Technical report
A-037/2021

Accident on 31 July 2021 involving a Boeing 737-8AS aircraft, registration number EI-EPC, while on approach to Barcelona Airport

Please note that this report is not presented in its final layout and therefore it could include minor errors or need type corrections, but not related to its content. The final layout with its NIPO included (Identification Number for Official Publications) will substitute the present report when available.

GOBIERNO DE ESPAÑA
MINISTERIO DE TRANSPORTES, MOVILIDAD Y AGENDA URBANA
UNDERSECRETARIAT
CIVIL AVIATION
ACCIDENT AND INCIDENT
INVESTIGATION COMMISSION

Notice

This report is a technical document that reflects the point of view of the Civil Aviation Accident and Incident Investigation Commission (CIAIAC) regarding the circumstances of the accident and its causes and consequences.

In accordance with the provisions in Article 5.4.1 of Annex 13 of the International Civil Aviation Convention; and with articles 5.6 of Regulation (UE) nº 996/2010, of the European Parliament and the Council, of 20 October 2010; Article 15 of Law 21/2003 on Air Safety and articles 1 and 21.2 of Regulation 389/1998, this investigation is exclusively of a technical nature, and its objective is the prevention of future civil aviation accidents and incidents by issuing, if necessary, safety recommendations to prevent from their reoccurrence. The investigation is not pointed to establish blame or liability whatsoever, and it's not prejudging the possible decision taken by the judicial authorities. Therefore, and according to above norms and regulations, the investigation was carried out using procedures not necessarily subject to the guarantees and rights usually used for the evidences in a judicial process.

Consequently, any use of this report for purposes other than that of preventing future accidents may lead to erroneous conclusions or interpretations.

This report was originally issued in Spanish. This English translation is provided for information purposes only.

CONTENTS

ABBREVIATIONS

° ‘ “	Sexagesimal degrees, minutes and seconds
°C	Degrees Celsius
AEMET	Spanish State Meteorological Agency
AFDS	Autopilot Flight Director System
ARM	Armed
ASR	Airport Surveillance Radar
ATC	Air Traffic Control (in general)
ATIS	Automatic Terminal Information Service
ATPL	Airline Transport Pilot Licence
CAS	Calibrated Airspeed
CRM	Crew Resource Management
CPL	Commercial Pilot Licence
CVR	Cockpit Voice Recorder
E	East
FCOM	Flight Crew Operating Manual
FCTM	Flight Crew Training Manual
FL	Flight Level
ft	Feet
g	Normal acceleration
GMFF	ICAO code for Fez Airport
h	Hours
hPa	Hectopascals
IF	Intermediate Fix
IFR	Instrument Flight Rules
ILS	Instrument Landing System
kg	Kilograms
km	Kilometres
kt	Knots
L	Left
LEBL	ICAO code for Josep Tarradellas Barcelona-El Prat Airport
LNAV	Lateral Navigation
m	Metres
MCP	Mode Control Panel
No.	Number
N	North
NM	Nautical Mile
ICAO	International Civil Aviation Organisation
PA	Public Announcement
PF	Pilot Flying
PFD	Primary Flight Display

PM	Pilot Monitoring
QAR	Quick Access Recorder
QNH	Altimeter subscale setting that indicates elevation while on the ground (precision setting indicating elevation above mean sea level)
R	Right
RW	Runway
SAT	Static Air Temperature
SEP	Safety and Emergency Procedures
SIGMET	Information regarding the meteorological conditions on route that could affect the safety of aircraft operations
SPD	Speed Mode
STAR	Standard Terminal Arrival Route
TAF	Terminal Aerodrome Forecast
TCP	Cabin Crew
UTC	Coordinated Universal Time
VMC	Visual Meteorological Conditions
V_{MO}	Maximum Operating Speed
W	West

Technical report

A-037/2021

Owner	Ryanair Designated Activity Company
Operator:	Ryanair Designated Activity Company
Aircraft:	Boeing 737-8AS, registration number EI-EPC (Ireland)
Date and time of accident:	31 July 2021, 14:00 h[1]
Site of accident:	On approach to Barcelona Airport
Persons on board:	6 (crew members), 172 (passengers)
Type of flight:	Commercial air transport – Scheduled – With passengers
Phase of flight:	On route - Normal descent
Type of operation:	**I**FR
Date of approval:	**30 March 2022**

Synopsis

Summary:

On Saturday 31 July 2021, the Boeing 737-8AS aircraft bearing registration number EI-EPC left Fez Airport (GMFF) in Morocco and made its way to Josep Tarradellas Barcelona-El Prat Airport (LEBL) in accordance with Standard Terminal Arrival Route (STAR) MATEX 2E. It was scheduled to land on runway 07L.

During the descent, the flight crew observed the presence of cumulonimbus on the weather radar and asked ATC to adjust the flight's intended track in order to avoid the cloud. The captain then informed the cabin crew of the possibility of turbulence during the approach and asked them to proceed to secure the cabin.

The aircraft continued its descent and entered an area of undetected turbulence that lasted for around two minutes, during which time the aircraft's speed increased until it approached the maximum operating speed (V_{MO}). In order to reduce speed, the pilot flying (PF) disengaged the autopilot and pitched nose up. Vertical acceleration of +3.09 g was recorded at that moment. One second later, he moved the control column in the opposite direction, lowering the aircraft's nose and recording vertical acceleration of -0.18 g.

While this was happening, the cabin crew members were on their feet and beginning the task of securing the cabin. As they did not have enough time to sit down or secure

[1] All times referenced in this report are local time. The UTC is 2 hours less.

themselves, they were thrown against various parts of the cabin and fell to the floor. After the aircraft had passed through the area of turbulence, one of the cabin crew members asked the flight crew to request an ambulance upon arrival at the airport, as two of the cabin crew members had been incapacitated.

Upon landing at Barcelona Airport, the injured cabin crew members were attended by the airport's medical service. In addition to the injured cabin crew members, one passenger also suffered head wounds. All of the injured parties were taken to hospital.

The investigation has concluded that the probable cause of the accident was the series of actions taken by the PF to prevent the aircraft from exceeding the V_{MO} while it was flying through an area of turbulence. This resulted in vertical acceleration that injured a passenger and two cabin crew members.

After carrying out an internal safety investigation into the accident, the operator reinforced the flight crew's training on the subject of turbulence and overspeed. Additionally, among other measures, it proposed to publish the lessons learnt from this event in its operational safety publications, and to include the event as a case study in its crew training activities. All of these measures are considered appropriate, and no safety recommendations are proposed.

1. THE FACTS OF THE INCIDENT

1.1. Overview of the accident

On Saturday, 31 July 2021, the Boeing 737-8AS aircraft bearing registration number EI-EPC travelled from Fez Airport (GMFF) in Morocco to Barcelona/Josep Tarradellas-El Prat Airport (LEBL). There were 178 people on board: two pilots, four cabin crew and 172 passengers[2].

After studying the meteorological information provided by the flight dispatcher, the flight crew concluded that the aircraft would probably encounter turbulence during the descent into Barcelona and informed the cabin crew accordingly.

The cockpit was occupied by the captain, in the capacity of pilot flying (PF); the co-pilot, in the capacity of pilot monitoring (PM); and an off-duty pilot from the same operator, who was sitting in the observer's seat.

The flight proceeded as normal and at 13:53:09 h, after 59 minutes in the air, the aircraft began its descent towards Barcelona Airport. The autopilot and autothrottle were engaged.

The aircraft proceeded to the MATEX point in order to follow the MATEX 2E STAR and land on runway 07L.

[2] It was the third of four flights that the crew had been assigned for that day.

Image 1: Extract from the STAR to runway RWY07/L/R at LEBL

The autopilot's vertical mode was MCP SPD[3] and the autothrottle was in ARM[4] mode. The aircraft descended to FL200, which had been selected on the MCP[5] altitude selector.

As ATC had delayed the start of the aircraft's descent, in order to comply with the altitude restrictions of the STAR the flight crew had gradually increased the speed selected in the MCP while keeping the throttle at idle, thereby increasing the rate of descent.

The descent took place under tailwind conditions, the intensity of which at the time was 70 kt.

As they were descending through FL280, in the section between MATEX and BL028 points of the MATEX 2E STAR the flight crew observed the presence of cumulonimbus on the weather radar and asked ATC to adjust the flight intended track in order to avoid the cloud. Consequently, at 13:57:32 h the aircraft adjusted its heading 14º to the left, to fly on a heading of 065º.

[3] In MCP SPD mode, the AFDS sets the pitch positions that are required in order to maintain the speed that has been selected in the MCP.

[4] In ARM mode, the autothrottle servos are inhibited, allowing the pilot to move the thrust levers manually. It is the mode that is activated after the RETARD mode, whereby the autothrottle sets thrust at idle.

[5] The pilot uses the MCP (Mode Control Panel) to instruct the autopilot to perform certain actions.

Subsequently, at 13:58:03 h (approximately 25 minutes before the estimated landing time), the captain informed the cabin crew of the possibility of turbulence during the approach and asked them to proceed to secure the cabin.

Directly afterwards, at 13:59:18 h ATC authorised the aircraft to descend to FL80 and, if flight conditions permitted, to proceed to ASTEK[6]. This was accepted by the flight crew.

At 13:59:24 h, the PF extended the speed brakes. The tailwind component was 58 kt.

