help prevent health problems or illness after incidents and contribute to a rapid return to normal everyday life.

1.4 Other Damage

Not applicable

1.5 Personnel Information

1.5.1 Flight Crew

1.5.1.1 Pilot in Command

The 55-year-old PIC held an Airline Transport Pilot License (ATPL(A)) issued on 1 December 2015 by the Luftfahrt-Bundesamt. It was valid until 31 October 2023 and listed the type rating for Airbus A330/350.

The BFU was provided with a class 1 medical certificate with the restriction VML[21], valid until 23 June 2023.

She had a total flying experience of 11,274 hours, of which 205 hours were flown on Airbus A330-200 and A330-900. It was her first flight duty on Airbus A330-900 without instructor after line training. For her this was the first flight of the day. Prior to that, she had five days off.

1.5.1.2 Co-pilot 1

The 44-year-old co-pilot held an Airline Transport Pilot License (ATPL(A)) issued on 11 April 2014 by the Luftfahrt-Bundesamt. It was valid until 31 October 2023 and listed the type rating for Airbus A330/350.

The BFU was provided with a class 1 medical certificate valid until 26 August 2023.

He had a total flying experience of 8,500 hours, of which 254 hours were flown on Airbus A330-200 and A330-900. It was his third flight duty on Airbus A330-900 without instructor after line training. For him this was the first flight of the day. Prior to that, he had 14 days off.

1.5.1.3 Co-pilot 2

The 31-year-old co-pilot held a Commercial Pilot Licence (CPL(A)) issued on 5 December 2016 by the Luftfahrt-Bundesamt. It was valid until 29 February 2024 and listed the type rating for Airbus A330/350.

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21 Correction for defective distant, intermediate and near vision.

The BFU was provided with a class 1 medical certificate with the restriction VDL[22] and RXO[23], valid until 28 July 2023.

He had a total flying experience of 2,342 hours, of which 1,030 hours were flown on Airbus A330-200 and A330-900. It was his third flight duty on Airbus A330-900 without instructor after line training. For him this was the first flight of the day. Prior to that, he had three days off.

1.5.1.4 Flight Duty and Rest Time

The flight crew's duty roster was made available to the BFU.

It showed that the flight crew checked in at Frankfurt/Main Airport on 1 March 2023 at 1330 UTC. Due to the occurrence, the operator ordered another 30 min finishing work in addition to the regular check-out time. Check-out was at Sir Seewoosagur Ramgoolam Airport on 2 March 2023 at 0337 UTC (on-block at 0237 UTC plus 30 min. regular finishing work and the additional 30 min finishing work).

According to the duty roster, flight time was 14:07 hours. Maximum permissible duty time, in accordance with In-flight Rest Class 1, OM-A, chapter 7.4.2.3, was 17:00 hours for the flight crew and 14:30 hours for the cabin crew.

1.5.2 Cabin Crew

1.5.2.1 Experience

The cabin crew was experienced on long-haul flights. The senior cabin crew member was a long-time employee of the operator.

1.5.2.2 Flight Duty and Rest Time

Flight duty and rest times were adhered to.

1.5.2.3 Cabin Crew Statement

According to the statement of the senior cabin crew member, immediately after the occurrence, initial treatment and care of the injured passengers was started. According to the statement of the other cabin crew members, they viewed the coordination and cooperation with the medical personnel on board as effective.

22 Correction for defective distant vision.
23 Specialist ophthalmological examinations required.

1.6 Aircraft Information

1.6.1 General

The Airbus A330-941 is a medium and long-range transport aircraft. The airplane is equipped with two turbofan engines. The cockpit is a two-pilot glass cockpit with sidesticks.

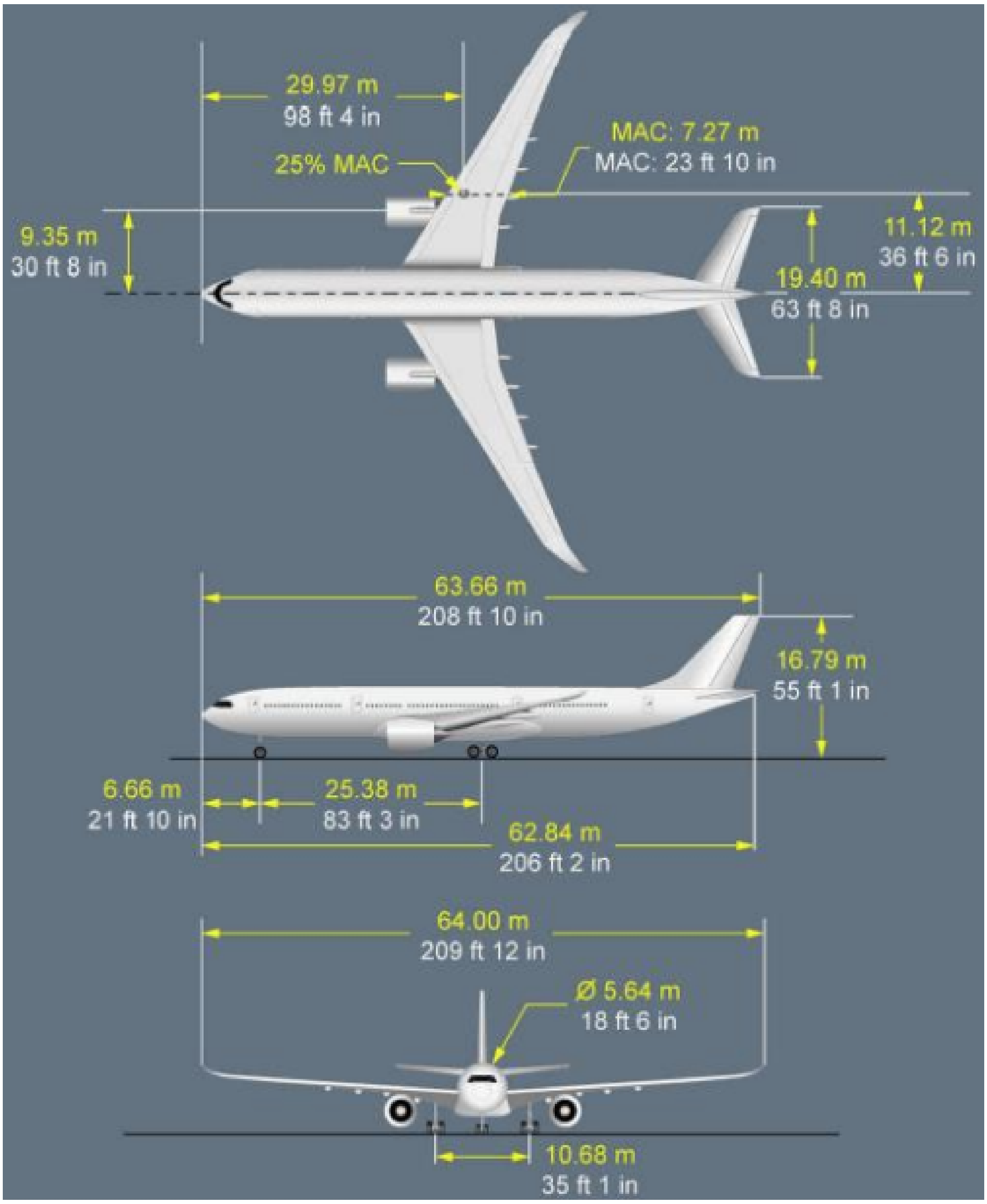


Fig. 1: Three-way view of the Airbus A330-941 Source: Aircraft manufacturer

1.6.2 Aircraft Information

The aircraft had a German certificate of registration and was operated by a German operator in commercial passenger transport. The BFU was provided with a valid Airworthiness Review Certificate.

Manufacturer	Airbus
Type	A330-941
Year of Manufacture	2022
MSN	1966
Total Operating Time	850 hours
Landings	89
Engines	Rolls-Royce, Trent-7000
MTOM	245,000 kg
MLM	191,000 kg

1.6.3 Centre of Gravity and Landing Mass

The centre of gravity, converted to per cent of the Mean Aerodynamic Chord (MAC[24]) of the flying mass, was within the permissible operating limitations. Landing mass was 166,898 kg.

1.6.4 Maintenance Organisation

The operator’s maintenance organisation examined the aircraft on site after the occurrence. The technical report of the maintenance organisation showed that there was no damage on the structural elements of the aircraft, but in the cabin, mainly at the overhead bins. In agreement with the aircraft manufacturer, several days later, the aircraft was flown to Frankfurt/Main Airport without any passengers on board.

24 In large aircraft, center of gravity limitations and the actual center of gravity are expressed in terms of percent MAC.

1.6.5 Weather Radar

1.6.5.1 General

The description of the weather radar is part of the operator's Flight Crew Operating Manual/Systems/Surveillance/Weather Radar - Description, 30 Aug 2021.

The aircraft was equipped with two IntuVue RDR-4000 weather radar components with the function Predictive Windshear (PWS) and for forecasting weather risks.

The weather data can be depicted on the PIC's and/or the co-pilot's ND.

The weather radar scans the airspace in front of the aircraft with electromagnetic signals. The radar echoes are recorded and indicated according to the selected mode display as 2D image.

The indication WX depicts the precipitation in different colours. The colour depends on the intensity of the precipitation (red means high reflectivity and green low). The weather radar in this version did not have a vertical display.

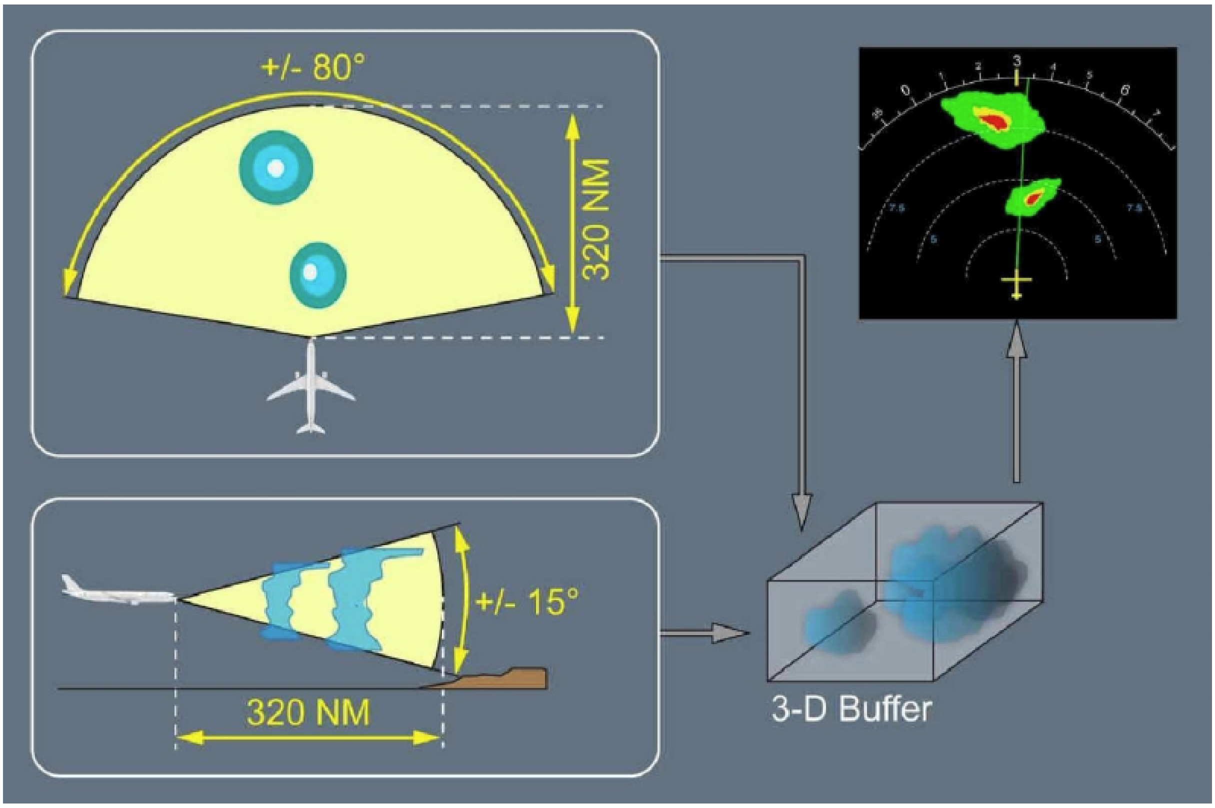


Fig. 2: 2D weather depiction Source: FCOM, Chapter DSC-34-20-30-10, P 1/2, 30 Aug 21

1.6.5.2 Weather Ahead

The function Weather Ahead[25] shall help flight crews to faster recognise potential weather and/or turbulence risks. The weather radar scans the area ahead of the aircraft and depicts weather and/or turbulence risks up to three minutes in advance on both ND. The respective textual warning WEATHER AHEAD is depicted in amber.

