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Report IN-036/2012

Incident involving a Boeing 737-800, registration EI-EKV, operated by Ryanair, climbing from Madrid airport (Spain), on 7 September 2012

GOBIERNO DE ESPAÑA
MINISTERIO DE FOMENTO

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COMISIÓN DE INVESTIGACIÓN DE ACCIDENTES E INCIDENTES DE AVIACIÓN CIVIL

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Foreword

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 object of the investigation, and its probable 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 5.5 of Regulation (UE) n.º 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, 4 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.

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Abbreviations

00º	Degree(s)
A/P	Autopilot
AMC	Airport Management Center
ATC	Air traffic control
ATPL(A)	Air transport pilot licence (airplane)
BITE	Built-In Test Equipment
CAVOK	Ceiling and visibility OK
CIMA	Centro de Instrucción de Medicina Aeroespacial (Aerospace Medicine Teaching Center)
CO	Carbon monoxide
CPC	Cabin pressure controller
CPL(A)	Comercial pilot license (airplane)
CVR	Cockpit voice recorder
EASA	European Aviation Safety Agency
F/O	First officer
FA	Flight Attendant
FDR	Flight data recorder
FL	Flight level
FMS	Flight Management System
fpm	Feet per minute
ft	Foot
h	Hour(s)
Hz	Hertz(s)
ILS	Instrument landing system
ISO	International Standard Organization
LEMD	ICAO code for Madrid-Barajas airport (ESP)
km	Kilometre(s)
kt	Knot(s)
m	Meter(s)
m/s	Meter(s) per second
MHz	Megahertz(s)
METAR	Airport routine weather report
MSDV	Motion sickness dosage value
NGS	Nitrogen Generator System
NITS	Nature, intentions, time, specific
NM	Nautical miles
P/N	Part number
PIOSEE	Problems, Information, Options, Select, Execute, Evaluate
psi	Pounds per square inch
QAR	Quick access recorder
QRH	Quick reference handbook
RFFS	Rescue & Firefighting Service
RVSM	Reduced vertical separation minima
S/N	Serial number
slfpm	Sea level feet per minute

Synopsis

Owner and operator:	Ryanair
Aircraft:	Boeing 737-800, registration EI-EKV
Date and time of incident:	Friday, 7 September 2012; 7:43 local time[1]
Site of incident:	Climbing to FL220 from Madrid-Barajas (LEMD)
Persons onboard:	6 crew, uninjured; 160 passengers, uninjured
Type of flight:	Commercial air transport – Scheduled – Domestic – Passenger
Phase of flight:	En route-climbing to cruising altitude
Date of approval:	24 June 2015

Summary of incident

On Friday, 7 September 2012, aircraft EI-EKV, a Boeing 737-800 operated by Ryanair en route to Las Palmas de Gran Canaria (Spain) with 166 persons onboard, made an emergency return to the Madrid-Barajas Airport (Spain), from which it had taken off, due to what the crew identified as a pressurization problem.

At 07:43 local time, climbing to FL220, without any contact between the cabin and cockpit, the purser contacted the cockpit and informed the captain that the cabin crew were feeling unwell. This confirmed his own feeling of being unwell. After the purser's call, the captain decided to declare an emergency, stop the climb, start the CABIN ALTITUDE WARNING procedure, although no such warning was received, and return to the Madrid-Barajas Airport. As a consequence of the CABIN ALTITUDE WARNING procedure the outflow valve kept closed until the end of the flight, causing the subsequent overpressurization and depressurization of the cabin.

The investigation determined that the pressurization system on aircraft EI-EKV worked correctly during the incident flight. At the time of the incident, the cabin altitude was 3,774 ft.

The investigation could not determine the cause of the symptoms reported by several members of the crew. The hypotheses considered to possibly explain said symptoms were hypoxia by poisoning, motion sickness, suggestion among members of the crew or a combination of the last two.

[1] All times in this report are local.

The following factors contributed to the incident and to the handling of the emergency:

- the crew's suspicion that the aircraft was malfunctioning, as evidenced by the constant problems since taking off, specifically the operation of the CABIN ALTITUDE WARNING, which had not worked prior to the flight, and
- the possible confusion in executing the CABIN ALTITUDE WARNING or Rapid Depressurization checklist due to:

  – including an option between two choices as part of memory item 5,
  – having a second option (item 6) on a different page, and
  – completing the checklist and redirecting to another as part of the memory items.