At 14:00:07 h, two minutes after the captain had spoken to the cabin crew and while descending through FL180, the aircraft entered an area of turbulence. At that time, the speed selected by the flight crew in the MCP was 320 kt, while the aircraft's CAS was 325 kt. The engines' N1 was at idle.

Over the next 29 seconds, the speed selected in the MCP was reduced to 308 kt. During this period, the aircraft's CAS ranged from 306 kt to 329 kt. Fluctuations in vertical acceleration of between +0.50 g and +1.36 g were recorded, with changes that, on occasion, reached up to 0.7 g within the space of one second[7].

At 14:00:37, while descending through FL170, the aircraft's CAS suddenly increased, going from 322 kt to 334 kt within the space of one second.

In his statement, the captain explained that the PFD's speed trend vector had started to show large oscillations. In his view, the level of turbulence had become severe. He stated that the flight was under VMC conditions.

In the captain's opinion, the autopilot was unable to maintain the correct speed, so he decided to disengage it to avoid exceeding the V_{MO} (340 kt). At 14:00:38 h, he disengaged the autopilot. An increase of +48 lb was then recorded with regard to the amount of force applied to the control column.

One second later, at 14:00:39 h, the pitch angle had increased from -1.8º to +6.2º, reaching vertical acceleration of +3.09 g.

After applying a force of -51 lb to the control column in the opposite direction, at 14:00:40 the pitch angle was reduced to -1.6º, with vertical acceleration of -0.18 g.

Meanwhile, the cabin crew members had begun their preparations to secure the cabin and were at the rear of the aircraft. Two and a half minutes had passed since the captain had made his call. The senior flight attendant, who was issuing a turbulence warning to the passengers, was in the rear galley along with two other cabin crew members. The fourth

[6] ASTEK is the intermediate fix (IF) of the ILS approach to runway 07L. It is positioned at 12 NM, at the end of heading 07L.

[7] Changes in the accelerometer's readings of between 0.5 g and 1.0 g at the aircraft's centre of gravity indicate moderate turbulence. Changes in the accelerometer's readings of 1.0 g and above at the aircraft's centre of gravity indicate severe turbulence.

cabin crew member was at row 29, attending to a passenger request. Suddenly, all of the cabin crew members were thrown against different parts of the cabin and fell to the floor.

Activation of the AFT ENTRY DOOR[8] Master Caution light was recorded at 14:00:41 h. The co-pilot stated that he noted the activation of said light.

For the next 21 seconds, the aircraft remained practically level at FL170 and the force exerted on the control column varied between +32 lb and -36 lb. Positive pitch angles were recorded, while the CAS began to fall.

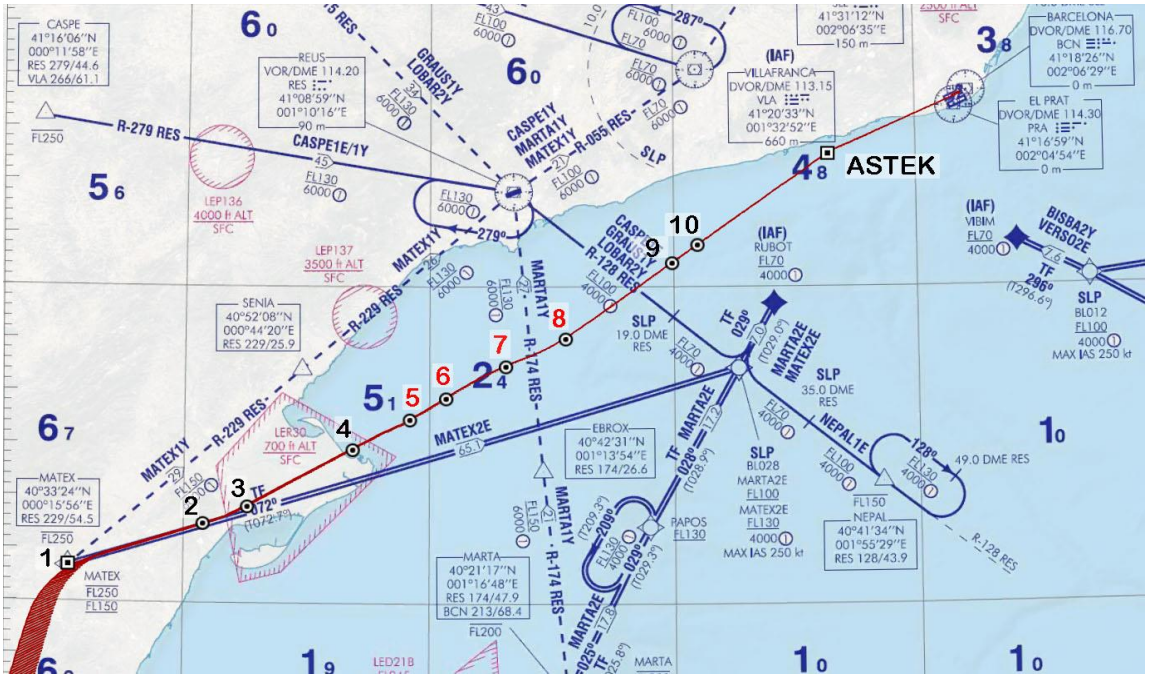
At 14:01:00 h, the CAS was 283 kt and the aircraft resumed its descent.

At 14:01:30h, while descending through 15,900 ft, the autopilot was re-engaged.

At 14:02:24 h, the aircraft exited the area of turbulence.

At 14:03:53 h, ATC authorised the aircraft to descend to 3,000 ft and maintain 250 kt to ASTEK as number 1 and to ILS Z for runway 07L.

[8] This light was activated when the senior flight attendant was thrown against the door.



1	13:56:00	FL310	CAS 290 kt	The aircraft overflies MATEX.
2	13:57:32	FL270	CAS 305 kt	The aircraft begins its diversion onto a heading of 065º.
3	13:58:03	FL250	CAS 314 kt	The captain warns the cabin crew of likely turbulence during the approach.
4	13:59:18 – 13:59:24	FL210	CAS 318 kt	ATC authorises the aircraft to proceed to ASTEK and the speed brakes are extended.
5	14:00:07	FL180	CAS 325 kt	The aircraft enters the area of turbulence.
6	14:00:38	FL170	CAS 334 kt	Autopilot disengaged; vertical acceleration of +3.09 g.
7	14:01:30	FL160	CAS 289 kt	Autopilot re-engaged.
8	14:02:24	FL130	CAS 296 kt	The aircraft exits the area of turbulence.
9	14:04:21	FL90	CAS 276 kt	Call from the cabin crew, advising that crew members have been injured.
10	14:04:53	FL80	CAS 259 kt	The flight crew contacts ATC to request an ambulance upon arrival

Image 2: Path of the aircraft during the descent

At 14:04:21 h, one of the cabin crew members called the flight crew to inform them that two cabin crew members had been injured and that an ambulance would be required upon arrival.

At 14:04:53 h, the flight crew contacted ATC to request an ambulance upon arrival at Barcelona.

After landing at Barcelona/Josep Tarradellas-El Prat Airport, the injured cabin crew members were attended to by the airport's medical service. In addition to the injured cabin

crew members, one passenger also suffered head wounds. All of the injured parties were taken to hospital.

1.2. Injuries to persons

Injuries	Crew	Passengers	Total in the aircraft	Others
Fatal				
Serious	1	1	2	
Minor	1		1	
Unharmed	4	171	175	
TOTAL	6[9]	172	178	

1.3. Damage to the aircraft

The aircraft did not sustain any damage.

1.4. Other damage

There was no other damage.

1.5. Information about the personnel

1.5.1. Information about the captain

The 29-year-old captain had an ATPL (Airline Transport Pilot Licence) issued for the first time on 29 April 2019, with a B737 300-900 rating and an instrument flight rating, both valid until 30 April 2022.

His Class 1 medical certificate was valid until 7 June 2022.

As of 31 July 2021, he had amassed a total of 4,041.77 h of experience.

With regard to his training, amongst other items, he had received specific training in the following:

- Recovery from overspeed while cruising, on 15 April 2021.
- Procedures upon entering an area of severe turbulence, recovery from overspeed and awareness of g-load factor, on 10 April 2019.
- Effective communication and coordination within and outside the cockpit and with other operational personnel and ground services, on 13 April 2019.

[9] The crew comprised two flight crew and four cabin crew.

1.5.2. Information about the co-pilot

The 26-year-old co-pilot had a CPL (Commercial Pilot Licence) issued for the first time on 7 March 2018, with a B737 300-900 rating and an instrument flight rating, both valid until 31 March 2022.

His Class 1 medical certificate was valid until 1 December 2021.

As of 31 July 2021, he had amassed a total of 1,692.8 h of experience.

With regard to his training, amongst other items, he had received specific training in the following:

- Recovery from overspeed while cruising, on 10 April 2021.
- Recovery from overspeed and awareness of g-load factor, on 23 January 2019.
- Effective communication and coordination within and outside the cockpit and with other operational personnel and ground services, on 1 February 2018.

1.6. Information about the aircraft

- Make: Boeing
- Model: 737-8AS
- Year of manufacture: 2011
- Serial number: 40312
- Registration number: EI-EPC
- Maximum take-off weight: 66,990 kg
- Number of engines: 2
- Type of engines: CFM56-7B26
- Information about the owner and operator: The aircraft has been registered in the Irish Aircraft Register in the name of Ryanair Designated Activity Company since 23 March 2011.