The Weather Ahead function scans the area up to:

- 3 min ahead of the aircraft
- 2 NM left and right of the current flight path
- 4,000 ft above and below the current flight path

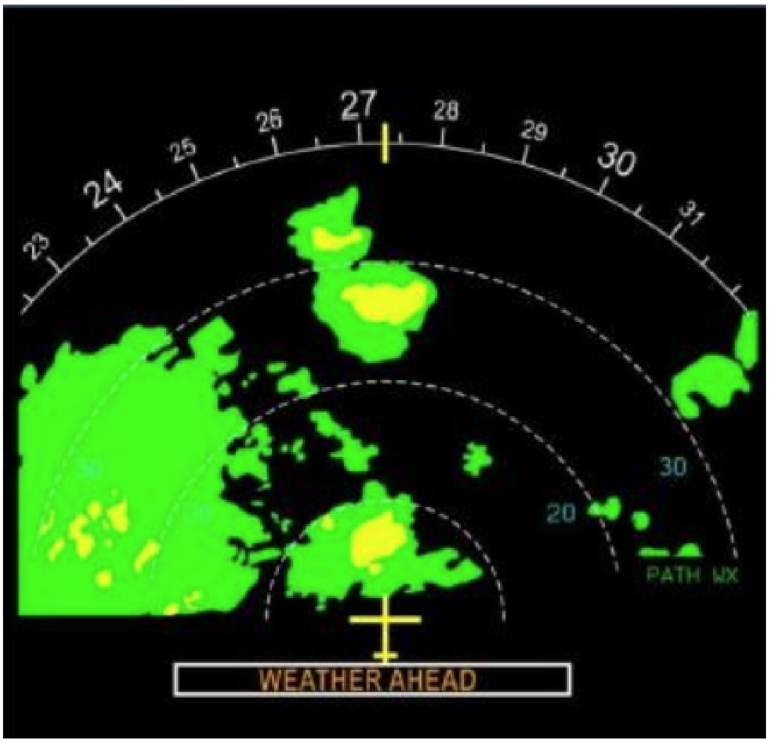


Fig. 3: Example of the Weather Ahead Function Source: Operator

1.6.5.3 Turbulence Detection

Turbulence detection (TURB) is based on the Doppler effect and detects turbulence in precipitation in a volume ahead of the aircraft. This function is based on the movement of precipitation. Turbulence detection scans ± 80° in Azimuth between 0 ft and

25 FCOM, Chapter Weather Ahead Function Indication on ND, Chapter DSC-34-20-30-30, P 11/14, 16 Nov 22

60,000 ft MSL and up to 40 NM ahead of the aircraft. The ND shows the area of detectable turbulence in the colour magenta. Turbulence detection does not detect turbulences in clear air. It is automatically active if the weather radar button WX at the Electronic Flight Instrument System (EFIS) is pushed and set for display. Turbulence detection does not generate acoustic warnings.

1.6.5.4 Software Version of the Weather Radar

The installed software version was V-002. Version V-003 was available, it optimised the reliability of the sender unit of the weather radar, among other things. Functionally there was no difference between Version V-003 and V-002.

1.6.5.5 ON PATH Envelope

The following information was taken from the operator’s Flight Crew Operating Manual.

The weather radar IntuVue RDR-4000 processes the weather data in a so-called vertical envelope which moves along the vertical trajectory of the aircraft. It is depicted on the ND in the usual colours. The following image shows the limits of the operative area of the ON PATH function.

ON PATH envelope limits

<table>
<tr><th>Aircraft Altitude (feet MSL)</th><th>Lower Envelope Boundary (feet MSL)</th><th>Upper Envelope Boundary (feet MSL)</th></tr>
<tr><td>> 29,000</td><td>Flight Altitude minus 4.000 or 25.000 if convective weather</td><td rowspan="2">Flight Altitude plus 4,000 (max: 60,000)</td></tr>
<tr><td>6,000 to 29,000</td><td rowspan="2">Flight Altitude minus 4,000 (min: Gnd Elev)</td></tr>
<tr><td>< 6,000</td><td>10,000</td></tr>
</table>

Fig. 4: Definition of the limits of the ON PATH envelope function

Source: FCOM, DSC-34-20-30-15, P 1/10, 16 Nov 22

In horizontal flight, the ON PATH envelope stretches from 4,000 ft above to at least 4,000 ft below the aircraft's altitude. In the presence of a column of convection, the weather is shown below the aircraft's altitude to 25,000 ft MSL.

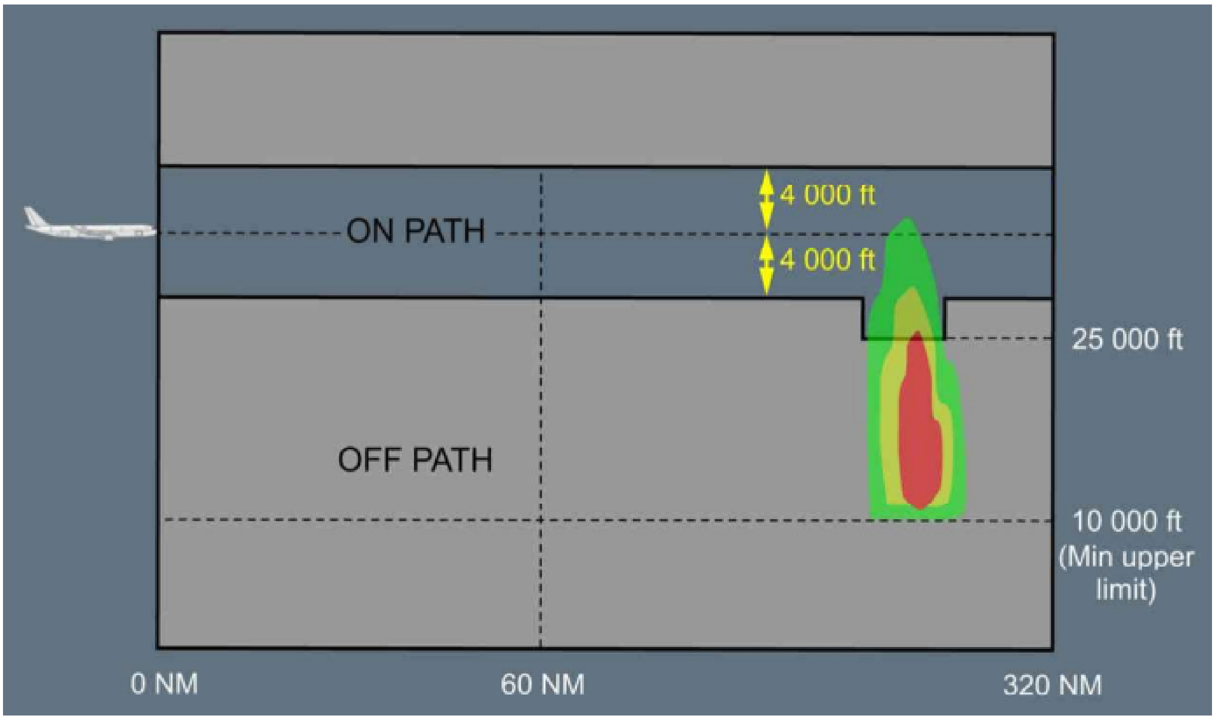


Fig. 5: ON PATH weather depiction Source: FCOM, DSC-34-20-30-15, P 8/10, 16 Nov 22

In ALL WX modes, the OFF PATH weather is the weather which is not on the aircraft's path (i. e. the weather outside of the envelope, which is depicted on the ND in black parallel lines with reduced intensity).

1.6.5.6 Weather Radar Control Panel

The following depiction shows the weather radar control panel which is located in the central pedestal of the cockpit. The picture below is self-explanatory. In the FCOM, the numbers are explained.

As excerpts, the switch positions ALL WX and PATH WX are described. In the switch position ALL WX weather data for both ON PATH and OFF PATH envelopes are indicated. With the switch position PATH WX only the ON PATH weather is depicted. In both modes, the functions Predictive Windshear and detection of turbulence are active.

Fig. 6: Control panel and switch designation of the weather radar RDR-4000.

Source: FCOM, DSC-34-20-30-00014713.0002001, 01 Mar 18

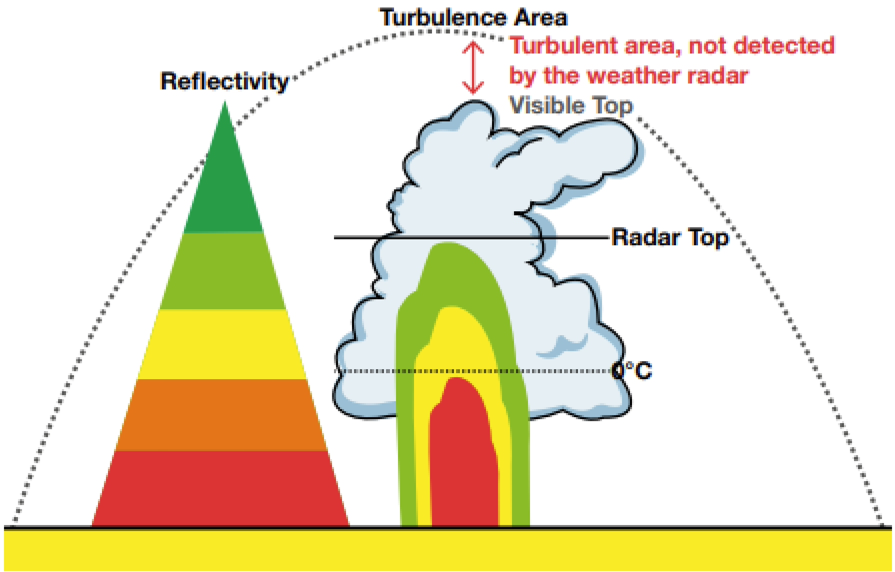
1.6.6 Weather Radar Limitations

In the Safety First #22, July 2016, “Optimum use of weather radar” of the aircraft manufacturer, the general function and which weather phenomena can be detected was described:

> *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. 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.



The weather radar detects:	The weather radar does not detect:
- Rainfall - Wet hail and wet turbulence - Windshear	- Ice crystals, dry hail * and snow - Clear air turbulence - Sandstorms (solid particles are almost transparent to the radar beam) - Lightning *

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

Fig. 7: Weather radar detection Source: Aircraft manufacturer

1.6.7 Other Information about the Weather Radar

1.6.7.1 Technical Follow Up Document

On 12 December 2023, the aircraft manufacturer published the Operators Information Transmission "ATA 34 – Weather Radar Performance of the Honeywell RDR-4000/AESS" and distributed it to the relevant operators. The following was described in the document:

[…]

1. PURPOSE

This OIT is issued to bring to attention two different incorrect behaviors concerning the weather radar performance of the Honeywell RDR-4000/AESS.

In both cases, symptoms can occur without any related WXR fault messages.

2. BACKGROUND

Airbus has received some reports of incorrect display of weather conditions with RDR-4000/AESS WXR without indication of failure.

Two typical behaviours are reported:

Case 1: Low weather radar performance above 80 NM (Ref.1)

Case 2: Severe attenuation of WXR display independently of range (Ref.2)

Note: In case the WXR BITE detects a failure, we remind that the fault should be treated in accordance with applicable troubleshooting procedures.

Case 1: Low weather radar performance above 80 NM

In this case, the weather condition is not shown or under-estimated by the radar at ranges above 80 NM. The weather radar display starts to be correct from ranges below 80 NM. Reports of this mis-behavior have been received mostly with the aircraft operating over open water or rain forests.