No safety recommendations are issued.

1. FACTUAL INFORMATION

1.1. History of the flight

On Friday, 7 September 2012, aircraft EI-EKV, a Boeing 737-800 operated by Ryanair en route to Las Palmas de Gran Canaria (Spain) with 166 persons onboard, made an emergency return to the Madrid-Barajas Airport (Spain), from which it had taken off, due to what the crew identified as a pressurization problem.

The aircraft had landed at the Madrid-Barajas Airport the day before at 22:37 inbound from Stansted (United Kingdom). Upon arriving, the captain commented to the maintenance shift leader that the aircraft had made a strange movement during the flight, that he had disengaged the autopilot and that, after engaging it again, the problem had not reappeared.

As a result of this comment, the shift leader[2] carried out the Land Verify Test, one of the checks of the digital flight control system[3]. The performance of this test left the aircraft with a circuit breaker (LANDING GEAR AURAL WARNING CIRCUIT BREAKER) and a switch (AUTOPILOT STAB TRIM SWITCH) in incorrect positions. Another mechanic then did the RAMP 1[4] inspection on the aircraft and the passenger cabin was cleaned. These activities were carried out that same night, at about 23:00 on 6 September 2012, after which the aircraft was closed up.

At 06:41 on 7 September 2012, the CVR recording of the incident was started. In the first conversations the captain can be heard asking a mechanic to change the weight[5] and to solve a problem with the TAKEOFF WARNING SYSTEM. Two minutes later, at 06:43, the passengers are heard boarding. The mechanic arrived at 07:07, who a minute later received a call from the dayshift leader. In this call he explained he was on the airplane changing the weight, but that the airplane also had a problem because when they advanced the throttle levers, the TAKEOFF CONFIG warning lit up, and he did not know why and to go help him[6].

At 07:13 the dayshift leader arrived and noticed the tripped circuit breaker (LANDING GEAR AURAL WARNING CIRCUIT BREAKER), which he reset. After this, the crew did the test of the TAKEOFF WARNING SYSTEM, which was satisfactory. The shift leader then left and the crew continued with the flight preparations.

At 07:17 the FDR (flight data recorder) began recording. At 07:17:45 and 07:18:34 engines number 2 and 1 were started, respectively. At 07:31:27 they were cleared to take off from runway 36L. The cabin pressure was 13.8 psi, equivalent[7] to 1,731 ft, the elevation of Madrid-Barajas.

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[2] EASA B1 License.
[3] This test was not logged in the aircraft's documentation. It was recorded on the CVR (cockpit voice recorder).
[4] Maintenance inspection done at a frequency not to exceed 48 h. See Section 1.3.1 and note 17.
[5] See note 22.
[6] Only B1 or B2 engineers are authorised to troubleshoot defects on Take Off Config Warning system.
[7] Equivalence in standard atmospheres.

The captain was the pilot flying. The takeoff took place at 07:32:37. At 07:33:16 the SPEED TRIM FAIL[8] caution light illuminated and the MASTER CAUTION[9] activated for eight seconds until the crew deactivated it.

At 07:34:30 the MASTER CAUTION again activated for five seconds. The crew commented that it was the same, and that the trim was wrong. Three minutes later they were cleared to FL240, and the MASTER CAUTION again activated for one second. At 07:38:34 they started the SPEED TRIM FAIL checklist, which instructed them to resume normal operations[10].

At 07:38:40, with the aircraft at 15,229 ft, the captain asked for the autopilot to be engaged, and the first officer informed him that it would not engage. They started the AUTOPILOT DISENGAGE checklist, which instructed them to try again or fly manually[11]. The first officer took control of the aircraft and for the following two minutes no conversations were heard in the cockpit since the captain, according to his statement, stood up to check the breaker panel for the autopilot system to try to solve the problem. At 07:42:39 the captain answered a call from the purser, who informed him that he was not feeling well, that he felt strange and to ask if the pressurization was normal.

The conversation with the purser lasted 21 seconds and at 07:43:04, the captain was heard telling the first officer to "Stop the altitude", which the first officer repeated. The captain retook control of the aircraft and at 07:43:15, the captain declared an emergency, using the term "MAYDAY" three times and requesting to descend. The aircraft was reaching its maximum altitude, 21868 ft. From then on the crew began a constant descent to 4,200 ft, which they would reach 10 minutes later, at 07:53:03. The cabin pressure at the time they declared the emergency was 12.8 psi, equivalent to 3,774 ft.