The aircraft has an Airworthiness Certificate and an Airworthiness Review Certificate, valid until 22 March 2022.

After the accident, an inspection was carried out as specified in the Aircraft Maintenance Manual for severe turbulence. No anomalies were found.

The aircraft's V_{MO} is 340 kt.

1.7. Meteorological information

1.7.1 Local meteorological conditions

The ATIS for Barcelona Airport at 12:00 UTC on the day of the accident was:

31/07/2021 12:00:16 ATIS_ARRIVAL LEBL INFO ARR Y TIME 1200 ILS Z APCH EXPECTED RWY IN USE FOR ARR 07L AND FOR DEP 07R TRL 75 REMAIN ON TWR FREQ AFT LDG CTN RNAV APCH TRANSITIONS IN USE FM IAF CHECK FMS EXPECT 1E APCH TRANSITIONS FOR RWY 07L WIND TDZ 140 DEG 6 KT VRB BTN 110 AND 180 DEG CAVOK T 25 DP 16 QNH 1010 NOSIG[10]

The TAF for Barcelona Airport issued at 11:00 UTC on the day of the accident indicated a likelihood of storm activity from 14:00 UTC onwards:

TAF LEBL 311100Z 3112/0112 13010KT 9999 FEW020 TX29/3114Z TN20/0106Z PROB40 TEMPO 3114/3121 VRB20G35KT 3000 TSRA SCT020CB BECMG 3117/3120 34005KT PROB30 TEMPO 0100/0106 BKN014 BECMG 0110/0112 20010KT

SIGMET number 4 issued by the weather monitoring station in Valencia was:

LECB SIGMET 4 VALID 311100/311500 LEVALECB
BARCELONA FIR/UIR FRQ TSGR FCST WI N4008 W00026 – N41 E00005 – N4133 E00123 – N4058 E00155 – N3946 E00111 – N4008 W00026 TOP FL460 STNR NC

The SIGMET message indicated a forecast of storms between 11:00 UTC and 15:00 UTC in the area delimited by the red polygonal line (see the image on the right), which comprised the aircraft's arrival and approach path

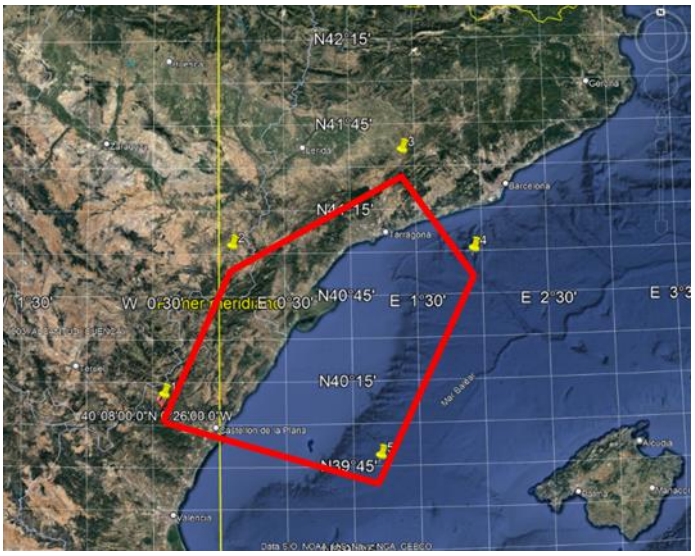


Image 3: Area in which storms were forecast, as delimited in the SIGMET

For its part, AEMET provided the investigation with a weather report in which it concluded that the meteorological conditions on 31 July 2021 during the aircraft's approach into Barcelona Airport at 12:15 UTC were characterised by the presence of wind shear, originating from the gust fronts of the storm formations located in the vicinity of the airport.

1.7.2 Meteorological information extracted from the QAR data

Data on outside temperature, wind speed and intensity were extracted from the QAR for the period in which the aircraft crossed the area of turbulence.

[10] The runway in use for landing was 07L. Wind intensity was 6 knots, with a direction of 140º, varying between 110º and 180º. Visibility was greater than 10 km, with an absence of clouds below the CAVOK reference height and an absence of cumulonimbus and tower-shaped cumulus clouds. The temperature was 25°C, with a dew point of 16°C. The QNH was 1010 hPa.

During this period, changes were recorded in wind direction and intensity, along with oscillations in the figures for static air temperature (SAT). These variations are shown in the following graphs:

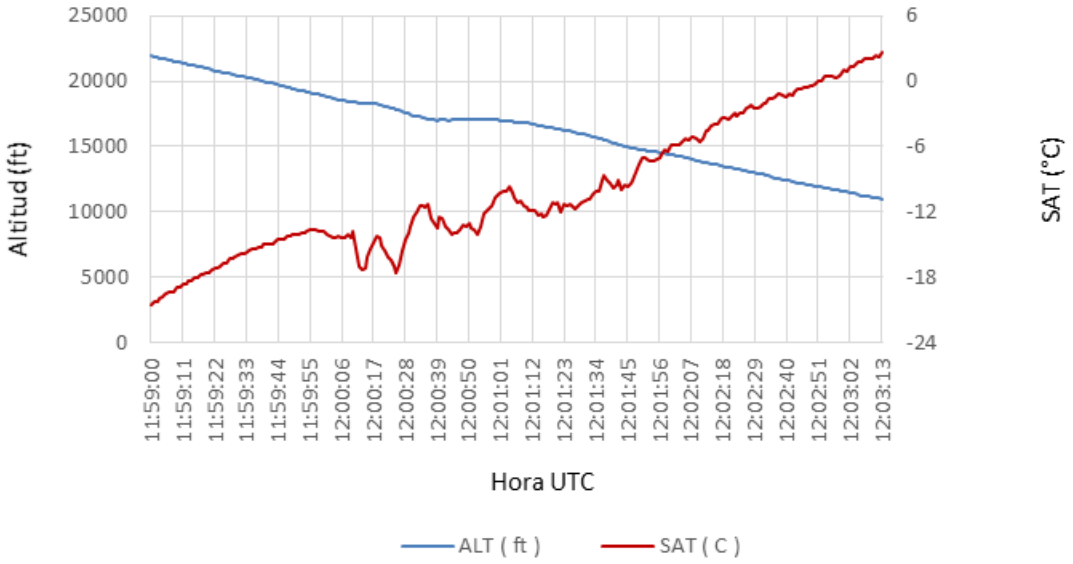


Image 4: Graph showing the variation in SAT with altitude in the area of turbulence

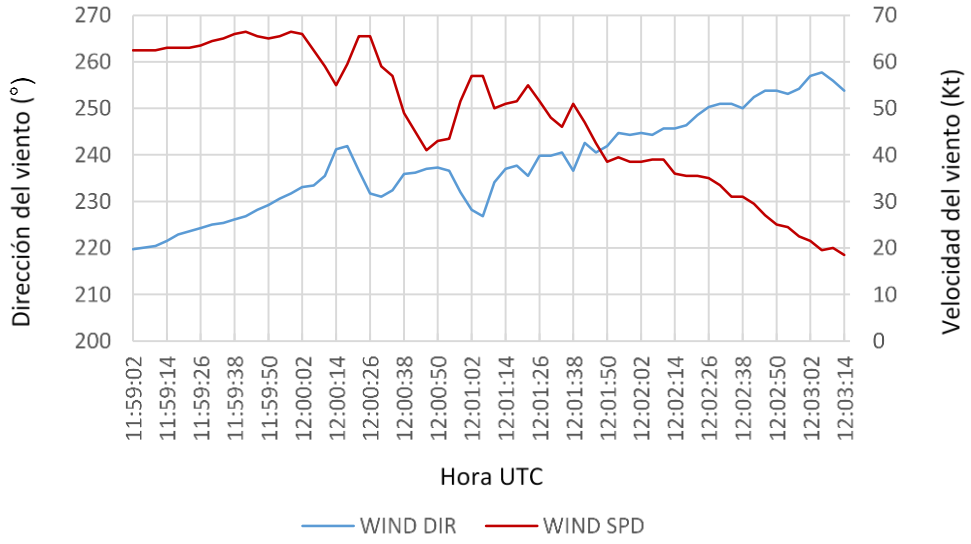


Image 5: Graph showing the variation in wind direction and speed in the area of turbulence

1.8. Aids to navigation

N/A.

1.9. Communications

The most relevant communications between the flight crew and ATC are detailed in section 1.11. There were no reports of turbulence from other aircraft or ATC; however, requests for track deviations from aircraft to avoid storm clouds were heard on the frequency.

1.10. Information about the aerodrome

Josep Tarradellas Barcelona-El Prat Airport (ICAO code LEBL) is located 10 km south-west of the city of Barcelona. Its elevation is 4 m and it has three runways: 02/20, 07L/25R and 07R/25L. The coordinates of its reference point are as follows: 41º17'49" N, 002º04'42" E.

At the time of the accident, the daytime non-preferred configuration was being used, i.e. the Easterly configuration, with parallel runways. Consequently, flights were landing on runway 07L.

1.11. Flight recorders

This section presents all of the information taken from the flight recorders (CVR and QAR), along with the information from the air traffic services, from the moment when the aircraft began its descent from its cruising altitude of FL380 to the moment when it landed.