Weather display at 120 Nm from Weather condition [left] and at 70 Nm from Weather condition [right]

Investigations identified the following root-causes:

- *Weather returns have in some cases been misclassified as ground returns. Ground returns are filtered by the weather radar and not displayed on the ND in WX mode (may be shown in MAP mode instead).*
- *Weather radar returns may be displayed with a too low gain at mid-ranges.*

The planning of a corrective software standard for all programs is shared and followed-up in TFU 34.71.00016.

In case low weather radar performance is reported above 80 NM, no maintenance action is required if no WXR related fault message is recorded, as the low weather radar performance is software related and not caused by a hardware fault.

Case 2: Severe attenuation of WXR display independently of range

A few cases of weather conditions not shown or severely under-estimated, independently of the range and without failure indication have been reported.

Comparison between degraded and healthy WXR system at same area, time and settings

Honeywell has confirmed that, on 5 RTUs removed on the Airbus in-service fleet, undetected loss of weather display was caused by a failure within the downconverter part (receiver part) of the RTU. Diodes were identified as the failed component. This failure cannot be detected by the BITE, therefore, no failure messages are raised.

The topic has been extensively reviewed between Honeywell and Airbus. This case has occurred on extremely rare occasions and Airbus closely monitors the situation in the fleet and will adapt the fleet approach accordingly.

The troubleshooting manuals will be updated to take into account this failure mode.

[…]

1.6.7.2 In-Service Information

On 7 June 2023, the aircraft manufacturer published the In-Service Information (ISI) document No. 34.41.00111, “HONEYWELL – WXR – AESS - RDR-4000 - Attenuation of WXR display without failure indication”. The application range included Airbus A320 and Airbus A330/340 equipped with a Honeywell RDR-4000. The background to the publication was:

[….]

Airbus has recently received a small number of reports from the in-service fleet concerning a strong attenuation of the weather radar display on aircraft equipped with Honeywell RDR-4000 or AESS (Aircraft Environment Surveillance System).

[…]

The following is an excerpt from the ISI:

[…]

Initial findings suggest that such attenuation can be caused by a degradation either within the receiver part of the RTU (receiver transmitter unit) or within the waveguide section of the WADU/DA (weather antenna drive unit/drive antenna). Such a degradation cannot in all cases be detected by the BITE. This explains why no failure message is shown in the above example. The troubleshooting manuals will be updated to address this failure mode. We will update this ISI once the target date for revision updates is available.

[…]

1.6.7.3 Weather Radar - Temporary Abnormal Behaviours

In July 2023, the aircraft manufacturer changed the Airbus A330/340 FCOM, Chapter Aircraft Systems, Surveillance, Weather Radar - Temporary Abnormal Behaviours. The operator included this in the FCOM, DSC-34-20-30-40-00026346.0002001.

A330/A340 FLIGHT CREW OPERATING MANUAL	AIRCRAFT SYSTEMS SURVEILLANCE WEATHER RADAR - TEMPORARY ABNORMAL BEHAVIORS

WEATHER RADAR PERFORMANCE ABOVE 80 NM

1 Ident.: DSC-34-20-30-40-00026346.0002001 / 06 JUL 23
Applicable to: ALL

DESCRIPTION

In some operational conditions, the performance of the weather radar may be below its standard level at detection ranges above 80 NM.
This reduced performance of the weather radar above 80 NM can result in an underestimation, or late detection of the weather by the flight crew.

OPERATIONAL RECOMMENDATIONS

The flight crew should take into account all weather information displayed on the ND.
The flight crew should pay attention to the possibility of a late weather display, particularly in areas where convective weather is expected.

Fig. 9: Change in the FCOM of the aircraft type A330 and A340 Source: Aircraft manufacturer

1.6.7.4 Weather Radar Malfunction

In the Troubleshooting Data (TSD), which the operator's Continuing Airworthiness Management Organisation (CAMO) performed based on Work Order 115600442 of 6 May 2023, there was no entry concerning a weather radar malfunction. The TSD contained several flights prior to and after the occurrence.

1.6.8 High Angle of Attack Protection

The Airbus A330-900 is equipped with a High Angle of Attack Protection. This shall prevent that high angle of attack occurs during a flight where dynamic manoeuvres or gusts may cause stall. The protection becomes active when a certain angle of attack (α_{prot}) is reached.

The speed band in the PFD shows the speeds $V\alpha_{prot}$ und $V\alpha_{max}$ which correspond with the aircraft's speed if it is flying in stabilised flight conditions (α_{prot}) and at maximum permissible angle of attack (α_{max}), respectively.

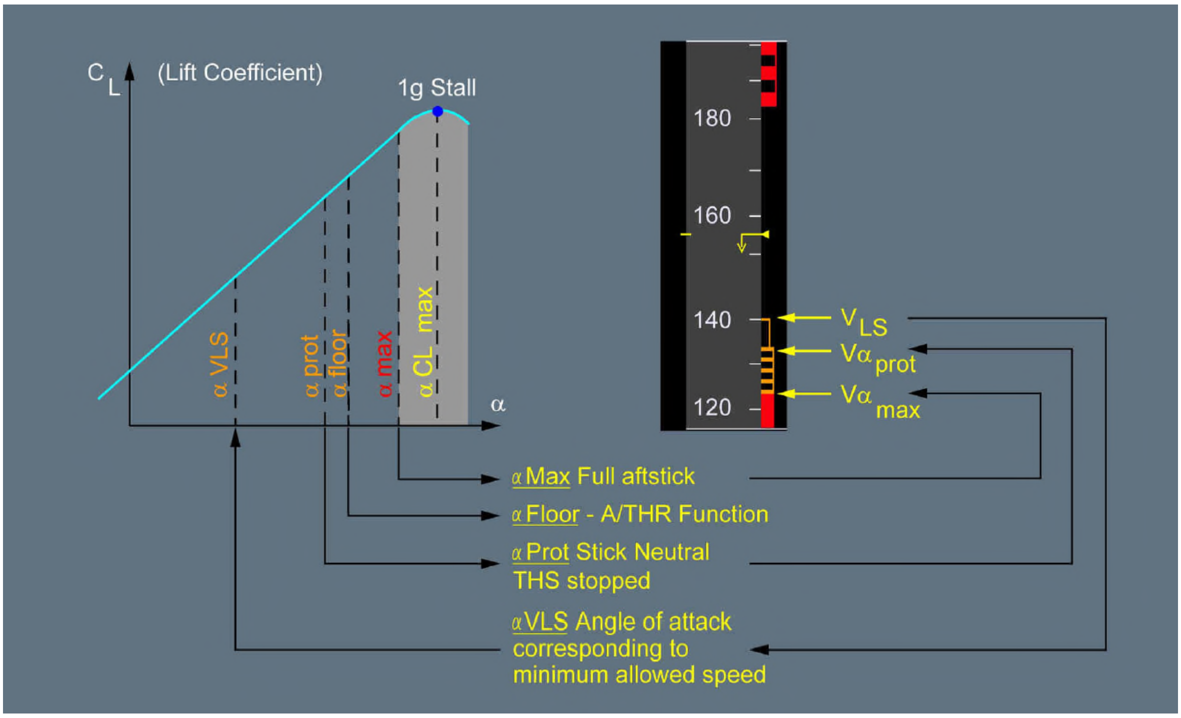


Fig. 10: Connection between certain angle of attack values and speeds Source: FCOM

During manual flight, if AOA increases to $V\alpha_{prot}$, the High Angle of Attack Protection becomes active, automatic trim is stopped and the sidestick input corresponds with the AOA demand and no longer with the load factor demand.

If the autopilot is active in cruise flight, it is deactivated automatically if the filtered AOA value is higher than $V\alpha_{prot}$+0.7°. The aircraft then enters manual flight mode with activated High Angle of Attack Protection.

If the side stick is put into neutral position, the angle of attack is automatically reduced to $V\alpha_{prot}$ so that the aircraft is accelerated to $V\alpha_{prot}$.

Below a certain Mach, from an angle of attack of α_{floor}, which is between α_{prot} and α_{max}, the autothrust system automatically activates take-off thrust, independent of the position of the thrust levers.

In Normal Law, the aircraft is protected against stall, in dynamic manoeuvres or gusts. The High Angle of Attack protection is activated:

- During rotation or flare, when the angle of attack becomes greater than α_{prot}.
- In all other flight phases, when the angle of attack becomes greater than α_{prot} or below α_{prot} when the dynamic will eventually lead to exceed α_{prot}.

Without the flight crew input, the F/CTL computers will maintain the angle of attack equal to α_{prot}. The AOA can be further increased by the flight crew input, up to a maximum value equal to α_{max}. When the High AOA protection is activated, the Normal Law demand is modified and the side stick input is an angle of attack demand, instead of a load factor demand.

1.7 Meteorological Information

1.7.1 General

At 0020 UTC, in the vicinity of waypoint UVESO, it was night. According to both co-pilots, there were stars visible in the sky at the time of the occurrence.

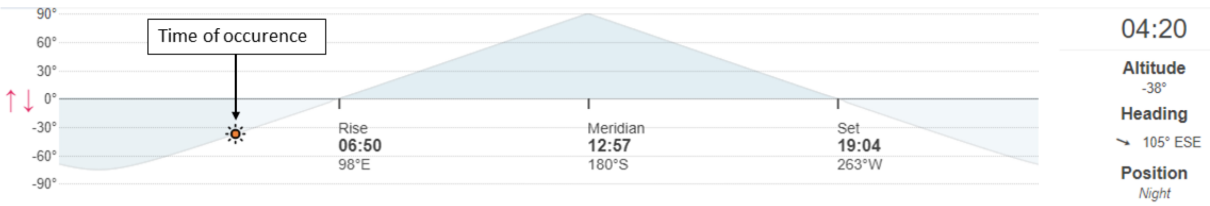


Fig. 11: Time of the occurrence 0420 hrs local (UTC+4 h) Source: Timeanddate, adaptation BFU

1.7.2 Weather Charts - Nowcasting Procedure

The BFU asked the Deutscher Wetterdienst (German meteorological service provider (DWD)) to compile weather charts for the area of the occurrence.

The high-resolution forecast maps were created using the nowcasting method NowCastSat. The definition of Nowcasting applications was taken from the DWD's website:

> *Nowcasting applications are developed to obtain the best possible forecasts for the coming minutes up to the next few hours. These are based on spatially and temporally highly resolved observations, with a rapid update cycle. Numerical weather forecasts are the basis for the weather forecast process. Nowcasting applications complement numerical weather forecasts. They use observational data and extrapolate the information into the future using the latest results of numerical weather prediction models. In this way, forecasts for the next few hours are improved. Rapid nonlinear developments in the atmosphere often lead to large differences between the observed weather and the latest available numerical weather forecasts.*
>
> [...] *Therefore, Nowcasting applications are particularly valuable in meteorologically unstable situations that are often associated with severe weather hazards* […]

1.7.3 Flight Path

The following is an excerpt of the Nowcasting weather chart in which the DWD drew the approximate flight path. The white circle indicates the occurrence area. The chart was compiled for 2 March 2023 at 0030 UTC and shows severe convection[26] with an isolated flash in the occurrence region. The convections are depicted in green, yellow, orange and red (light, moderate, moderate to severe and severe convection).