At 07:43:20 the oxygen masks could be heard being switched on, after which the oxygen masks for the passengers dropped. After donning his mask, the captain repeated the emergency declaration and requested to descend to FL100. Following the emergency declaration, the crew combined the handling of the emergency with constant conversations with ATC to coordinate the descent, the return to Madrid and to execute the waiting maneuvers the crew repeatedly requested in order to configure the aircraft for landing.

At 07:43:59 the MASTER CAUTION again activated for 14 seconds.

[8] This caution is not recorded on the FDR. The information was obtained from the crew, which stated that this caution was intermittent throughout the flight. This caution is associated with the activation of the MASTER CAUTION.

[9] This warning was recorded on the FDR. It is a caution light that has no associated aural caution.

[10] Non-normal checklist SPEED TRIM FAIL: Condition: the speed trim system failed. 1 Continue normal operation.

[11] Non-normal checklist AUTOPILOT DISENGAGE. Condition: all autopilots are disengaged. The red light flashes and the aural tone sounds. 1 Fly the airplane manually or re-engage an autopilot.

At 07:44:16 the outflow valve[12] was commanded closed, as a result of a checklist action, and three seconds later, at 07:44:19, it was fully closed. The pressure in the cabin then started to rise until the completion of the flight.

At 07:44:56 the MASTER CAUTION again activated for four seconds.

At 07:49:23 the completion of the CABIN ALTITUDE WARNING checklist and the start of the EMERGENCY DESCENT checklist were heard. At 07:50:52 the captain suggested removing their oxygen masks as they were "below 10,000 ft" (the cabin pressure was 20.4 psi).

At 07:53:03 they completed the EMERGENCY DESCENT checklist. The captain passed control of the aircraft to the first officer and called the purser to hold the NITS[13] briefing with the cabin crew, whom he informed they were returning to Madrid. The captain made an announcement to the passengers. The aircraft was stable at 4,200 ft and 220 kt.

At 07:54:30 the MASTER CAUTION again activated for five seconds and the crew was heard commenting that it was the same fault.

At 07:56:05 the MASTER CAUTION again activated for 18 seconds.

At 07:57:50 the MASTER CAUTION activated for 68 seconds, during which the captain was preparing the approach to runway 33L, selecting the maneuver in the Flight Management System (FMS), the associated ILS frequency and holding the briefing for the go-around maneuver. The first officer continued as the pilot flying. The captain mentioned the MASTER CAUTION and related it to the oxygen for the passengers.

At 07:59:30 the MASTER CAUTION again activated for another 41 seconds.

At 08:00:30 the captain reminded the first officer that he would be taking control when they were established (on the ILS). At 08:01:10, 08:02:51 and 08:04:34 the MASTER CAUTION reactivated for five, five and three seconds, followed by the captain's comment that it was the same caution. At 08:04:14 the aircraft started its descent from the 4,200 ft where it had been for 11 minutes. He confirmed to ATC that they would not need assistance during the landing.

At 08:05:47 the captain confirmed capturing the localizer, and seven seconds later they were cleared to land on runway 33L. At 08:06:11 they captured the glide path and the captain took over the controls. They completed the landing checklist at 08:07:17, and 20 seconds later the MASTER CAUTION was again activated for another four seconds.

[12] See Section 1.3.6.

[13] NITS (nature, intentions, time, specifics). The cabin crew is told about the nature of the emergency, their destination, the estimated time and any special instructions involving the passenger cabin (planned evacuation, etc.).

At 08:08:37 the airplane landed on the runway. The outflow valve remained closed and there was a pressure of 22.36 psi in the cabin. The MASTER CAUTION activated for another three seconds. The captain informed ATC they were clear of the runway and the MASTER CAUTION activated for another two seconds. This was the last of the twenty MASTER CAUTION activations during the flight. The aircraft was taxiing toward parking stand 34 and the first officer, at the captain's request, called the company's Operations Department to report the emergency and to request a mechanic and stairs for the passengers.

At 08:14:11, still taxiing, the cabin pressure was 22.59 psi. The captain complained of an ear ache and two seconds later, at 08:14:29, the two air conditioning packs were turned off.