1.11.1 Descent

At 13:50:47 h, when the aircraft was flying at FL380, the flight crew asked ATC for authorisation to begin the descent. ATC delayed the aircraft's descent for the next two minutes before finally authorising it to descend to FL330. This was then selected by the flight crew using the MCP altitude selector. With the autopilot and autothrottle engaged, the flight crew carried out the descent in ARM/LNAV/MCP SPD modes[11].

Via the MCP speed selector, the pilots selected a speed of 240 kt/0.76 Mach, which they increased as the aircraft descended.

The flight crew commented on the impossibility of complying with the restriction on overflying the MATEX point at FL250 or lower, owing to the delayed authorisation of the descent.

The weather radar was being used.

At 13:53:51 h, the aircraft was authorised to descend to FL310, which was then selected by the flight crew using the MCP altitude selector. The pilots continued to increase the aircraft's speed in order to increase the rate of descent.

[11] The AFDS flight mode indications are expressed as follows: AUTOTHROTTLE MODE/ LATERAL MODE/ VERTICAL MODE.

At 13:54:51 h the aircraft was authorised to descend to FL200, which was then selected by the flight crew using the MCP altitude selector. The speed selected had been increased to 270 kt, while the CAS was 268 kt. The tailwind component was 70 kt.

At 13:56:00 h, the aircraft overflew the MATEX point while descending through FL310.

At 13:57:10 h, the flight crew requested a heading of 065° to avoid a cloud formation. The request was approved by ATC.

At 13:58:03 h, the captain called the cabin crew to inform them that they may experience turbulence during the approach and that they should begin to prepare the cabin for landing.

At 13:58:54 h, while descending through FL220, the aircraft was authorised to descend to FL150, which was then selected by the flight crew using the MCP altitude selector. The speed selected had been increased to 320 kt, while the CAS was 317 kt.

At 13:59:18 h, the aircraft was authorised to proceed to ASTEK if flight conditions permitted. This was accepted by the flight crew. The aircraft was 64 NM from the touchdown zone.

At 13:59:24 h, deployment of the speed brakes commenced, during the descent through FL200. The tailwind component was 58 kt.

At 13:59:33 h, the aircraft was authorised to descend to FL80, which was then selected by the flight crew using the MCP altitude selector.

1.11.2 Flight through the area of turbulence

At 14:00:07 h, while descending through FL180, the aircraft entered an area of turbulence that lasted for approximately two minutes, until 14:02:24 h. During this period, the speed selected was 320 kt, while the CAS was 325 kt.

<u>From the start of the turbulence to the disengagement of the autopilot</u>

Over the next 29 seconds the speed selected was reduced to 308 kt. During this period, the aircraft's CAS ranged from 306 kt to 329 kt. Fluctuations in vertical acceleration of between +0.50 g and +1.36 g were recorded, with changes that, on occasion, reached up to 0.7 g within the space of one second.

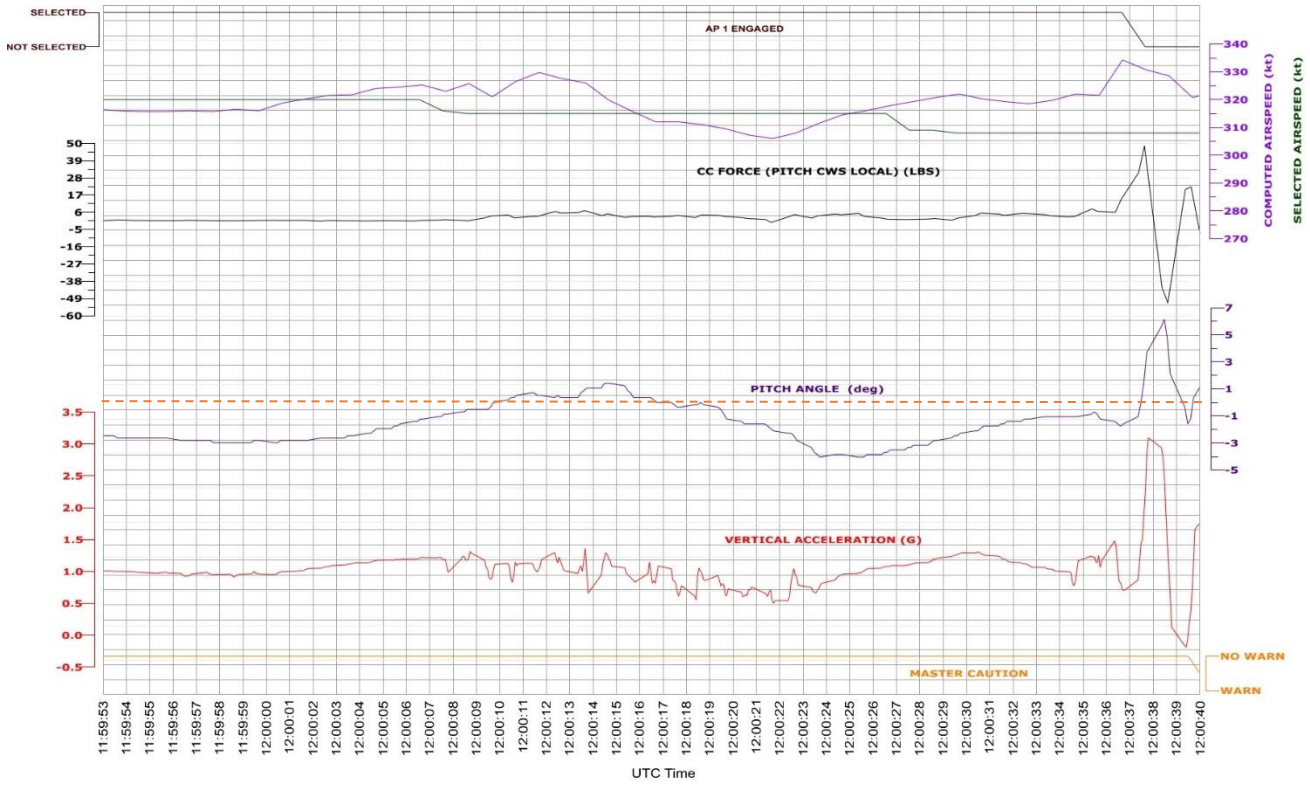


Image 6: Flight parameters from the start of the turbulence to the disengagement of the autopilot

At 14:00:36 h, while descending through FL170, the CAS was 322 kt and the speed selected was 308 kt.

One second later, at 14:00:37 h, the CAS increased to 334 kt. The pitch angle was -1.8º.

Interval in which the autopilot was disengaged

At 14:00:38 h, the disengagement of the autopilot was recorded. The force on the control column increased to +48 lb. Vertical acceleration increased to +3.09 g: the highest amount recorded during this period.

One second later, at 14:00:39 h, the pitch angle was +6.2º, the force on the control column was -51 lb, and the CAS was 328 kt. Vertical acceleration decreased to -0.18 g: the lowest amount recorded during this period.

At 14:00:41 h, the Master Caution light was activated.

For the next 21 seconds, the aircraft remained practically level at FL170 and the force exerted on the control column varied between +32 lb and -36 lb.

Positive pitch angles were recorded, while the CAS began to fall. At 14:01:00 h, the CAS was 283 kt and the aircraft resumed its descent.

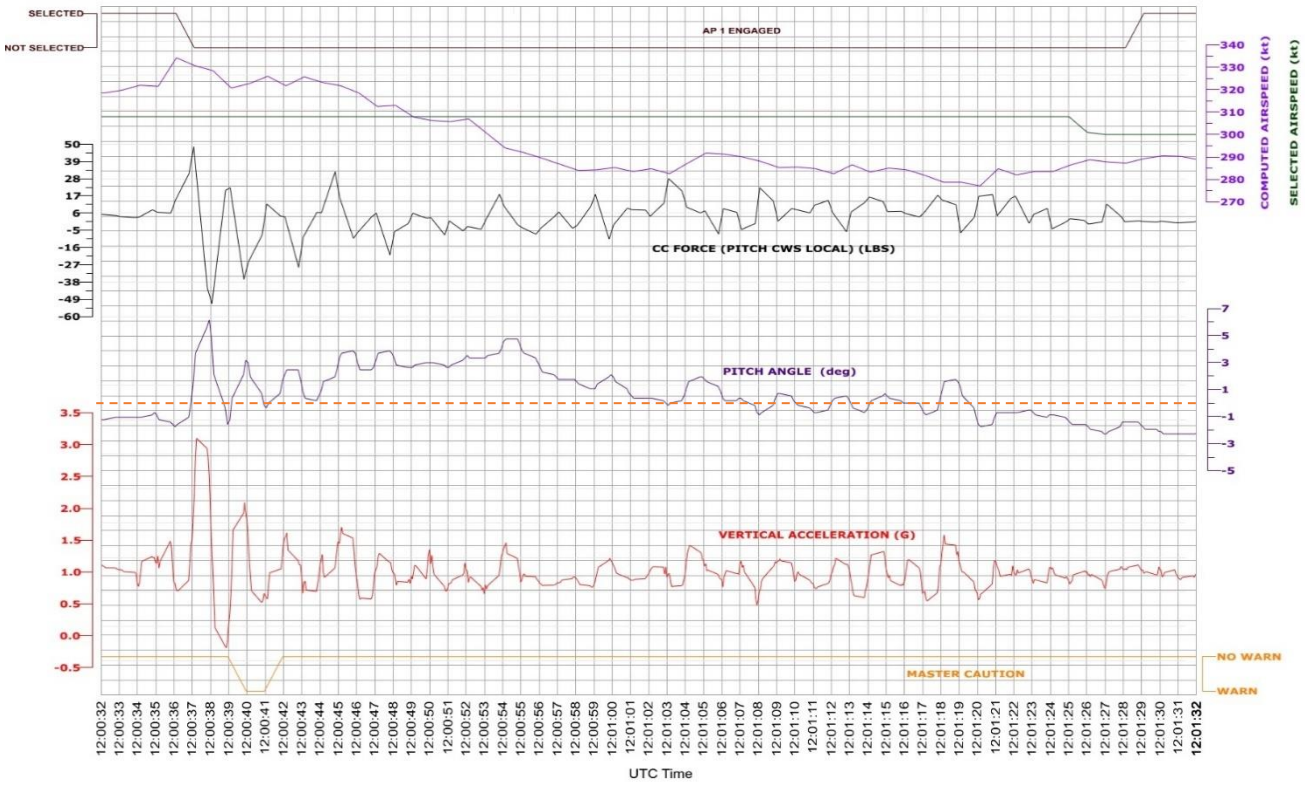


Image 7: Flight parameters for the interval in which the autopilot was disengaged

The captain stated that he did not want to exceed the V_{MO} and that he was going to temporarily disengage the autopilot.