26 Vertical circulation flow around a horizontal axis. Warm air rises upward, cools down and descents again sideways. This process quickly and effectively transports heat from the lower heating surface to higher layers of air. The upward movement of the convection cell, which takes the form of individual bodies of air that are warmer or less dense in relation to the surrounding air, is called thermals (Source: DWD)

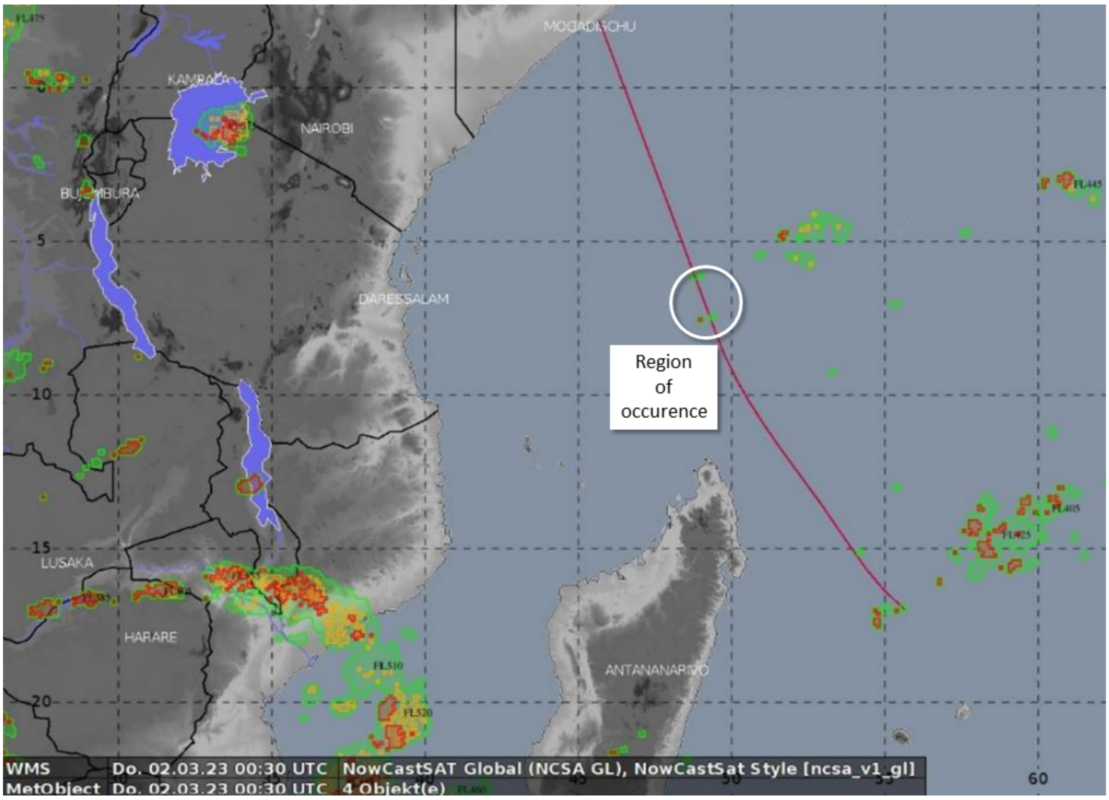


Fig. 12: Nowcasting weather chart with approximate flight path (red) of 2 March 2023 at 0030 UTC.

Source: DWD, adaptation BFU

The following weather chart is an enlarged section of the occurrence area.

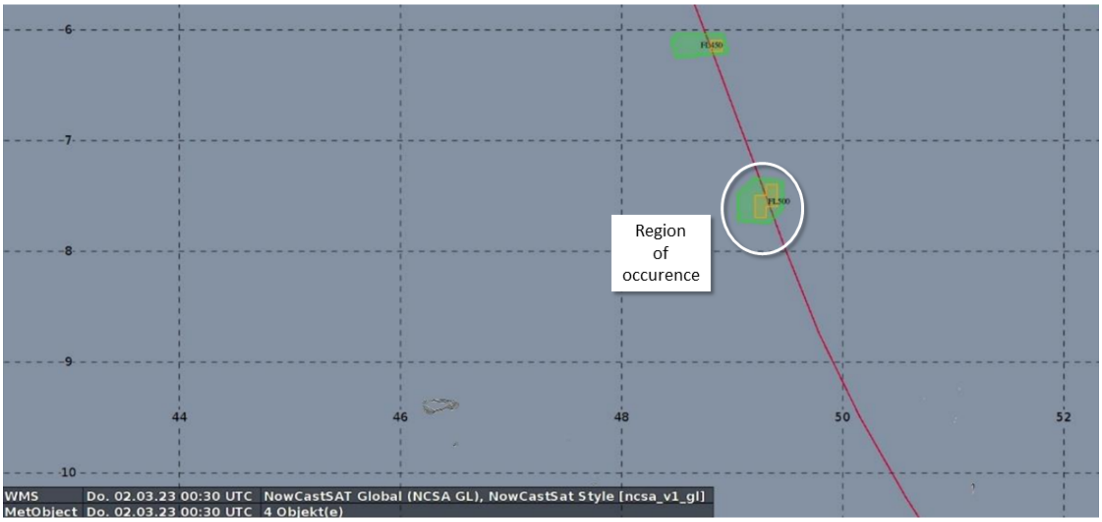


Fig. 13: Nowcasting weather chart with approximate flight path (red) of 2 March 2023 at 0030 UTC.

Source: DWD, adaptation BFU

For the weather depiction, the NowCastSat forecasting method took into account the Composite IR satellite images (Infrared channel 10.8 µm, ICAO Area E) of the EUMETSAT satellite for 1 March 2023 at 2300 UTC and 2 March 2023 at 0130 UTC, among other things. The images show small and local cloud activities (Fig. 14).

The Cumulonimbus (CB) causing the turbulence extended to FL 420 within about 15 minutes (2345 – 0000 UTC) and then up to FL 500.

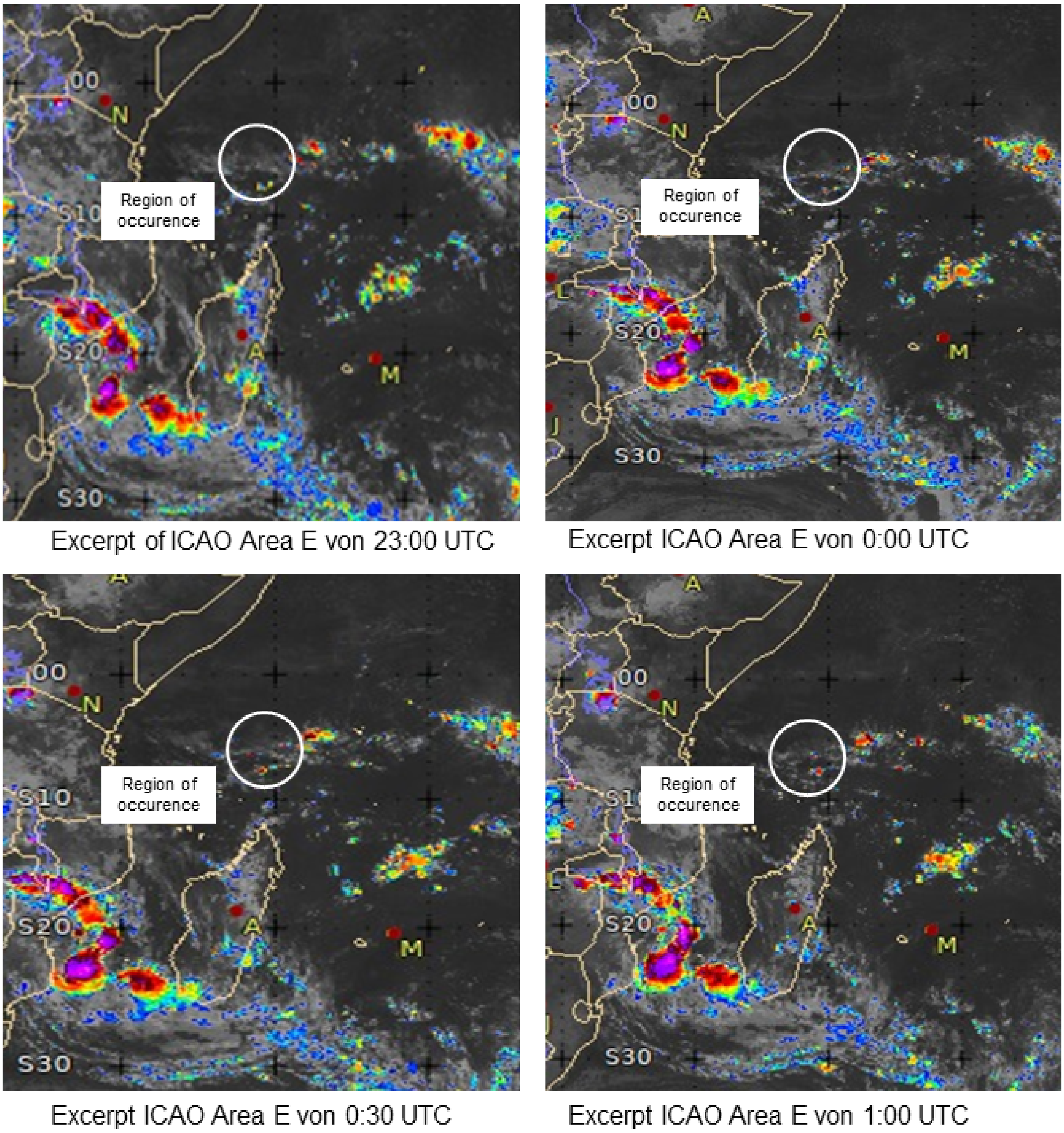


Fig. 14: Satellite images of the infrared channel 10.8 µm, excerpt ICAO Area E Source: DWD, adaptation BFU

The DWD provided the BFU with the WAFC high-altitude, ICAO Area E, chart valid for 2 March 2023 at 0000 UTC (24 hour forecast) wind chart for FL 390.

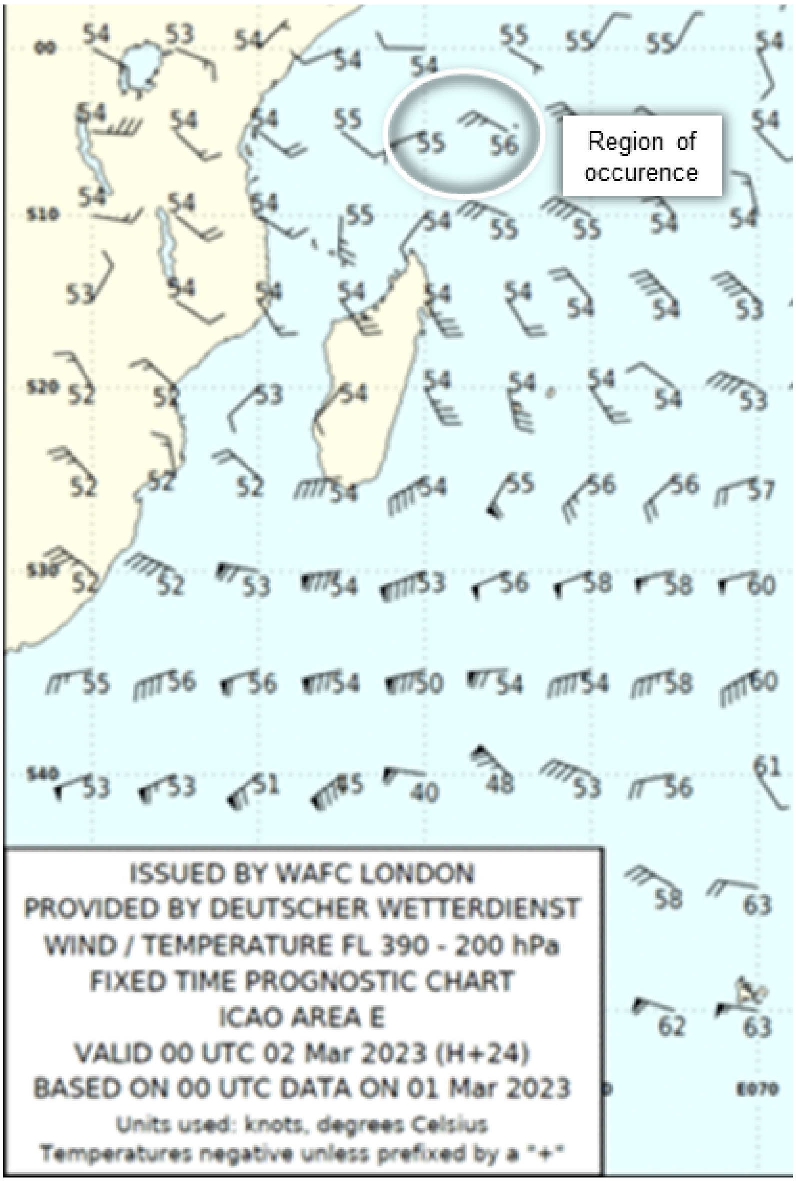


Fig. 15: High altitude wind at FL 390 / 200 hPa Source: DWD, adaptation BFU

The briefing package the flight crew had available contained the high-altitude wind charts for FL 370 and FL 410, but not the one for FL 390.

1.7.4 Significant Weather Chart

The following was part of the briefing package and adapted by the BFU.

The Significant Weather Chart (SIGWX) HIG LON ENT 0200, with the planned flight path (red), showed embedded cumulonimbus clouds in the northern part of Madagascar.

Fig. 16: SIGWX weather chart with planned flight path Source: Operator, adaptation BFU

1.7.5 Intertropical Convergence Zone

The flight path led through the intertropical convergence zone.