At 08:14:48 the outflow was opened very slowly. The cabin pressure started to go down and at 08:15:49, a sound was heard similar to that of a balloon deflating.

The aircraft stopped at 08:15:53 and at 08:16:09 the internal pressure in the aircraft equalized with the pressure outside. A minute later the front and rear left doors were opened.

The airport had activated the local alarm and when the aircraft landed, the rescue and firefighting service was waiting for the aircraft. There was no emergency evacuation and the passengers were disembarked normally. Of the 160 passengers, four were treated on the airplane by the airport's medical service and two were taken to the Ramón y Cajal Hospital, where they were released. They exhibited pathologies consistent with barotrauma of the middle ear and anxiety.

At no point in the flight did the crew report having noticed smoke, odors or irritated eyes or throat.

1.2. Personnel information

1.2.1. *Captain*

The captain, a 36-year old Belgian national, had an airline transport pilot license (ATPL(A))[14] and a medical certificate, both valid and in force at the time of the incident. He had ratings for the Boeing 737 series 300-900 and for instrument flight. Between 27 April and 10 May he had renewed his multi-pilot airplane type rating (including instrument rating), and had his line check and the simulator phase of the three-year recurrent training program.

He had been an airline pilot for eight years and had 5,111 total flight hours, 3,600 on type. He had started working for the operator five years earlier (1 May 2007). His base of operations was Bergamo (Italy). On 4 September, three days before the incident, the

[14] Issued by the aviation authority of Ireland.

captain had deadheaded to Madrid to work from there for a few days. He was staying at a hotel near the airport.

In the three months before the incident he had 355 duty hours (of which 259 had been flight hours) and 50 rest days. In those three months he had only flown to Madrid once, on 5 June 2012. He deadheaded to Madrid on the 4th and was staying at a hotel near the airport. From the 5th until the 7th (incident) he had the following activity:

Day	Origin*		Destination		Activity
5 Sep	Madrid	06:30	Stansted	08:58	Flight: 04:43 Active: 05:59
	Stansted	09:29	Madrid	11:44	
6 Sep	Madrid	06:25	Rome-Ciampino	08:47	Flight: 04:40 Active: 06:06
	Roma-Ciampino	09:28	Madrid	11:46	
7 Sep	Madrid	07:10	Gran Canaria		—

* The time zone used is local time for takeoff and landing.

The day before the incident he had been off almost the entire day (the last flight had landed at 11:46). He rode a stationary bike at the hotel. The captain stated he was well rested and had slept well. He had had breakfast at the hotel and had not had anything at the office or on the airplane.

On the day of the incident he was not in a hurry to start the operation and he confirmed he had had enough time to do all of the pre-flight activities. They only had two flights scheduled that day: Madrid-Gran Canaria (the incident flight) and Gran Canaria-Madrid.

1.2.2. *First officer*

The first officer was a 21-year old British national. He had had a commercial pilot license (CPL(A))[15] since April 2012 and a medical certificate, both valid and in force at the time of the incident. He was rated on the Boeing 737 series 300-900. In March 2012 he had obtained his multi-pilot airplane rating and in July 2012 he had completed the operator's line training.

He had been working for the operator for nine months (1 January 2012) and had a total of 542 flight hours, 345 on the type.

In the three months before the incident he had 305 duty hours (of which 240 had ben flight hours) and 51 rest days. He had been assigned to Madrid since 17 August. He had been off from Friday, 31 August until Monday, 3 September. He returned to duty on Tuesday, 4 September.

[15] Issued by the aviation authority of Ireland.

Day	Origin*		Destination		Activity
4 Sep	Madrid	06:23	Malta	08:50	Flight: 05:11 Active: 06:34
	Malta	09:30	Madrid	12:14	
6 Sep	Madrid	07:10	Gran Canaria	10:10	Flight: 05:53 Active: 07:13
	Gran Canaria	09:45	Madrid	13:38	
7 Sep	Madrid	07:10	Gran Canaria		—

* The time zone used is local time for takeoff and landing.

The day before he had had the entire afternoon off and he stated that he was very well rested. On the day of the incident he had breakfast at home and had a coffee at the office before the flight. He did not have anything on the airplane.

1.2.3. *Cabin crew*

The purser, flight assistant number 1, had been working for the operator since 2009. He was a 33-year old Polish national, and in October 2011 he had passed the company's line check.