<u>From the re-engagement of the autopilot to the aircraft's exit from the area of turbulence</u>

At 14:01:30 h, while descending through 15,900 ft, the autopilot was re-engaged.

During this period, vertical acceleration reached a maximum of +1.31 g and a minimum of + 0.68 g, with changes that, on occasion, reached 0.4 g within the space of one second.

At 14:02:24 h, the aircraft exited the area of turbulence.

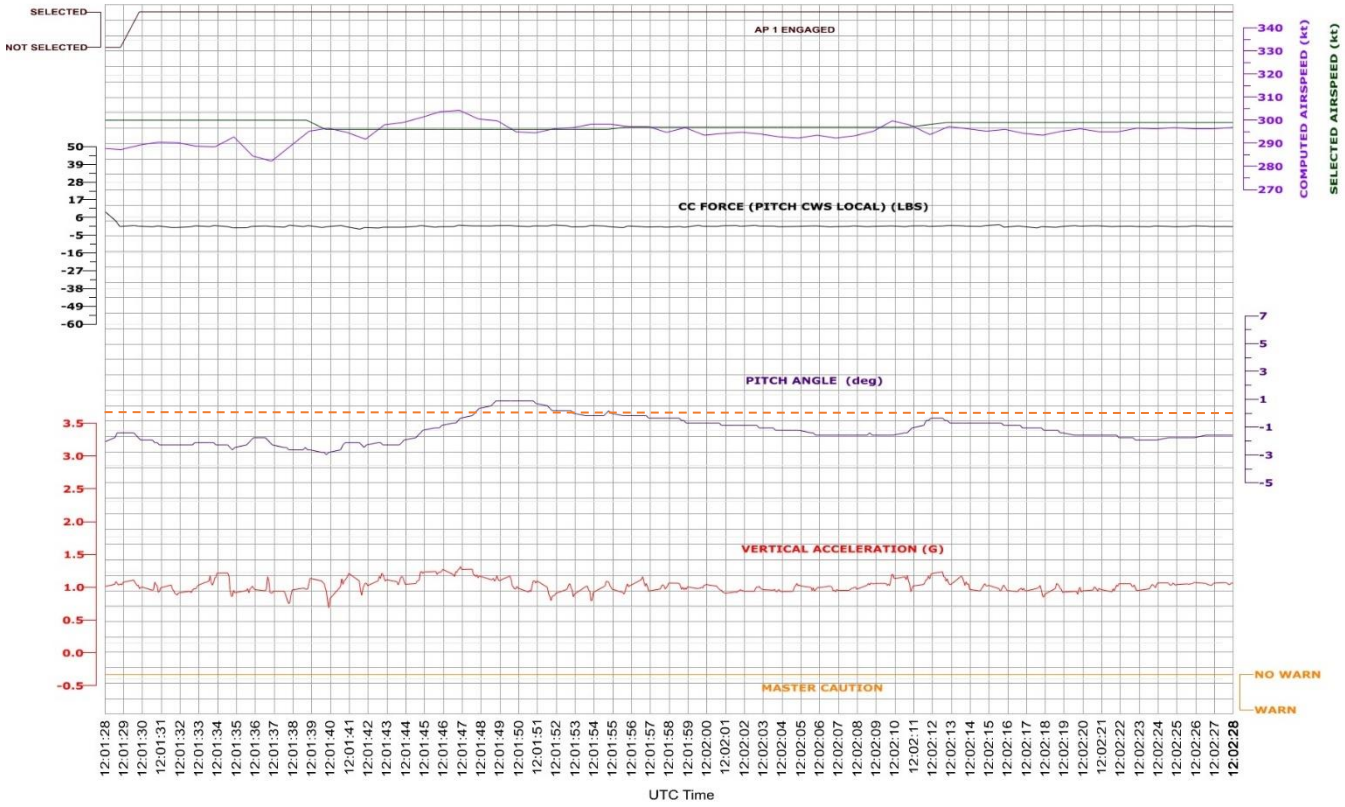


Image 8: Flight parameters for the period from the re-engagement of the autopilot to the aircraft's exit from the area of turbulence

1.11.3 Approach and landing

At 14:03:53 h, the aircraft was authorised to descend to 3,000 ft and to ILS Z for runway 07L at Barcelona Airport. ATC informed the flight crew that it was number 1 and that it could maintain 250 kt until ASTEK.

At 14:04:21 h, TCP (cabin crew member) 2 called the cockpit and informed the flight crew that TCPs 1 and 4 had suffered injuries and would require an ambulance upon arrival at the airport. At 14:04:53 h, the flight crew contacted ATC to request an ambulance upon arrival at Barcelona.

Throughout the rest of the flight, the cabin crew updated the pilots with regard to the condition of the injured cabin crew members. In turn, the pilots passed this information on to ATC.

The aircraft landed on runway 07L at 14:12:01 h.

1.12. Aircraft wreckage and impact information

N/A.

1.13. Medical and pathological information

We have found no evidence to suggest that the actions of the cabin crew or flight crew were affected by any physiological or disabling factors.

1.14. Fire

There were no signs of fire during the flight or after the impact.

1.15. Survival aspects

The cabin crew was comprised of four crew members. According to their statements, 20 or 30 minutes before landing the captain called them and asked them to proceed to secure the cabin[12]. He also mentioned that there might be turbulence during the approach, although he did not specify how intense it would be.

The captain's call was taken in the rear galley by TCP 2, who passed the information on to TCPs 1 and 3, who were also in the rear galley.

They had just started to secure the cabin. TCP 1 was in the process of making a passenger announcement (in English) warning the passengers of turbulence; however, he/she had to interrupt the announcement when the aircraft experienced - as the cabin crew described it - severe turbulence, which affected the crew members in various ways.

- TCP 1 was standing up in the rear galley, issuing the passenger warning. His/her head hit the ceiling of the aircraft and he/she fell to the floor, between door L2[13] and the left-hand jump seat. During the fall, he/she also hit the door. TCP 1 was left unable to breathe and with severe pain in his/her back. TCP 2 moved him/her to the outer left-hand jump seat; however, he/she was unable to sit down correctly as he/she had suffered a spinal fracture. TCP 1 remained in the same position for the remainder of the flight.

- TCP 2 was also standing up in the rear galley. Although he/she cannot recall it happening, he/she believes he/she must have been thrown against the door or the galley. TCP 2 then managed to sit on the outer right-hand jump seat, although he/she was unable to fasten the harness. TCP 2 suffered bruising and other lesions. Subsequently, he/she was able to assist TCP 1 and move him/her from the floor to the outer left-hand jump seat. TCP 2 remained seated with the senior flight attendant.

- TCP 3, who was also standing up in the rear galley, was thrown against the equipment above the right-hand jump seat, and then against the galley. TCP 3 suffered bruising and other lesions. TCP 3 sat down in the inner right-hand jump

[12] According to the operator, the normal procedure for securing the cabin begins 15 minutes before landing.

[13] Door L2 is the rear left door of the aircraft.

seat and fastened the harness. TCP 3 also had to take care of his/her colleagues, TCPs 1 and 4, who were unable to perform their functions.

- TCP 4 was at row 29, attending to a passenger request, when he/she fell down and was thrown against the toilet door. With the help of TCP 3 he/she was able to sit in the outer right-hand jump seat and fasten the harness. TCP 4 remained there for the rest of the flight.

The following diagram shows the position of each cabin crew member, marked with a light grey circle. The position of the passenger who suffered serious injuries is marked with a purple circle.