The intertropical convergence zone is an equatorial low pressure trough, where the trade winds of the northern and southern hemispheres meet. It is characterised by convective activity which often produces violent thunderstorms over large areas. During the day, it is most active over land and less active over the oceans. With weak trade winds, the ITCZ is characterised by isolated Cumulus and Cumulonimbus cells. If the trade winds are stronger, the ITCZ can generate a firm line of active CB cells in which other cloud types are embedded which develop due to the instability in higher areas. The Cumulonimbus clouds can reach heights of up to 55,000 ft (SKYbrary).

1.7.6 Wind Reconstruction of the Aircraft Manufacturer

Using corrected anemometrical and inertial data of the DFDR, the aircraft manufacturer calculated the influence of the wind on the flight behaviour of the aircraft. The result of this calculation is depicted in the following graph together with the time of activation and deactivation of the autopilots.

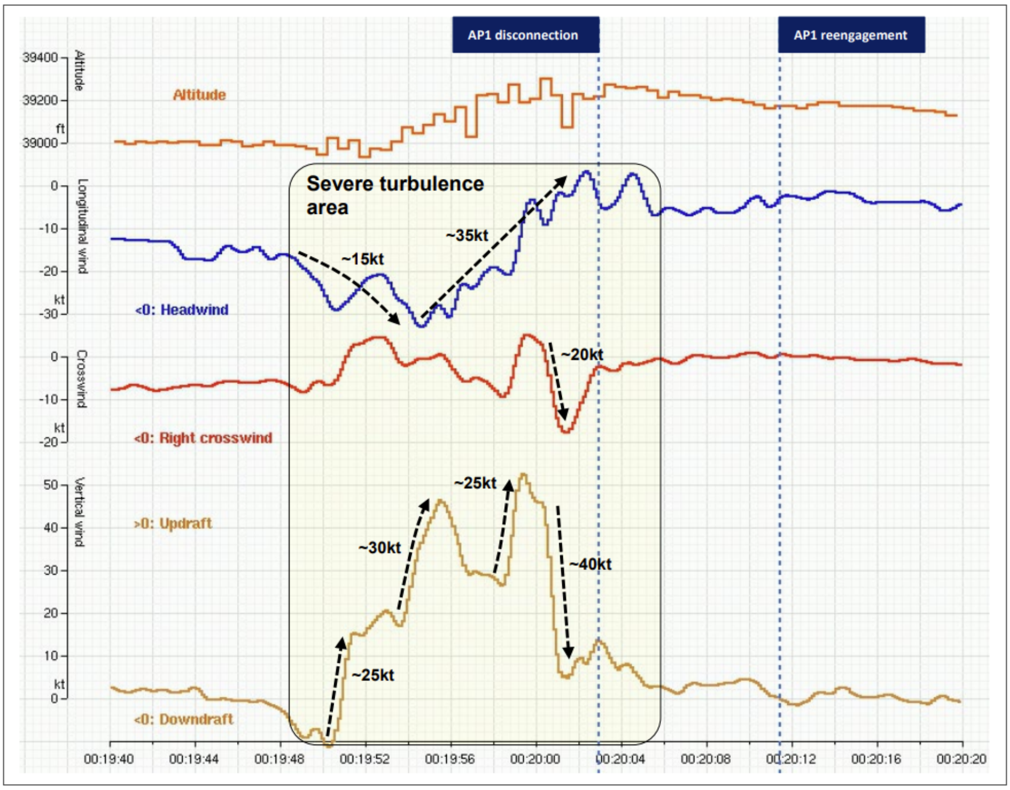


Fig. 17: Influence of the wind on the aircraft (times in UTC) Source: Aircraft manufacturer

Prior to the occurrence, at 0019:48 UTC, the mean wind came from about 180° with +15 kt.

During the occurrence, between 0019:48 UTC and 0020:06 UTC, the following wind data was recorded:

- Gusts of about +15 kt followed by the decrease in headwind of about +35 kt.
- Crosswind gusts of about +20 kt.
- Several up- and downdrafts of up to +40 kt.

1.8 Aids to Navigation

The aircraft was fitted with the required navigation equipment which functioned properly.

Position during the occurrence:

At the time, the aircraft was in Seychelles Airspace and flying 1 NM right of Airway UM 665, south flying direction between waypoint UVESO (Latitude 07° 00' 00.00" S; Longitude 048° 39' 35.75" E) and ANKOR (Latitude 10° 00' 00.00" S; Longitude 050° 34' 50.00" E).

1.9 Radio Communications

In this region, the communication between flight crew and air traffic control did not occur via VHF radio[27]. Communications occurred via Controller Pilot Data Link Communications.

1.10 Aerodrome Information

The accident occurred in cruise flight, therefore this information is omitted.

27 Flight radio frequency range 118 MHz to 136,975 MHz

1.11 Flight Recorders

1.11.1 General

The airplane was equipped with a Digital Flight Data Recorder (DFDR) and a Cockpit Voice Recorder (CVR). Both recorders were read out at the BFU laboratory. The two recorders were undamaged.

Manufacturer DFDR	Honeywell
Model	HFR5-D
Part number	4750-980-002
Serial number	FDR-09394
Recording duration	95,866 s

Manufacturer CVR	L3
Model	SRVIVR25
Part number	7100-1000-30
Serial number	002078261

The CVR had recorded four audio channels with a recording capacity of 70 hours each. The quality of the CVR recording was good.

The data of the DFDR could be downloaded without errors. Appendix 5.1 shows the DFDR plot with the occurrence in relation to the time.

1.12 Findings on the Aircraft

1.12.1 Damage in the Cabin Area

In the cabin area various types of damage occurred. The armrests of several seats had been fractured. Damaged PSU coverings were found in several rows. Cracks in the ceiling lining and damaged lighting was found throughout the cabin. The following images are examples of types of damage.

Fig. 18: Damage on passenger service units Source: Operator

Fig. 19: Damage in the area of the ceiling lining, row 46 Source: Operator

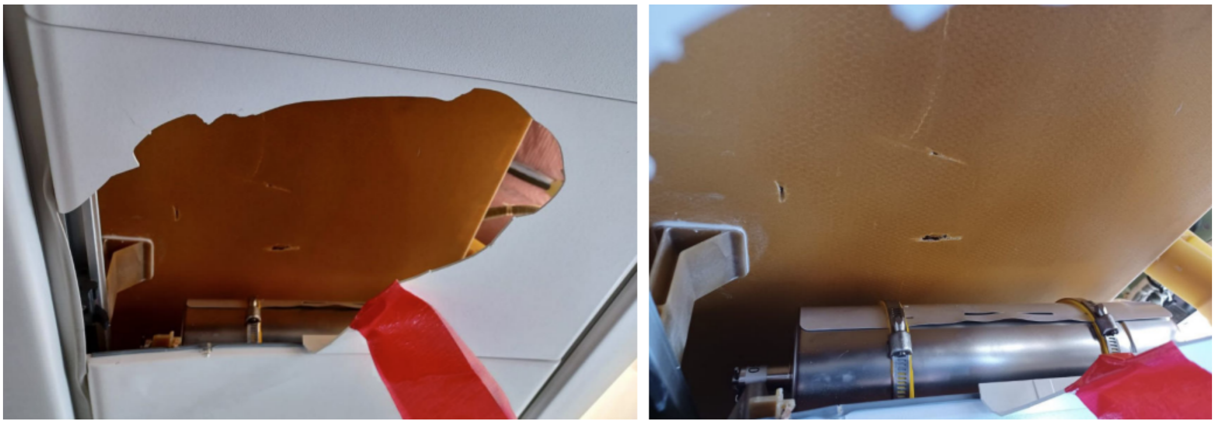


Fig. 20: Damage in the area of the ceiling lining, row 23 HK Source: Operator

Fig. 21: Damaged seats Source: Operator

1.12.2 Seating Plan

In the image below the seats of the six passengers who suffered severe injuries are marked. The seating plan was taken from the operator's Safety Equipment Check/Security Check, Revision 01/2023, FRA HO/T-S.

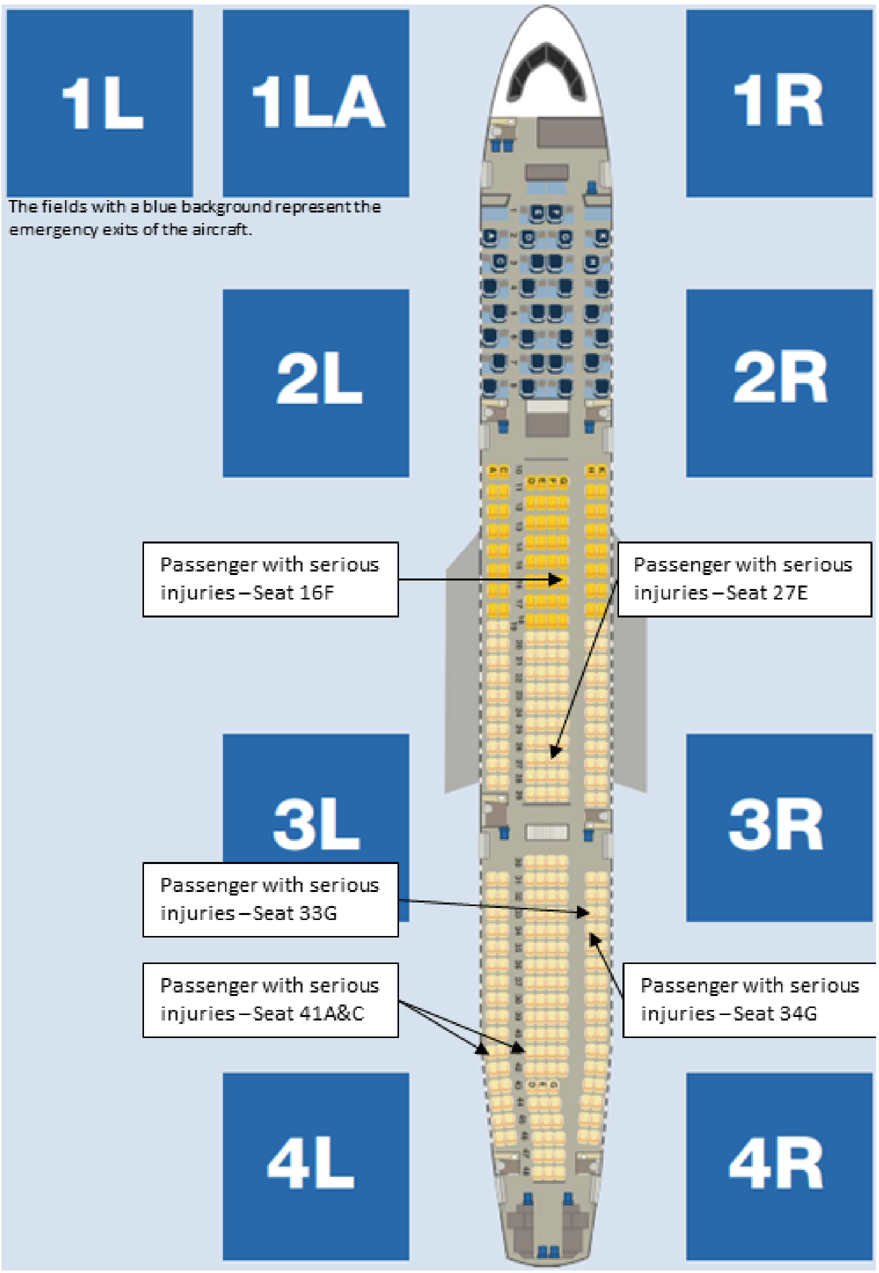


Fig. 22: Seating plan of the airplane including the marked seats of the passengers who suffered severe injuries

Source: Operator, adaptation BFU

1.13 Medical and Pathological Information

1.13.1 Number of Injured Persons

The documentation the first responders had compiled showed that 22 persons were taken to hospital. The BFU re-evaluated the severity of the injuries and the precise injury pattern. The result was that 15 passengers and one cabin crew member suffered minor injuries and 6 passengers severe injuries.

1.13.2 Injury Pattern

The persons with minor injuries suffered soft tissue defects in the sense of lacerations and abrasions as well as contusions and overstretching of the ligamentous apparatus. The persons with severe injuries suffered broken bones. There were four cases of vertebral fractures, followed by rib fractures and an ankle fracture.