Flight attendant number 2 had been working for the operator since August 2007 and had passed the company's line check in April 2012. He was a Spanish national.

Flight attendant number 3 had been working for the operator since February 2009 and had passed the company's line check in October 2011.

Flight attendant number 4 had been working at the company since August 2009 and was a Hungarian national. She had passed the operator's last line check in May 2012.

1.3. Aircraft information

The aircraft, registration EI-EKV, was a Boeing 737-8AS model with serial number 38507 and two CFM56-7B engines. The aircraft had been delivered new to Ryanair on 18th March 2010, and had accumulated 7658 flight hours and 4484 cycles since then. Last A check had been carried out on 30th August 2012.

1.3.1. *Organization at the Madrid base*

Aircraft EI-EKV, a Boeing 737-800, was operated and maintained by Ryanair.

Ryanair's aircraft at its Madrid base had been maintained by another operator until 31 August 2012. On 1 September 2012, a week before the incident, Ryanair took over the

maintenance, and some of the mechanics staff who had previously worked for another operator went on to work for Ryanair. The maintenance tasks that could be carried out at this base were the Transit Check, RAMP 1, RAMP 2 and 50 CF[16]. For all other scheduled maintenance tasks, the operator sent the aircraft to other bases with greater resources.

Due to this change in the maintenance organization at the Madrid base, the operator brought a shift leader with EASA B1 license from Ireland to supervise and help the organization of the base. The base had two 12-hour shifts from 19:00 to 07:00. There were usually 6-7 engineers and mechanics on the night shift and 2-3 on the day shift.

On the night from 6 to 7 September 2012, there were seven engineers and mechanics at the Madrid base: two B1 engineers (one of whom was the shift leader brought in from Ireland[17]), three Cat A engineers and two mechanics. On the day shift on 7 September there were two B1 engineers and one mechanic. The routine at the bases meant that all of the maintenance tasks on aircraft were complete by 04:00. Then, in the office, the mechanics would enter the maintenance information into the operators computerized maintenance record system, called AMOS.

1.3.2. *Maintenance prior to the incident*

On 4 September 2012, three days before the incident, a crew reported that the AUTOFAIL and ALTN[18] lights turned on during a landing. Maintenance did a BITE[19] check and a verification test of the number 1 and 2 cabin pressure controllers (CPC), finding no faults.

On the day before the incident, aircraft EI-EKV flew eight flights with two different crews, neither of which made any written entries in the flight logs noting any defects. The last flight has been Stansted-Madrid, and the arrival time at Madrid had been 22:37. The captain of that flight verbally informed one of the engineers (the shift leader) that he had noticed the aircraft make a strange sideways movement, that he had disengaged the

[16] Based on its approved maintenance plan, the operator specified a:
- Transit Check (Preflight Check): Done before every flight. This check is basically a walk-around and can be done by maintenance or by the pilots.
- RAMP 1: more complete than the transit check, it must be carried out by maintenance personnel at intervals not to exceed 48 h.
- 50FC: 50 cycle check.
- RAMP 2: check done every 330 flight hours, 300 cycles or 45 days.

[17] The shift leader had arrived at 19:00 h, then he booked into a hotel close to the airport and the he start ed his shift.

[18] These two lights are part of the pressurization system and are in the overhead panel (see section 1.3.5, figure 3). When lit, these two lights indicate that there has been a fault in one of the cabin pressure controllers (CPC) and that the ALTN (alternate) mode has been automatically engaged. This situation does not affect the pressurization and the system continues to automatically pressurize the aircraft.

[19] BITE test: built in test equipment test.

autopilot at 21,000 ft and that after re-engaging it, the problem did not reappear[20]. As a result of this conversation, of which there is no record, the engineer did the Land Verify Test[21], of which there is also no written record, though it could be heard on the CVR. This test, as per the mechanic's statement, was done at about 23:00, that is, immediately after the flight. It was done by the shift leader and another mechanic.

After doing the Land Verify Test, the shift leader and the other mechanic did the RAMP 1 check, which was entered into the flight log at 05:00 on the morning of 7 September. The mechanic who did this inspection stated that when he left the aircraft, the cleaning contractor was working in the passenger cabin.