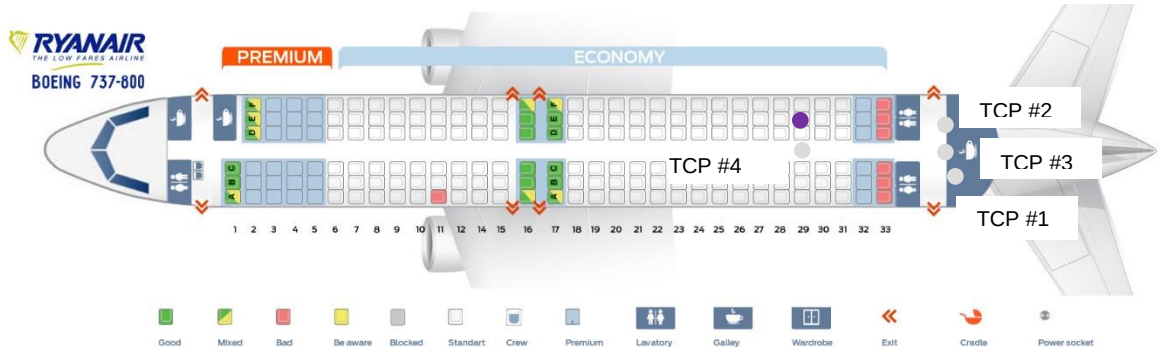


Image 9: Diagram showing the position of the cabin crew members and the passenger who was injured during the event

When the event occurred, all of the passengers were seated. The injured passenger was sitting in seat 29 E. When the aircraft landed, the cabin crew advised that the passenger had been injured.

As TCPs 1 and 4 were incapacitated, TCP 2 assumed the role of senior flight attendant. TCP 2 called the captain to request an ambulance and informed him that two cabin crew members were injured. The ambulance was waiting for them when the aircraft landed. The medical team entered the aircraft in order to attend to the crew and passenger, who were subsequently taken to hospital in the ambulance.

1.16. Tests and research

N/A

1.17. Organisational and management information

N/A.

1.18. Additional information

1.18.1. Meteorological information supplied to the crew during flight preparation

The meteorological information supplied to the flight crew during flight preparation was similar to that detailed in section 1.7.1 of this report. The captain explained that he based the likelihood of encountering turbulence during the approach on the forecasts warning of storms in the area and in the vicinity of Barcelona Airport.

Additionally, the operational flight plan between Fez and Barcelona airports indicated wind shear of between 3 and 4 units at the STAR points. The operator explained that wind shear of 3 units or above indicates a likelihood of moderate turbulence.

1.18.2. Boeing's turbulence and overspeed procedures.

The 737 Flight Crew Operations Manual (FCOM) drawn up by Boeing sets out the procedure for operating the aircraft in the event that turbulence is encountered while flying. Annex I of this report includes an excerpt from this document.

The FCOM explains that in the event of light or moderate turbulence, the autopilot and/or the autothrottle may remain engaged, unless their performance is unsatisfactory. There may be temporary speed variations of between 10 and 15 kt

In the event of severe turbulence, the FCOM states that the use of autopilot is optional and recommends adjusting the aircraft's speed to 0.76 Mach or 280 kt and maintaining its attitude with the wings level, thereby permitting variations in altitude. It warns that the control systems should not be subjected to sudden large inputs.

The 737 Flight Crew Training Manual (FCTM) drawn up by Boeing sets out the procedure for operating the aircraft in the event of overspeed. Annex II of this report includes an excerpt from this document.

The FCTM for the 737 NG/MAX recommends that in the event of unexpected overspeed, the flight crew should keep the autopilot engaged, unless it is clear that the autopilot is not correcting the overspeed event.

The FCTM also warns that disengaging the autopilot to prevent or reduce the severity of an accidental overspeed event can result in abrupt changes to the pitch angle.

1.18.3. Ryanair Operations Manual: Turbulence Procedure.

Section 8.3.8.3 of Ryanair Operations Manual Part A, which addresses the subject of turbulence, states the following:

Flights shall not be planned through areas with severe turbulence. *The procedures are included in FCOM Volume 1 and in the SEP.*

ATC must be notified of severe turbulence. Additionally, an ASR must be filled out and a note made in the aircraft's technical logbook.

1.18.4 Coordination procedures in the event of turbulence

The operator's Operations Manual Part A describes the procedures for coordination between the flight crew and cabin crew when turbulence is expected during the flight. It also explains how to act in the event of unexpected turbulence.

If the flight crew anticipates the possibility of passing through areas of turbulence during the flight, it must inform the cabin crew accordingly. Although the procedure does not include a standard message for communicating this information, it does stipulate that the following terms be used when communicating the level of turbulence: LIGHT, MODERATE and SEVERE, when referring to said turbulence. Each of these levels is associated with a series of actions to be carried out by the cabin crew, ranging from continuing their activities with caution, to ceasing their activities immediately.

The operator's procedures state that if the information provided during flight preparation predicts that the aircraft will be flying through areas of turbulence, this information must be communicated to the cabin crew before the flight begins. Once in the air, the flight crew must communicate with the cabin crew in order to inform them of the possibility of passing through an area of turbulence. The flight crew will also activate the fasten-seatbelt sign.

The procedure specifies that the cabin crew should not wait to receive a warning from the flight crew in order to cease their activities, in the event that the level of turbulence is such that they need to cease their activities and sit down. In particular, the procedure specifies that in the event of suddenly and unexpectedly encountering moderate or severe turbulence, the senior flight attendant must instruct the rest of the TCPs to go to their seats and issue a passenger warning instructing passengers to remain seated and fasten their seatbelts.

In the event of severe turbulence, the cabin crew must sit down in the nearest available seat, even if it is a seat intended for passengers.

1.18.5 Actions taken by the operator after the event

After the event, the operator carried out an internal safety investigation, the outcome of which was the provision of additional simulator and line training for the flight crew on the subjects of overspeed and flying through turbulence.

It also considered[14] the following measures:

- A debriefing on the event for the cabin crew.
- Inclusion of the event as a case study in the CRM training activities.

[14] As of the date of publication of this report, Ryanair has confirmed to the investigation that two of the three measures have been implemented.

- Inclusion of the event in the operator's publications promoting operational safety.

1.19. Special investigation techniques

N/A.

2. ANALYSIS

Several factors have been analysed in relation to this accident: those relating to the meteorological conditions during the flight and in the area where the accident occurred; the coordination between the flight crew and cabin crew; and the actions of the flight crew.

2.1 Analysis of the meteorological factors related to the accident.

Analysis of the meteorological information supplied to the flight crew

The meteorological forecasts supplied to the flight crew prior to beginning the flight predicted storms in both the Barcelona area and in the vicinity of the airport. Additionally, the operational flight plan between Fez and Barcelona airports indicated wind shear of between 3 and 4 units at the STAR points, which meant it was likely that the aircraft's descent and approach would take place within an area of turbulence.

The captain concurred with the assessment, and he informed the cabin crew accordingly.

Analysis of the meteorological conditions in the area of the accident

The flight crew were following the MATEX 2E STAR, and had the weather radar connected, when they detected a storm formation in the section between MATEX and BL028 points. In order to avoid entering the storm, they asked ATC to divert them 14º to the left. According to the captain, this gave them a sufficient margin of separation from the cloud. He also stated that they were in VMC and the air was stable.

There had been no reports of turbulence; however, requests for track deviations from aircraft to avoid storm clouds were heard on the frequency.

According to the flight crew, a few moments later the aircraft began to pass through an area of turbulence. The crew's statement concurs with the data obtained from the QAR, which show significant changes in vertical acceleration as well as variations in outside temperature and wind intensity, direction and speed. From the moment the aircraft entered the area of turbulence to the moment the autopilot was disengaged, the level of turbulence varied from light to moderate, with variations in vertical acceleration that, on occasion, reached 0.7 g within the space of one second. During this same period, the aircraft's speed underwent fluctuations that reached a maximum of 12 kt within the space of one second, moments before the disengagement of the autopilot.

With regard to the period after the disengagement of the autopilot, it has not been possible to determine the level of turbulence, as the actions applied to the control column contributed to the variations in vertical acceleration that occurred while the autopilot was disengaged. During this period, changes in vertical acceleration reaching 3.2 g were recorded within the space of one second, coinciding with changes to the pitch angle and the level of force exerted on the control column.

During the period after the autopilot was re-engaged, the level of turbulence was light, with variations in vertical acceleration that, on occasion, reached 0.4 g within the space of one second.

2.2 Analysis of the coordination between the flight crew and cabin crew regarding the turbulence.

During the pre-flight briefing, the flight crew informed the cabin crew of the likelihood of encountering turbulence during the descent into Barcelona. According to the statements of both the pilots and the cabin crew, the captain also informed the passengers of this likelihood in his passenger announcement.

Once the aircraft had begun to descend, and after deviating in order to avoid entering a storm cloud, the captain called the cabin crew to inform them that they might encounter turbulence during the approach and that they should start to secure the cabin. During this call, the captain did not specify the level of turbulence (light/moderate/severe), nor did he indicate how much time the cabin crew would have to secure the cabin.

At the time of the captain's call, the estimated remaining flight time was approximately 25 minutes. In other words, he asked the cabin crew to start preparing to secure the cabin earlier than usual (normally the request is made 15 minutes before landing), as he anticipated having to cross an area of cloud - whose associated turbulence might affect the passengers and cabin crew - during the approach. The message did not communicate a sense of urgency with regard to securing the cabin; however, the request to begin preparations was issued early, as a precaution, so that the cabin would be secure for the approach.

Barely two minutes after the captain called to inform the cabin crew of the likelihood of encountering turbulence during the approach, the aircraft entered an area of turbulence that had not been detected by the flight crew. According to the TCP, they were starting to secure the cabin when they were suddenly thrown against various parts of the galley and cabin, and then fell to the floor. From their perspective, it was a sudden encounter with severe turbulence in which they did not have enough time to sit down or even grab onto any elements within the cabin.