1.14 Fire

There was no evidence of in-flight fire or fire during the landing.

1.15 Survival Aspects

Not applicable

1.16 Tests and Research

Not applicable

1.17 Organisational and Management Information

1.17.1 Procedures of the Operator

1.17.1.1 Procedure for the Fasten Seat Belt Sign

The manual Safety and Emergency Procedures, General Procedures - Cabin Crew, Chapter 2.21.3 Turbulence, SEP 2-27, Manual Rev. 2.1, of 01.11.2022 described the procedure for switching on the seat belt signs during severe turbulence. The BFU compiled the table below which is part of the procedure “Severe Turbulence”.

Turbulence Categories	Conditions	Action Required
Severe Turbulence *Turbulence that causes large, abrupt changes in altitude and attitude. It usually causes large variations in indicated airspeed. Aircraft may be momentarily out of control.*	*Passengers are forced violently against seat belts.* *Unsecured items are tossed about or lifted off the floor.* *Cabin Service is impossible. Walking is impossible.*	***Commander*** *'Fasten seat belt' sign must be ON. PA **"Cabin Crew be seated".*** *When safe to move around Commander to liaise with SCCM.* ***Cabin Crew** Sit down immediately on nearest seat and fasten seat belt. Secure carts as best as possible. Advise passengers to sit down and fasten seat belts. Do not check passenger seat belts.*

Tab. 1: Procedure for switching the fasten seat belt signs on

Source: Safety and Emergency Procedures, General Procedures - Cabin Crew, Chapter 2.21.3 Turbulence

1.17.1.2 Standard Operating Procedures - Taxi

The FCOM, Procedures, Normal Procedures, Standard Operating Procedures Taxi PRO-NOR-SOP 10, 09 Nov 21, described that the weather radar should be switched on during Taxi Checklist completion. According to the SOP, the weather radar display shall be set to 'ALL' mode on both sides, the PIC's and the co-pilot's, prior to take-off.

1 **WEATHER RADAR**

	PREDICTIVE WINDSHEAR SYSTEM (1 or 2 ...)	ON	PM
	RADAR CAPT DISPLAY mode selector	ALL	PM
L2	*30 s are necessary for the 3D buffer of the radar to be filled.*		
L1	RADAR F/O DISPLAY mode selector	ALL	PM
L2	*30 s are necessary for the 3D buffer of the radar to be filled.*		

Ident.: PRO-NOR-SOP-10-A-00011956.0001001 / 09 NOV 21
Applicable to: ALL

Fig. 23: Excerpt taxi checklist Source: FCOM of the operator

1.17.1.3 Entering Turbulence

At the time of the occurrence, the valid OM-A, Rev. 2.3, Chapter 8.3.8.3 described in regard to severe turbulence on the flight path:

[…]

> *Severe turbulence should be avoided if at all possible. If severe turbulence cannot be avoided, an increased buffet margin is recommended.*

[…]

1.17.2 Training of the Flight and Cabin Crew Members

1.17.2.1 Weather Radar Training

The operator conducted an LBA-approved training which included IntuVue RDR-4000 weather radar orientation, among other things.

During the re-training of the pilots, the operator had distributed the document A339 NEO - RR Trent 7000 - Difference Training Handout, Rev 0.2, which explained the differences between the A330-200 and the A330-900, to the pilots.

The weather radar IntuVue RDR-4000 had already been used in the Airbus A330-200. The training handbook described on Page 3 the differences regarding the technically advanced version which the Airbus A330-900 is fitted with.

1.17.2.2 Aircraft Orientation

The entire training met the legal requirements and was LBA approved.

The operator had recognised insufficiencies in the training department and the implementation of the Operator Difference Requirements (ODR) stipulated by the aircraft manufacturer. This was already established during the review of the training content for the Airbus A330-900.

The training material often referred to generic Airbus A330 aircraft configurations and not consistently to the Airbus A330-900 configuration. The flight and cabin crews involved attended these trainings. At the time, the final Airbus A330-900 configuration had not been determined by the operator.

The flight and cabin crew members informed the operator about the deficit of not being able to familiarise oneself with the new cabin layout (including the SEP locations), e. g. by walking through an airplane.

1.17.3 Application on the Electronic Flight Bag

According to internal procedures of the operator (OM-A, Chapter 8.1.6 Meteorological Information, Rev 2.3), on the pilots' Electronic Flight Bag (EFB) the application eWAS[28] Pilot by the manufacturer SITA FOR AIRCRAFT had been installed. According to the operator's procedures, this software should be started prior to the flight and the current weather information loaded. During the flight, the pilots had the option to update the weather information in the eWAS App via internet, if it was available[29]. According to the procedure Electronic Flight Bag Policy and Procedure Manual (EPPM), Chapter 9.2.1.1.3, Rev. 0.6, the pilots should use the App to detect significant weather phenomena. The weather radar should be used as primary source for the avoidance of turbulence, among other things.

The following is an excerpt from OM-A, Chapter 9.2.1.1.3:

[…]

> *To increase safety on all flights by improving strategic weather-related decision making, it is mandatory that at least one active CM monitors the eWAS Pilot application above FL100. It is permitted to minimize the eWAS Pilot App temporarily in order to use other operationally relevant applications. Furthermore, report relevant turbulence or icing phenomena as per datalink short coding for upload to the eWAS server.*
>
> *Caution! For tactical weather avoidance, always rely on WX radar.*

[…]

28 Developed by the company SITA

29 As a rule, this happens automatically every 15 minutes, provided there is an internet connection.

The following is an excerpt of the eWAS App description:[30]

[…]

- *SITA eWAS gathers extensive, accurate and up-to date weather information anywhere in the world, in real time.* […] *SITA eWAS visualises a real-time, 4D picture of weather conditions for your relevant flight path - using a combination of 2D weather data, altitude based data and changes during the planned duration of your flight.* […]
- *Prepare alternative flight plans ahead of time*

  Take positive action to avoid adverse weather before it happens - by preparing alternative airport landings and routes, pre-flight. weather conditions.

[…]

1.18 Additional Information

1.18.1 Other Operational Aspects

In mid-2022, the operator began the fleet introduction of the Airbus A330-900 and the training of the flight and cabin crew members. Due to the high training effort, newly trained personnel were only available to a limited extent.

1.18.2 Operational Control Center

During the flight, four employees were working in the Operational Control Center (OCC). According to the statement of the operator, they were using the eWAS software to observe the overall weather situation along the flight path. The software had depicted amber-coloured spots, i. e. smaller Cumulonimbus clouds. In the flight planning software, the internal company procedures were stored as filter functions. It considers known weather phenomena over a large area along the planned flight route and generates warnings to the flight planner, if appropriate[31]. At the time of the flight plan's compilation, the software had not generated a warning.

30 www.sita.aero/globalassets/docs/brochures

31 Initially performed exclusively with HF voice communication, the cockpit SATCOM which operates in the L-band radio frequency is now recognized as an alternative means of communication with the Air Traffic Control or Airline Operation Centre.

The employees in the OCC observed the occurrence flight and had not send a weather warning via ACARS data link or SATCOM to the flight crew. A change in flight path was not planned.

Small local weather phenomena are identified with the help of the weather radar and have to be flown around tactically.

1.18.3 Reported Severe Turbulence

The operator had analysed and summarised reports of other operators regarding occurrences with severe turbulences during cruise flight in the Safety First #29 issue of November 2019:

[…]

> *240 severe turbulence events were reported to Airbus between 2014 and 2018. Injuries to passengers and cabin crew occurred on:*
>
> > *30 % of long-haul flights where severe turbulence events were reported.*
> >
> > *12 % of short-haul flights where severe turbulence events were reported.*
>
> *Passengers tend to unfasten their seatbelt during long haul flights to move around the cabin and use the lavatories more during long haul flights and this is likely to be the reason for the higher rate of injuries when compared to the figures for short haul flights.*

[…]

1.18.4 Possible Influence of Wake Turbulence

The aircraft manufacturer had analysed a possible influence of wake turbulence from the Airbus A350 flying higher and ahead and largely eliminated. The following reasons were given:

- *The two aircraft, although relatively close longitudinally, were separated by 2000 ft all the time. Wake vortices rarely descend by more than 1000 ft, even those of very large aircraft, and if they do they usually have lost much of their intensity. An A350 wake would not have the strength to create that kind of load factor on an A330 anymore.*
- *Additionally, given that there was atmospheric turbulence at the location of the incident* […]*, this would have accelerated the decay of the vortices even more, making it even less likely to cause strong load factors.*

- *Finally, as the incident happened during a turn, it is very unlikely to only encounter vertical loads and no significant roll reaction. In this scenario, the aircraft would have had to cross the vortex cores at some point, inducing a noticeable roll reaction.*

1.18.5 Passenger Data

Regulation (EU) No. 996/2010 obliged the airlines to treat passenger data confidentiality until all family members had been contacted in case of an occurrence. Article 20, “Information on persons and dangerous goods on board”, Item 1 stipulated:

[…]

a) as soon as possible, and at the latest within two hours of the notification of the occurrence of an accident to the aircraft, of a validated list, based on the best available information, of all the persons on board; and

[…]

Article 20, Item 3 stipulated:

In order to allow passengers’ relatives to obtain information quickly concerning the presence of their relatives on board an aircraft involved in an accident, airlines shall offer travellers the opportunity to give the name and contact details of a person to be contacted in the event of an accident. This information may be used by the airlines only in the event of an accident and shall not be communicated to third parties or used for commercial purposes.

The operator had promptly reported the occurrence to the BFU and communicated that several persons had been injured and in which hospital they were treated.

The BFU was able to obtain a summary list of personal data and injury patterns from an on-site team of the operator.

The compilation of this documentation was made significantly more difficult by the insufficient willingness to cooperate of the primary care hospital in regards to the exchange of patient data. Based on this, the BFU established contact with the passengers involved to validate the injury patterns previously communicated and compare them with the definitions of “severe injuries” in accordance with Regulation (EU) No. 996/2010, Art. 2, Para 17. Due to the special protection status of medical data, the request for detailed injury patterns and therapies was carried out on a voluntary basis and required the cooperation of the passengers asked.

The result was that the number of passengers who suffered serious injuries increased to six from the original three.

1.18.6 Crises Management of the Operator

1.18.6.1 Emergency Response Plan

The operator's Emergency Response Plan[32] stipulated that only the operator's crisis management group are authorised to release the passenger, freight and crew lists. No other department is authorised to do so and therefore, the manifest has to be closed as soon as possible.

The Emergency Response Plan, Chapter 6.2 "Passenger and Cargo Manifest" described, among other things:

[…]

Full list of passengers who boarded and travelled on flight.

[…]

1.18.6.2 Personal Assistance in Crisis Situations

At once, the operator sent a Critical Incident Stress Management Team as support for passengers, flight and cabin crew and a Special Assistance Team (SAT) to assist the passengers.

1.18.7 Tracking of Passenger Data

The following is an example of an incident in which difficulties with the traceability of passenger data arose during the investigation.

In 2018, a malfunction of the cabin pressure control system in a Boeing B737-800 occurred in cruise flight which resulted in an emergency descent to Frankfurt-Hahn Airport. Several passengers suffered minor injuries. The BFU classified the occurrence as serious incident and investigated it (File No. BFU18-0975-EX).

Due to inconsistencies in the patient documentation kept on site, it was not possible until the publication of the report to give a definite number of injured persons, because

32 Safety, Security & Crisis Department Emergency Response Plan, Revision 7.0, 16.05.2022, Effective from 17.01.2023

of diverging information. The follow-up of individuals to evaluate their exact injury pattern and the correct classification of the occurrence in accordance with Regulation (EU) No. 996/2010 was made considerably more difficult.

1.18.8 General Data Protection Regulation

Data protection regulation plays a crucial role in protecting the privacy and personal data of a country's citizens. In Germany, data protection is regulated by the German Data Protection Act (BDSG) and the General Data Protection Regulation (GDPR[33]) of the European Union.

The GDPR sets uniform standards for data protection throughout the European Union and pursue the objective of strengthening the protection of personal data and ensuring the free movement of such data within the European Union. The regulation concerns companies and organisations that process personal data, whether they are based in the EU or not. This means that international companies that process data of EU citizens must also comply with the provisions of the GDPR.