By 06:41 the crew was already on the aircraft starting the pre-flight checks. The captain requested a mechanic to change the weight[22] and to solve the problem with the TAKEOFF CONFIG[23] warning. The mechanic who handled the problem was not the same one who had been on the aircraft that night, since the shift turnover had been at 07:00. The mechanic was new (as he said to the pilots) and requested help from a shift leader. At 07:14 the shift leader immediately identified that the LANDING GEAR AURAL WARNING CIRCUIT BREAKER[24] was pulled ("the breaker for the aural is closed"). After fixing it, the crew continued preparing for the flight. No further maintenance actions were done.

The Hold Item List[25] did not contain any components that affected the aircraft's pressurization system.

1.3.3. *Condition of the aircraft after the incident*

After the event the aircraft was found with the following configuration (figures 1 and 2):

- Pressurization system control switch in MAN.
- FLT ALT: 37,000.
- LAND ALT: 2,000.
- AUTOPILOT STAB TRIM SWITCH in the CUT-OUT[26] position.
- The passengers' oxygen selector was actuated (Pass Oxygen).
- Cockpit and cabin oxygen masks deployed.

[20] The operator reported this event to Boeing, which reviewed the flight data and concluded that the likely cause of the strange movement of the aircraft was an external perturbation (atmospheric or wake).

[21] AMM 22-11-00-740-801. The Land Verify Test checks the connection between the DFCS (digital flight control system) and its LRUs (line replacement units). See section 1.10.3.

[22] According to Boeing's SB737-11-1077, the operator adjusts the MTOW (maximum takeoff weight) to one of three options before each flight, which requires a signature from the certifying mechanic.

[23] The red TAKEOFF CONFIGURATION WARNING LIGHT illuminates on the ground when the throttle lever is advanced and the airplane is not correctly configured for takeoff.

[24] This circuit breaker is located on the F/O's electrical panel, behind the crew member's seat.

[25] The Hold Item List is a list where component mulfuncions are recorded.

[26] This switch position is one of the conditions that impedes engaging the autopilot.