2.3 Analysis of the actions of the flight crew

Because ATC had delayed the aircraft's descent, the PF increased the speed selected in the MCP as the aircraft descended, to increase the rate of descent. Subsequently, the flight crew was authorised to proceed to ASTEK, which shortened the route to the touchdown area and kept the aircraft positioned above the descent profile. The tailwind component was 58 kt. The PF extended the speed brakes to continue increasing the rate of descent.

According to the pilots, they had managed to avoid the storm cloud and were under VMC.

Thus, the aircraft entered an area of undetected turbulence with its speed brakes extended and at a CAS of 325 kt.

The PF reduced the speed selected to 308 kt; however, the area of turbulence caused changes in the aircraft's calibrated speed, which fluctuated between 306 kt and 329 kt.

Some 30 seconds after entering the area of turbulence, the aircraft's speed suddenly increased from 322 kt to 334 kt. According to the PF, the speed trend vector was showing large oscillations and he saw that the autopilot was not correcting the changes in speed.

The PF disengaged the autopilot and pitched nose up, to reduce speed. During this manoeuvre, vertical acceleration of +3.09 g was reached. One second later, the pilot performed the opposite action, lowering the aircraft's nose. This resulted in vertical acceleration of -0.18 g, representing a change of 3.2 g within the space of one second.

Although the V_{MO} was not exceeded in this instance, the manufacturer recommends that in the event of unexpected overspeed, the flight crew should keep the autopilot engaged, unless it is clear that the autopilot is not correcting the overspeed event. It also warns that disengaging the autopilot to prevent or reduce the severity of an unexpected overspeed event can result in abrupt changes to the pitch angle.

The PF explained that, in his opinion, the turbulence had become severe. Under such conditions, the manufacturer recommends reducing speed to 280 kt. The aircraft reached speeds near to 280 kt during the period in which the autopilot was disengaged.

After carrying out an internal safety investigation into the accident, the operator reinforced the flight crew's training on the subject of turbulence and overspeed. Additionally, among other measures, it proposed to publish the lessons learnt from this event in its operational safety publications, and to include the event as a case study in its crew training activities. All of these measures are considered appropriate, and no safety recommendations are proposed.

3. CONCLUSIONS

3.1. Findings

- The pilots had been given training on the subject of overspeed and flying under turbulent conditions.
- After analysing the meteorological information for the flight, the captain informed the cabin crew of the likelihood of encountering turbulence during the descent into Barcelona.
- There were no reports of turbulence from other aircraft or ATC.
- The fasten-seatbelt sign remained switched on throughout the flight, in line with the operator's COVID procedures.
- The aircraft's crew visually observed certain cloud formations and performed a visual manoeuvre to avoid them.
- The captain warned the cabin crew of the possibility of turbulence during the approach and asked them to begin their preparations to secure the cabin.

- Two minutes after the captain spoke to the cabin crew, the aircraft entered an area of undetected turbulence.
- The aircraft's speed suddenly increased to 334 kt, although it did not exceed the V_{MO} (340 kt).
- In order to avoid exceeding the V_{MO}, the PF disengaged the autopilot and pulled on the control column, lifting the aircraft's nose. He then moved the control column in the opposite direction, i.e., pushing it, which brought the aircraft's nose down.
- During this manoeuvre to avoid exceeding the V_{MO}, vertical acceleration reached +3.09 g, and one second later fell to -0.18 g.
- The cabin crew, who prior to that moment had been standing up, fell to the floor. Two of them were incapacitated for the remainder of the flight.
- When the aircraft landed, the crew advised that a passenger had been injured and had suffered wounds to his head.
- The aircraft involved in the accident did not report any turbulence to ATC. Commission Implementing Regulation (EU) 923/2012 of 26 September 2012 and the Air Traffic Regulation stipulate that moderate or severe turbulence must be reported by means of a special air report.

3.2. Causes/contributing factors

The investigation has concluded that the probable cause of the accident was the series of actions taken by the PF to prevent the aircraft from exceeding the V_{MO} while it was flying through an area of turbulence. This resulted in vertical acceleration that caused severe injuries to a passenger and two cabin crew members.

4. OPERATIONAL SAFETY RECOMMENDATIONS

The measures proposed by the operator are considered appropriate, and no operational safety recommendations are proposed.

ANNEX I: 737 FLIGHT CREW OPERATIONS MANUAL. TURBULENCE

Additional procedures for securing the airplane during sandy or dusty conditions may be needed. These procedures are normally done by maintenance personnel, and include, but are not limited to:

- engine covers installed, if applicable.
- protective covers and plugs installed (streamers should be used to remind personnel to remove before flight).
- doors and sliding windows closed.
- all compartments closed.

Turbulence (RYR)

The maximum degree of turbulence encountered at the pilot's station during certification flight tests was evaluated as moderate.

Flight through severe turbulence should be avoided, if possible. When flying at 30,000 feet or higher, it is not advisable to avoid a turbulent area by climbing over it unless it is obvious that it can be overflown well in the clear. For turbulence of the same intensity, greater buffet margins are achieved by flying the recommended speeds at reduced altitudes.

Light and Moderate Turbulence:

During flight in light to moderate turbulence, the autopilot and/or autothrottle may remain engage unless performance is unsatisfactory. Increased thrust lever activity can be expected when encountering wind, temperature changes and large pressure changes. Short-time airspeed excursions of 10 to 15 knots can be expected.

Passenger signs ..... ON

FMC N1 LIMIT page ..... Verify/Select CON

Advise passengers to fasten their seat belts prior to entering areas of reported or anticipated turbulence. Instruct the flight attendants to check that all passengers' seat belts are fastened.

Severe Turbulence:

Selection of the autopilot Control Wheel Steering (CWS) is recommended for operation in severe turbulence. Do not use Altitude Hold (ALT HLD) mode.

The recommended procedures for flight in severe turbulence are:

- Airspeed - Target airspeed should be approximately 280 KIAS or 0.76 MACH, whichever is lower during climb or descent. If below 15,000 feet and the airplane gross weight is less than the maximum landing weight, the airplane may be slowed to 250 knots in the clean configuration during the descent. If in cruise, set turbulence penetration N1 as highlighted by TURB N1 on the Cruise page. Severe turbulence will cause large and often rapid variations in indicated airspeed. DO NOT CHASE THE AIRSPEED
- FMC N1 LIMIT page - Verify/Select CON
- Yaw Damper - Engaged
- Autopilot - Optional - If the autopilot is engaged, use CWS position, do not use ALT HLD mode
- Autothrottle - Disengage
- Attitude - Maintain wings level and the desired pitch attitude. Use the attitude indicator as the primary instrument. In extreme drafts, large attitude changes may occur. DO NOT USE SUDDEN LARGE CONTROL INPUTS. After establishing the trim setting for penetration speed, DO NOT CHANGE STABILZER TRIM
- Altitude - Allow the altitude to vary. Large altitude variations are possible in sever turbulence. Sacrifice altitude in order to maintain the desired attitude and airspeed. DO NOT CHASE THE ALTITUDE
- Thrust - Engine ignition should be on. Position the ENGINE START switches to FLT. Make an initial thrust setting for the target airspeed. CHANGE THRUST ONLY IN CASE OF EXTREME AIRSPEED VARIATION. The FMC cruise page displays N1 target value for turbulence.

PHASE OF FLIGHT	AIRSPEED
CLIMB	280 knots or .76 Mach whichever is lower.
CRUISE	Use FMC recommended thrust settings. If the FMC is inoperative, refer to the Unreliable Airspeed page in the Performance–Inflight section of the QRH for approximate N1 settings that maintain near optimum penetration airspeed.
DESCENT	.76 Mach/280/250 knots whichever is lower.. If severe turbulence is encountered at altitudes below 15,000 feet and the airplane gross weight is less than the maximum landing weight, the airplane may be slowed to 250 knots in the clean configuration.

Note: If an approach must be made into an area of severe turbulence, delay flap extension as long as possible. The airplane can withstand higher gust loads in the clean configuration.

ANNEX II: 737 FLIGHT CREW TRAINING MANUAL. OVERSPEED

Overspeed

VMO/MMO is the airplane maximum certified operating speed and should not be exceeded intentionally. However, crews can occasionally experience an inadvertent overspeed. Airplanes have been flight tested beyond VMO/MMO to ensure smooth pilot inputs will return the airplane safely to the normal flight envelope.

At high altitude, wind speed or direction changes may lead to overspeed events. Although autothrottle logic provides for more aggressive control of speed as the airplane approaches VMO or MMO, there are some conditions that are beyond the capability of the autothrottle system to prevent short term overspeeds.

When correcting an overspeed during cruise at high altitude, avoid reducing thrust to idle which results in slow engine acceleration back to cruise thrust and may result in over-controlling the airspeed or a loss of altitude. If autothrottle corrections are not satisfactory, leave the autopilot engaged, deploy partial speedbrakes slowly until a noticeable reduction in airspeed is achieved. When the airspeed is below VMO/MMO, retract the speedbrakes at the same rate as they were deployed. The thrust levers can be expected to advance slowly to achieve cruise airspeed; if not, they should be pushed up more rapidly.