1.19 Useful or Effective Investigation Techniques

Not applicable.

33 GDPR has come into force in May 2018.

2. Analysis

While the aircraft was in Seychelles Airspace, it entered severe turbulence. Six persons suffered serious injuries. The flight crew recognised the bank of clouds depicted on the ND in green. The avoidance manoeuvre was initiated too late.

There are indications that the IntuVue RDR-4000 weather radar may only have depicted weather hazards in green, at the time of the occurrence. Testing of the RTUs did not reveal any failures that would prevent displaying detectable weather. Causality can therefore not be sufficiently proven.

2.1 Persons

2.1.1 Flight Crew

2.1.1.1 Flying Experience

The BFU rated the PIC and the co-pilots as experienced due to their long-time aeronautical occupation on long-range flights and high total flying experience.

Shortly before the occurrence, the PIC and co-pilot 1 had been retrained for the Airbus A330-900. Therefore, the type experience is considered low.

Shortly before the occurrence, co-pilot 2 had also been retrained for the Airbus A330-900. His type experience is considered high because of his experience on Airbus A330 of another operator.

2.1.1.2 Licences

The PIC and the co-pilots held the required and valid aeronautical licences and ratings.

2.1.1.3 Flight Duty and Rest Time

The flight crew adhered to the flight duty and rest times. During the flight, crew rest compartments were available and used. The BFU concludes that fatigue was not a contributing factor during this flight.

2.1.2 Cabin Crew

The cabin crew acted according to the operator’s procedures.

The cabin crew adhered to the flight duty and rest times. During the flight, crew rest compartments were available and used. The BFU concludes that fatigue was not a contributing factor during this flight.

2.2 Actions of the Flight and Cabin Crew Members

2.2.1 Actions of the Flight Crew

On the flight, the PIC was PF. During the occurrence, she was in the crew rest compartment and co-pilot 1 was PF. He had a greater flying experience as co-pilot 2.

During cruise flight, both pilots operated the weather radar in the mode Weather and Turbulence. Approximately 80 NM to 160 NM prior the waypoint UVESO, a bank of clouds was indicated in green on the ND. Thunderstorm activity was not indicated.

Therefore, co-pilot 2 attempted to analyse the weather ahead more precisely by changing the weather radar modes to Manual Gain and Manual ELEVN. The selected flight level for detection was set between FL 300 and FL 390. If the active part of the cell was below FL 300, it may have been missed at this point.

At the time, the flight crew would have had the option to opt for an alternative course. They decided to temporarily stay on course because the weather radar depicted the bank of clouds on the ND in green only. A possibly existing turbulence area would have been depicted in magenta.

Closer to the cloud area, the aircraft flying ahead performed a heading change. The flight crew decided to change the course as well. At the time, there was no VHF radio contact with ATC. Communications occurred via Controller Pilot Data Link Communications and were therefore delayed. The flight crew decided to change course independently.

The initiated change of heading about 20 NM ahead of the cloud area, could not avoid entering the clouds top layers. As the aircraft entered the cloud area, it was subject to severe turbulence. The DFDR recorded that autopilot No. 1 was deactivated. Based on the DFDR parameters, it was not possible to clearly clarify why autopilot No. 1 was deactivated. The aircraft manufacturer assumes that the activation of the High Angle of Attack Protection system resulted in the automatic deactivation of the autopilot.

The turbulence was so severe that passengers who were not wearing their seat belts were lifted out of their seats and six persons suffered serious injuries.

The influence of wake turbulence caused by the aircraft flying ahead and higher was ruled out in an analysis of the aircraft manufacturer.

According to the DWD analysis, the cloud area showed a high growth dynamic. However, especially in these warm regions (near the ITCZ), the cloud areas often contain strong updrafts and downdrafts. Based on the flying experience of the flight crew, it could therefore have been expected that they would have changed their heading early in order to avoid the cloud area.

2.2.2 Actions of the Cabin Crew

The cabin crew acted immediately after they recognised the turbulence occurrence and began to treat and care for the injured passengers.

They organised the medical care in the business class in the front of the aircraft. This was seen as advantageous as more space was available and the passengers could lay on the flat seats of the business class. According to the statement of the cabin crew members, they viewed the coordination and cooperation with the medical personnel on board as effective.

The BFU concludes that the cabin crew acted discreet, prudently and without delay.

2.3 Training

The operator’s training department had a training program approved by the supervising authority according to their regulations for the continuous training of the pilots. According to the documentation provided, the flight and cabin crews involved were also trained in accordance with the operator’s training program.

2.3.1 Practical Training on Aircraft Type

During the Initial Safety & Emergency Procedures Training, current training material was not always available. At the time of the training of some of the cabin crew members, the final configuration of the A330-900 had not yet been determined, therefore the cabin crews were not able to sufficient familiarise themselves with the aircraft. The training material often referred to generic Airbus A330 aircraft configuration and not to the Airbus A330-900 configuration.

This deficit in handling the on-board systems was noticeable in the stressful situation of the severe turbulence (refer to the following chapter Service Interphone).

Compared to other flight and cabin crew members on long-range aircraft types, this resulted in a low experience on the Airbus A330-900.

2.3.2 Service Interphone

The flight and cabin crews still had little practical experience with the type and the on-board systems such as the Service Interphone. This was an additional burden.

It could not be clearly established why it was not possible for the cockpit to communicate via the Service Interphone with the Lower Deck Mobile Crew Rest after the turbulence occurrence.

One possible explanation is that the steps (push three buttons one at a time in the correct order) were not performed correctly. This may possibly be due to the stress level in the cockpit and/or the low experience on type. The operator identified corresponding training deficits (chapter Safety Actions).

2.3.3 Weather Radar

The operator conducted an LBA-approved training which included IntuVue RDR-4000 weather radar orientation, among other things.

During the training, the operator had handed out a document to the pilots describing the differences between the A330-200 and the A330-900. In it, detailed depictions and descriptions of the functions were missing.

There was no corresponding training or practical instruction. The A330-900 weather radar IntuVue RDR-4000 had many advanced functions compared with the one from the A330-200, which the flight crew knew. The BFU is of the opinion that it would have been sensible to compile a comprehensive training concept for the use of the weather radar. The BFU discussed this with the operator, who developed a corresponding training (Chapter Safety Actions).

2.3.4 Training the Importance of Weather Phenomena on Long-Range Flights

The operator conducts a number of long-range flights worldwide. Many of these flights in regions with the Intertropical Convergence Zone. Therefore, the operator’s initial type rating and the recurrent training included the importance of weather phenomena in general and especially in regions with the influence of the Intertropical Convergence Zone.

From the BFU's point of view, the training courses were sufficient. After the occurrence, the operator did not see any need for a special training, but initiated an exchange of experience with the DWD regarding the effects of climate change on the existing flight route network, with a view to new product developments, particularly in the areas of turbulence detection and NowCasting.

The operator continuously reviews and evaluates processes as part of a management of change procedure in order to analyse the impact of climate change on safety risk management. Aspects such as the influence of Clear Air Turbulence (CAT), convective weather phenomena, high ambient temperatures and deviation from the International Standard Atmosphere during cruise flights are considered.

2.4 Aircraft

As part of the Air Operator Certificate, the aircraft was certified for commercial passenger transport. In accordance with aviation regulations, the aircraft had a certificate of registration.

The documentation the operator provided and the DFDR data of the flight, did not contain any entries and indications which could have indicated a defect of the weather radar at the time of the occurrence. No other indications of technical defects were determined which could have affected a safe flight or distracted the flight crew.

2.5 Operator

2.5.1 Documents

All documents required and relevant for the investigation were up to date at the time of the occurrence.

2.5.2 Crisis Management

At once, the operator sent a Critical Incident Stress Management Team as support for the flight and cabin crew and a Special Assistance Team (SAT) to assist the passengers. The assistance team remained on site for several days.

2.6 Weather

At the time of the accident, it was night and the pilots did not see any lightning or other distinctive cloud formations. Due to their flying experience on long-range flights along the equator and the ITCZ, they were aware that severe turbulence, high cloud tops and intense precipitation are weather phenomena which are very distinct in these regions.

The reaction of co-pilot 2 to change the weather radar's setting so that the airspace ahead could be checked for possible weather phenomena was foresighted and appropriate.

2.7 eWas Application

The briefing package, which the pilots were provided with ahead of the flight, included the SIGWIX chart, among other things. In addition, the operator provided the pilots with the eWAS Weather App. It was updated prior to the flight and could also be updated during the flight via the internet, whenever there was a connection.

The application serves as a strategic tool to avoid flying into cloud formations with strong dynamic updrafts and downdrafts. The flight crew used it in accordance with the operator's procedures. However, the application does not replace weather radar or - where possible - the visual identification of cumulonimbus clouds.

2.8 Passenger Data

Passenger data is particularly protected by law.

After investigation relevant occurrences, this repeatedly led to difficulties in the past, as in the current case, with regard to the exchange of relevant data, in particular personal and medical information, as well as the transmission of individual contact details of passengers.

The reliable, timely traceability and contacting capability of individual passengers is absolutely necessary in the context of an accident investigation for several reasons:

- The number of persons injured by an occurrence must be clearly determinable.
- Detailed injury patterns of persons have to be promptly available to adequately classify the occurrence in accordance with Regulation (EU) No. 996/2010 and to be able to initiate any further measures that may be necessary in good time.
- Knowledge of the precise injury patterns are essential for the accident investigation for understanding the injury mechanisms that occurred. Among other things, conclusions can be drawn for sub-areas such as “Survivability” and “Cabin Safety“.

Investigation practice shows however, that currently obtaining medical data of individual passengers depends on the cooperation of the persons involved and a corresponding fact-based minimum standard for these sub-areas is currently not guaranteed.

The provision of passenger contact details in connection with the booking process for a flight is currently voluntary and not mandatory.

Directly after an occurrence, contact data of persons involved are not reliably collected by on-site personnel so that later contact is made more difficult. This is especially true if persons involved do not remain on site but continue their journey or receive medical treatment later.

3. Conclusions

3.1 Findings

3.1.1 Persons

3.1.1.1 Flight Crew

- PIC and the co-pilots had the required type ratings in their licences to control the aircraft.
- The pilots' flying experience on other long-range aircraft was to be considered as high.
- Shortly before the occurrence, the PIC and co-pilot 1 had been retrained for the Airbus A330-900. Therefore, the type experience is considered low.
- Shortly before the occurrence, co-pilot 2 also had been retrained for the Airbus A330-900. His type experience is considered high because of his experience on Airbus A330 of another operator.
- Flight duty and rest times were adhered to.

3.1.1.2 Cabin Crew

- The cabin crew acted according to the operator's procedures.
- Flight duty and rest times were adhered to.

3.1.2 Course of the Flight and Actions

- Prior to departure, the pilots had available weather forecast charts and NOTAMs required for the conduct of the flight.
- In ALL WX mode, the weather radar detected an area of cloud. By mode change to Manual Gain and Manual ELEVN, co-pilot 2 analysed the cloud area, which was displayed in green on the ND approximately 80 NM - 160 NM in front of the aircraft.
- The displayed radar echo of the weather radar was not correctly assessed by the flight crew.
- The initiated changed of heading about 20 NM before reaching the cloud formation was too late.
- Co-pilot 1, as PIC, informed the cabin crew via intercom after the occurrence.

3.1.3 Training

- The pilots had been trained about the weather radar IntuVue RDR-4000, in accordance with the trainings approved by the LBA.
- The BFU assessed the scope and depth of the training in the use of the weather radar and the on-board communication system of the Airbus A330-900 as insufficient.

3.1.4 Aircraft

- The aircraft was equipped for operations according to IFR.
- It had the required airworthiness certificate and was properly maintained by the maintenance organisation.
- There was no evidence of defects of the aircraft weather radar at the time of the occurrence.

3.1.5 Operator

- All documents required and relevant for the investigation were provided and up to date at the time of the occurrence.

3.1.6 Weather

- At the time of the accident, night prevailed.
- The clouds reached the altitude of the flight path.
- The encountered turbulence was very severe.

3.1.7 Passenger Data

- The operator informed the BFU that several persons had been injured and were treated at the local hospital.
- Deficiencies in the willingness of the primary care hospital to cooperate with regard to the exchange of patient data were found.
- The request for detailed injury patterns was carried out on a voluntary basis and required the cooperation of the passengers asked.
- Due to turbulence, six persons suffered serious injuries.