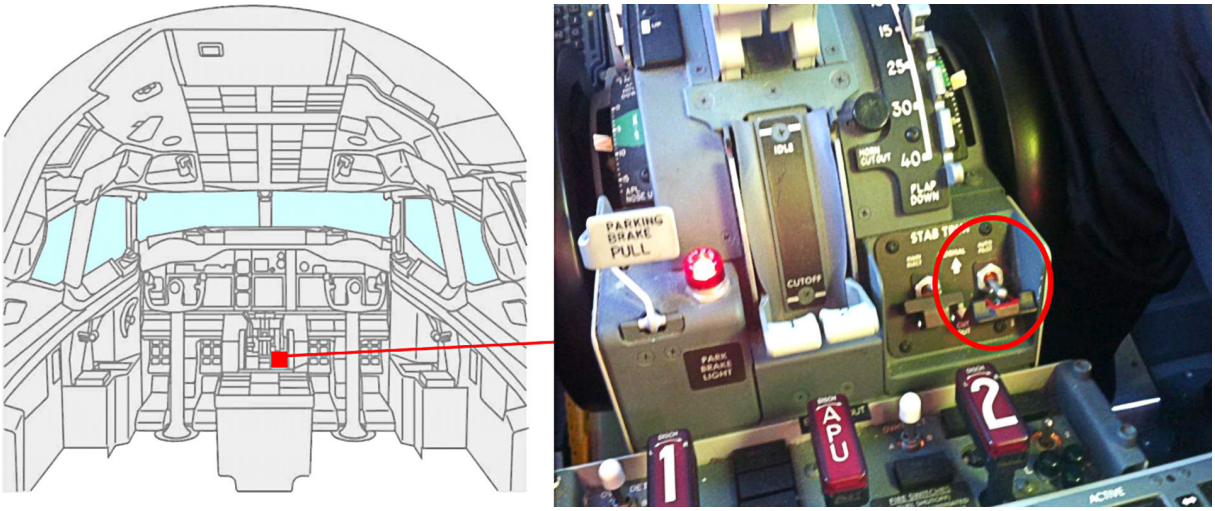

Figure 1. AUTOPILOT STAB TRIM switch in CUT-OUT

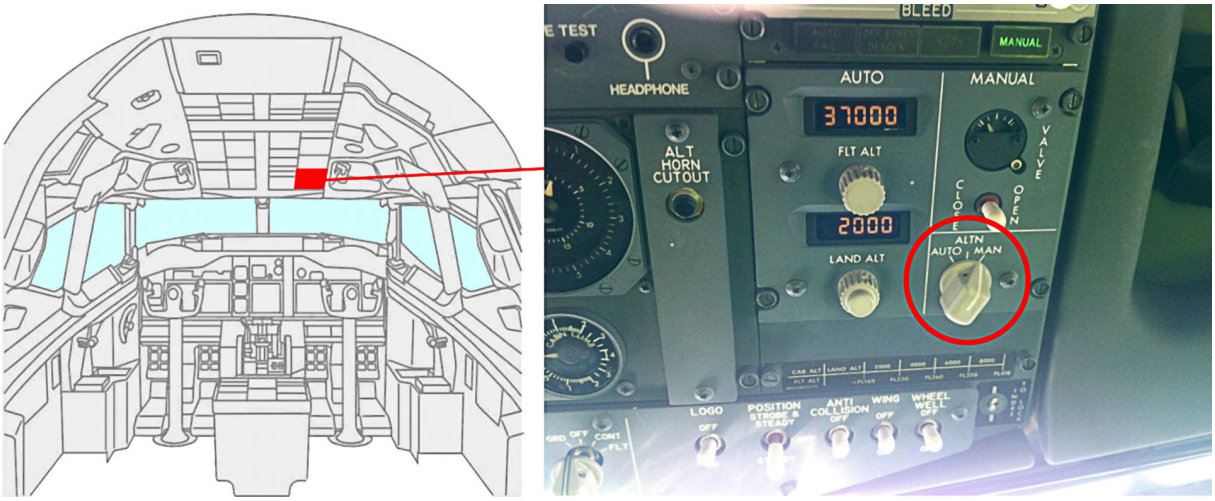

Figure 2. Pressurization mode switch in MAN

1.3.4. *Maintenance after the incident*

On the autopilot:

- The STAB TRIM AUTOPILOT SWITCH was placed in its correct position and the autopilot system was tested. No anomalies were found.
- The two flight control computers were interrogated and the information saved.

On the oxygen masks:

- The cockpit and cabin passenger masks were cleaned and stowed.
- The oxygen generators were replaced.

On the flight recorders:

- The FDR (flight data recorder) and CVR (cockpit voice recorder) were removed from the aircraft and new ones were installed.
- The information on the QAR (quick access recorder) was downloaded.

On the pressurization system:

- The operation of the air conditioning packs was checked and verified to be satisfactory.
- The air system on both engines was checked.
- A BITE (built-in test equipment) check of CPC 1 and CPC 2 was completed with satisfactory results.
- A ground check of the pressurization system was carried out with satisfactory results.
- The manual mode on the pressurization system was tested with satisfactory results.
- CPC 1 and CPC 2 were replaced as a precaution.
- The data on the memories for CPC 1 and CPC 2 were downloaded.
- An operational test of the CABIN ALTITUDE WARNING SYSTEM was carried out with satisfactory results.
- The cabin was checked for possible leaks.
- The outflow valve was replaced.
- CPC 2 was replaced a second time because it failed the post installation test.

On 9 September the aircraft was returned to service and it made five flights. There were no further problems like those involved in the incident.

There were no previous issues identified that would have contributed to the event.

1.3.5. *Aircraft's pressurization system*

Under normal conditions, the air breathed onboard the aircraft is provided by bleed air from the engines, whose temperature and pressure are regulated by the air conditioning system[27]. The air conditioning packs provide a constant flow of air for a given pressure and temperature. The function of the pressurization system is to maintain this air at a proper pressure inside the airplane, regardless of flight level. In the case of the B737-800, the maximum cabin pressure corresponds to an altitude of 8,000 ft when the airplane is at 41,000 ft.

A simple explanation of the pressurization system is that it regulates the pressure in the aircraft by opening or closing a valve through which air is expelled from the airplane (outflow valve). This valve can be operated automatically (AUTO and ALTN) by the system

[27] Under normal operating conditions, the pilots breathe dedicated un-recirculated air bled from the left engine. The air in the cabin is bled from both engines and is also recirculated.

through two identical controllers (CPC – cabin pressure controllers- 1 and 2), or manually (MAN) by the pilot. In the cockpit there is a pressurization panel (figure 2) where certain system parameters, such as cabin altitude (1 in figure 3), can be monitored, and the system's mode of operation (manual or automatic) can be selected (2 in figure 3). The system has two relief valves that limit the maximum differential pressure[28] between the inside and the outside of the airplane to prevent structural damage.