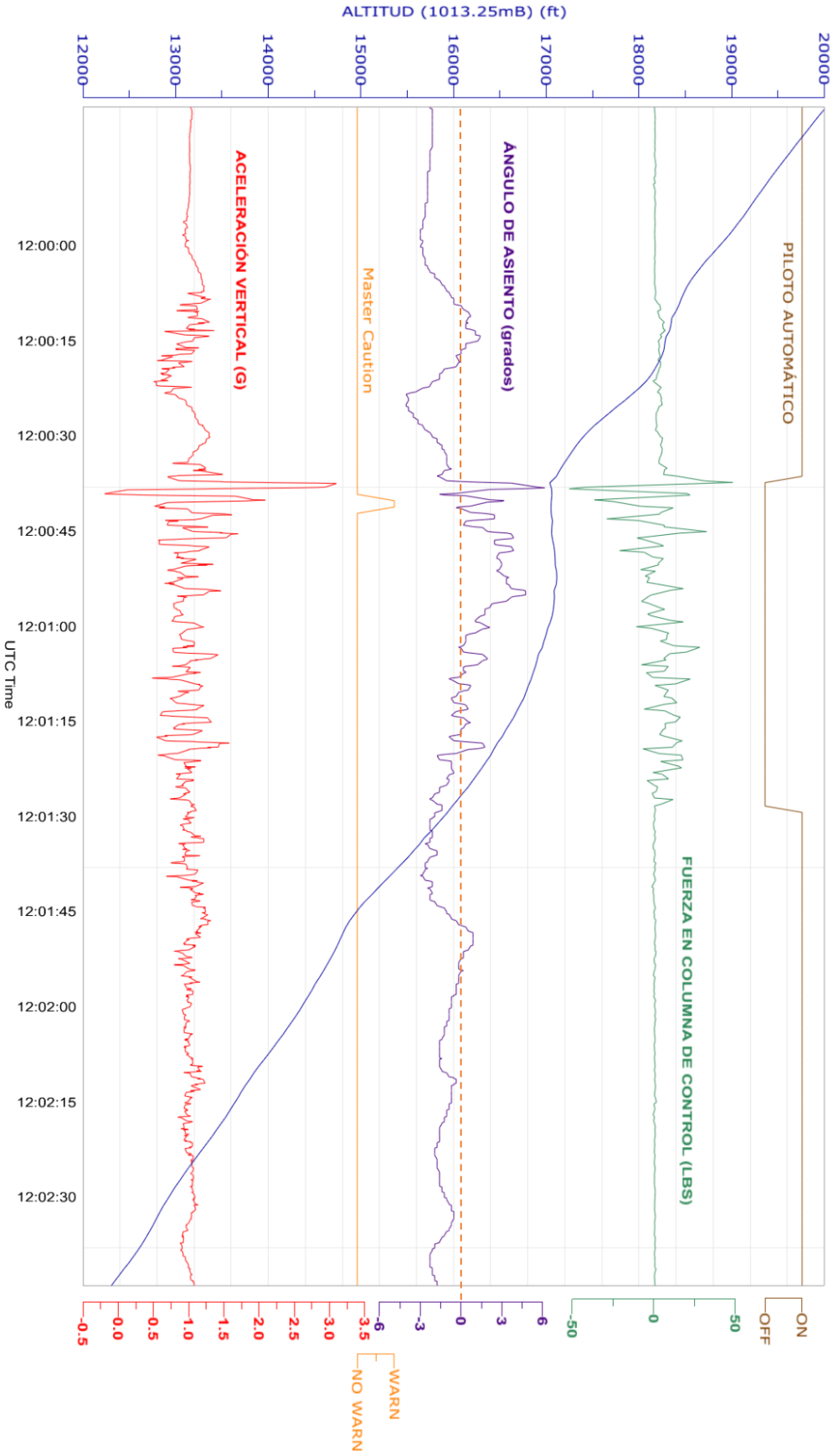
During descents at or near VMO/MMO, most overspeeds are encountered after the autopilot initiates capture of the VNAV path from above or during a level-off when the speedbrakes were required to maintain the path. In these cases, if the speedbrakes are retracted during the level-off, the airplane can momentarily overspeed. During descents using speedbrakes near VMO/MMO, delay retraction of the speedbrakes until after VNAV path or altitude capture is complete. Crews routinely climbing or descending in windshear conditions may wish to consider a 5 to 10 knot reduction in climb or descent speeds to reduce overspeed occurrences. This will have a minimal effect on fuel consumption and total trip time.

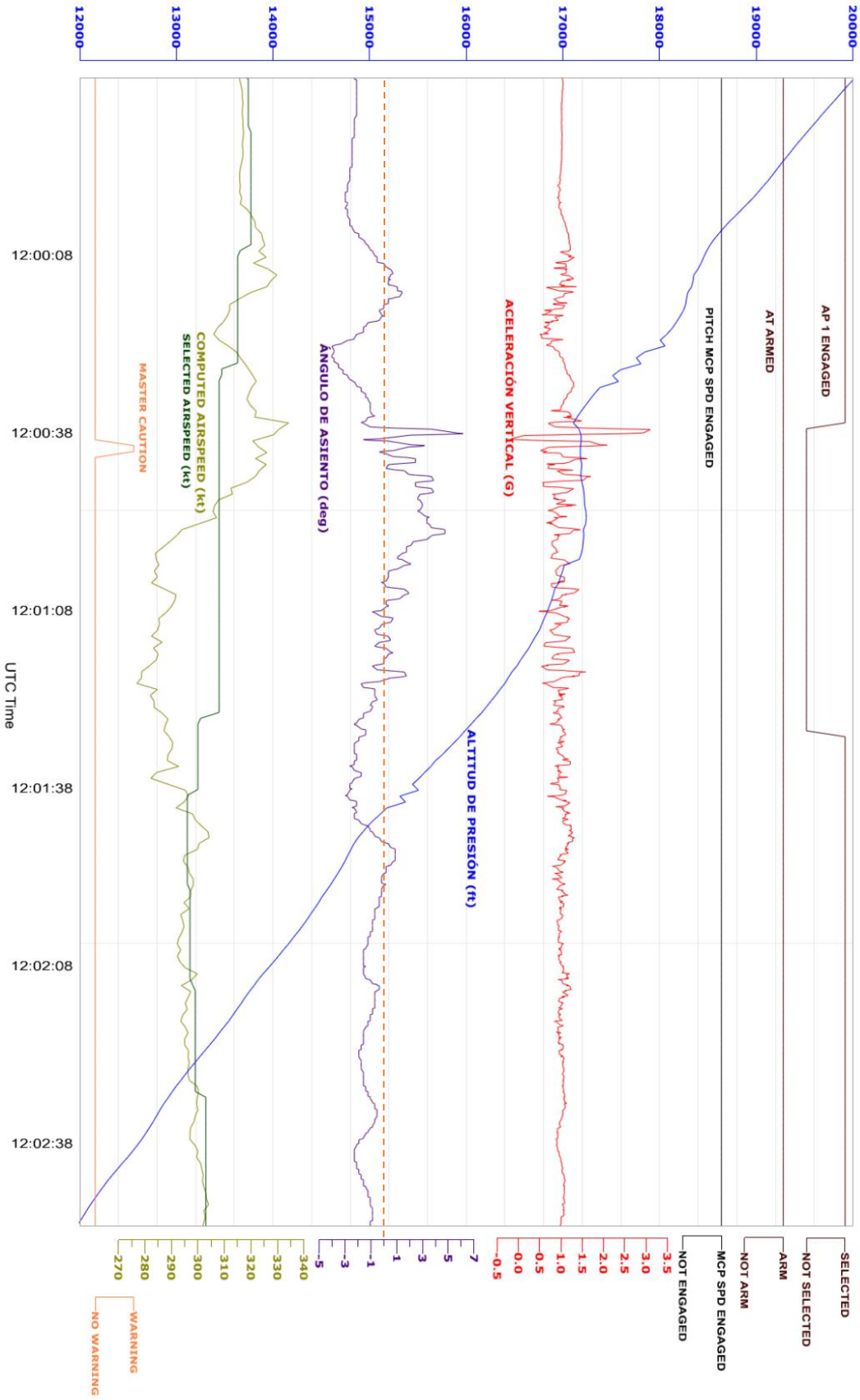
When encountering an inadvertent overspeed condition, crews should leave the autopilot engaged and use the speedbrakes as needed unless it is apparent that the autopilot is not correcting the overspeed. However, if manual inputs are required, disengage the autopilot. Be aware that disengaging the autopilot to avoid or reduce the severity of an inadvertent overspeed may result in an abrupt pitch change.

During climb or descent, if VNAV or LVL CHG pitch control is not correcting the overspeed satisfactorily, switching to the V/S mode temporarily may be helpful in controlling speed. In the V/S mode, the selected vertical speed can be adjusted slightly to increase the pitch attitude to help correct the overspeed. As soon as the speed is below VMO/MMO, VNAV or LVL CHG may be re-selected.

Note: Anytime VMO/MMO is exceeded, the maximum airspeed should be noted in the flight log.

ANNEX III: FLIGHT DATA

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19000
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12:01:38
12:02:08
12:02:38
UTC Time
AP 1 ENGAGED
AT ARMED
PITCH MCP SPD ENGAGED
ACELERACIÓN VERTICAL (G)
ÁNGULO DE ASIENTO (deg)
ALTITUD DE PRESIÓN (ft)
COMPUTED AIRSPEED (kt)
SELECTED AIRSPEED (kt)
MASTER CAUTION
SELECTED
NOT SELECTED
ARM
NOT ARM
MCP SPD ENGAGED
NOT ENGAGED
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
7
5
3
1
-1
-3
-5
340
330
320
310
300
290
280
270
WARNING
NO WARNING