3.2 Causes

The aircraft took off at Frankfurt/Main Airport, Germany, and landed at Sir Seewoosagur Ramgoolam International Airport, Mauritius. While the aircraft was in Seychelles airspace, at Flight Level (FL) 390, it encountered turbulence. Six passengers suffered severe, 15 passengers and one cabin crew member minor injuries, which were treated at hospital.

The accident which occurred in cruise flight during significant turbulences is due to the following direct causes:

- The weather radar captured a bank of clouds which was displayed in green on the Navigation Display (ND). The bank of clouds included an upwind and downwind region, which could not be recognised in its intensity by the flight crew and generated severe turbulence over a period of 10 s.
- The initiated change of heading about 20 NM ahead of the bank of clouds occurred too late so that the aircraft entered the top layer of clouds.
- Some passengers not wearing their seat belts, suffered injuries, some of them serious.

The investigation identified the following contributory factors:

- According to the co-pilots' statements the weather radar was set to the All WX mode and did not display turbulence on the ND.
  - Due to the dynamic growth of the cloud area, its actual extent was only recognised shortly before entering the bank of clouds.
  - The Initial Safety & Emergency Procedures Training the operator had conducted for flight and cabin crew members showed deficits in handling on-board systems, especially the on-board communications system.

4. Safety Actions

The BFU, in collaboration with the operator, discussed safety measures. Individual actions to improve safety were implemented internally by the operator under the coordination of the Safety Department.

List of actions and implementation timeline:

1) Flight Support Notice

- After the aircraft manufacturer had received information from other operators about function deviations of the IntuVue RDR-4000 weather radar, on 27 April 2023 a Flight Support Notice (FSN) was published to improve the flight crews' awareness about handling the IntuVue RDR-4000 weather radar. This temporary measure was part of the Airbus briefing package.
- Parallel to the Flight Support Notice, on 27 April 2023 a Flight Crew Notice (FCN) was published and provided to all Airbus A330 flight crews as part of the company documentation on the EFBs. In case of observed deficits of the IntuVue RDR-4000 weather radar, flight crews should document the information required by the manufacturer. As part of the Safety Report, this information is passed on to the aircraft manufacturer.

  During 2023, this FCN was amended several times based on updated information of the aircraft manufacturer.

2) Weather Radar Training

   The operator had identified deficits in the training of flight crews and how they have to handle the weather radar and process the information.

   It was decided that flight crews should receive additional information including an explanatory video of the weather radar manufacturer and beginning with the winter season 2023/2024 on-site training with discussion for the purpose of exchanging experiences.

3) Training with the DWD

   The analysis of the operator's existing training material showed that information on weather phenomena, which affect long-range operation including aspects of the Intertropical Convergence Zone have to be amended and updated especially in regard to the global climate changes and the increase in the intensity of weather-related occurrences worldwide.

Contact to the DWD was established and an informative exchange with representatives of the DWD initiated. The aim of this exchange is to receive information from weather experts to improve and deepen the weather-related training of flight crews. The general awareness for weather phenomena and an improved weather-related decision making of flight crews should be promoted.

4) Operation Control Center

Beginning with the summer season 2023, the operator deployed pilots to support the OCC as Flight Watch Pilots. In addition to their flying duties, they should contribute their knowledge and experience from everyday flying. This mainly concerns the monitoring of flights (using the eWAS Mission Watch) and the advice of flying flight crews (primarily via ACARS) especially in regard to short-term and large-scale weather phenomena.

In addition, the exchange with OCC employees should promote a common understanding in regard to weather-related aspects of the flight planning and monitoring. In addition, use of eWAS during flight planning was established and improved.

5) Service Interphone

The correct use of the Service Interphone of the Airbus A330-900 was trained during the Safety & Emergency Procedures recurrent training of all flight and cabin crew members in the season 2023/2024.

6) Crisis Management

To improve crisis management and customer service, measures were taken to train selected hotline personnel by experienced members of the operator's Special Assistance Team to be able to provide passengers and relatives with targeted support.

In addition, processes were checked and partially adapted to ensure that the passengers involved and their relatives have all the necessary information at their disposal and can be reached by the Special Assistance Team.

As a result of the measures taken, the BFU will not issue safety recommendations.

Investigator in charge: Norman Kretschmer

Assistance: Dr. Thomas Harendza, Michel Buchwald, Martin Beckert, Ekkehart Schubert

Braunschweig, 26 March 2025

5. Appendices

5.1 DFDR Plot

5.2 Visualization of the Aircraft Manufacturer's Parameters

5.1 DFDR Plots

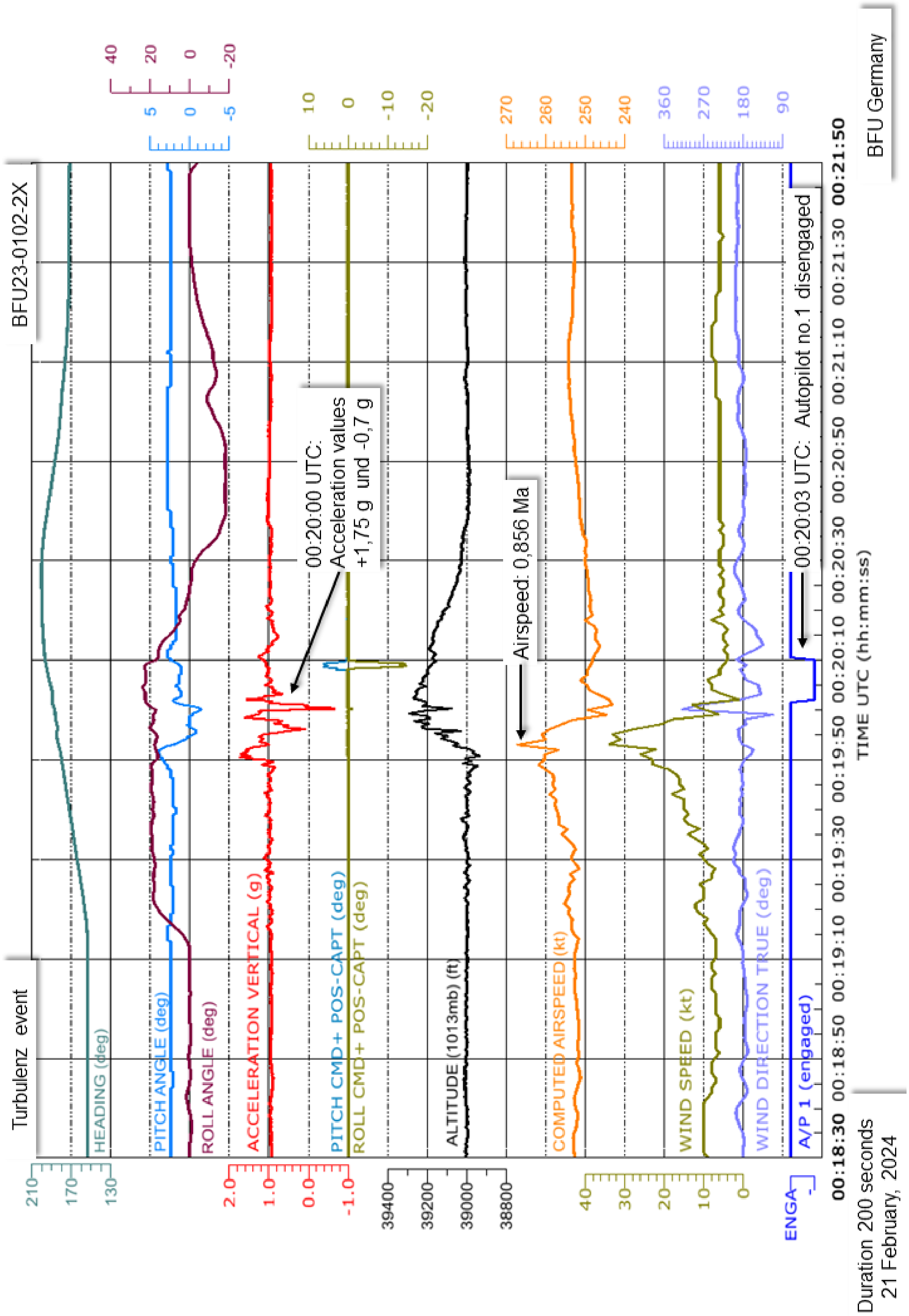


Fig. 24: FDR parameters of the occurrence during cruise flight

Source: BFU

5.2 Visualization of the Aircraft Manufacturer's Parameters

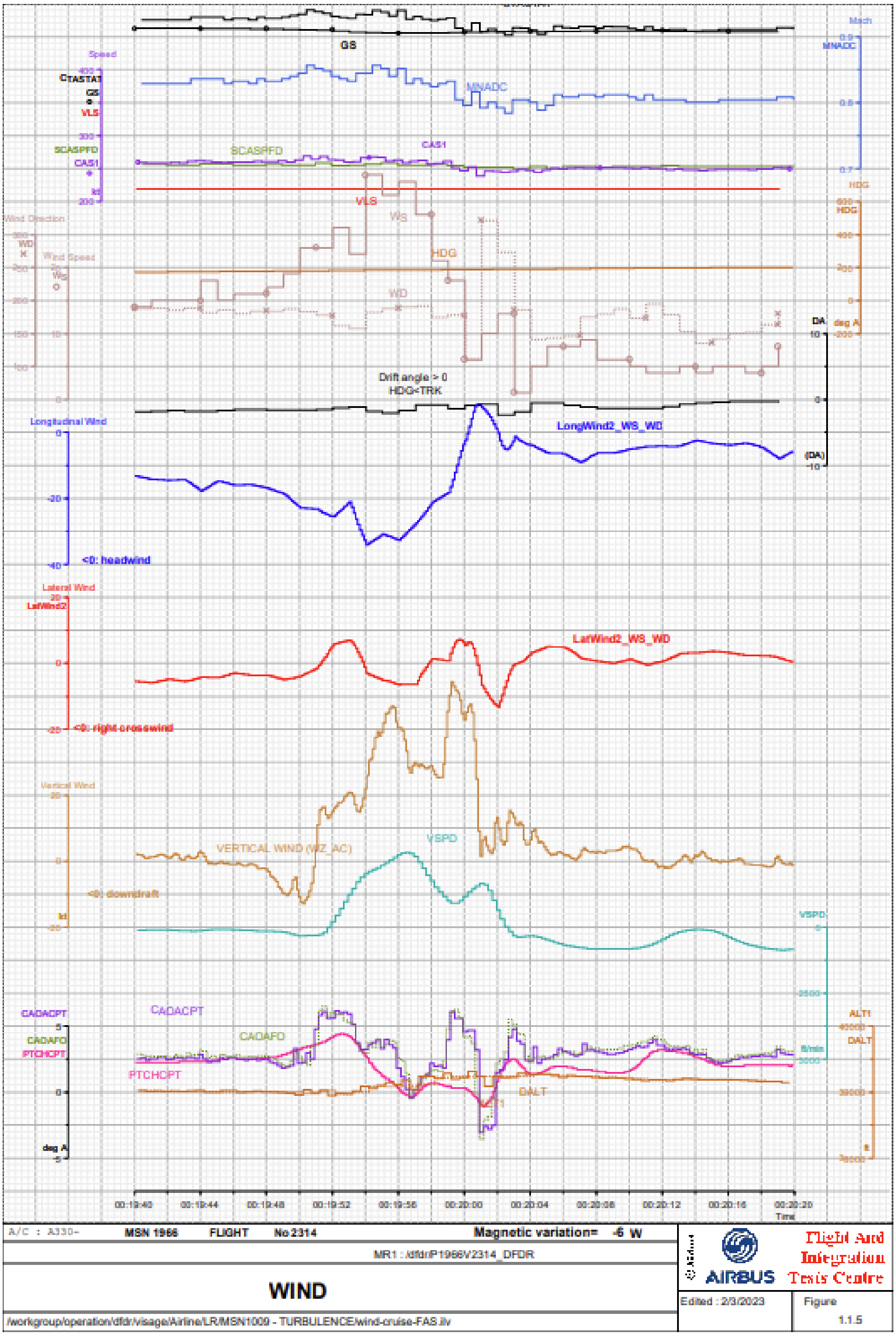


Fig. 25: Visualization of various parameters Source: Aircraft manufacturer