In automatic mode, the sequence of operation of the system is as follows:

- On the ground, with the airplane stopped and at low power, the outflow valve opens completely to depressurize the aircraft and allow the internal and external pressures to equalize.
- On the ground at high thrust (as the airplane starts its takeoff run), the system starts to pressurize the aircraft by closing the outflow valve.
- In the air, the pressure in the cabin is regulated based on preset conditions.

When the pressurization system is operated manually, the pressure in the cockpit is regulated by the crew's direct inputs to the outflow valve using its associated switch (3 in figure 3). This switch is located on the cabin pressurization panel, located in the overhead panel (figure 2). The switch only works when MAN mode is selected (2 in figure 3). To open the

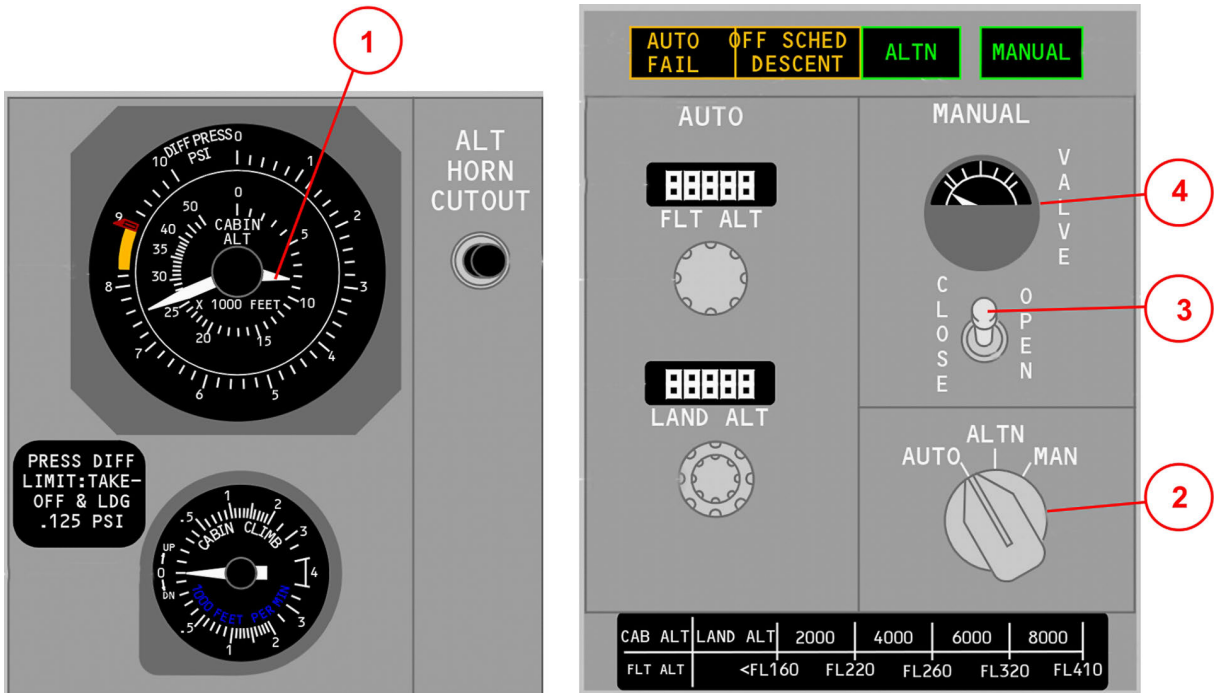

Figure 3. Pressurization system panel

[28] This maximum varies as a function of aircraft altitude: 7.45 psi at 28,000 ft or less; 7.8 psi between 28,000 and 37,000 ft; and 8.35 psi above 37,000 ft. The system regards a differential pressure of 8.75 psi as excessive. The maximum differential pressure value is 9.1 psi.

outflow valve, the switch has to be flipped to the right and held until the desired altitude is reached. When the switch is released, it returns to its central position. Manual control of the system requires monitoring the cabin altitude and differential pressure readings (1 in figure 3) and the position of the outflow valve (4 in figure 3).

1.4. Meteorological information

Weather conditions at Madrid-Barajas were good throughout the flight. The airport's METAR indicated weak winds (1 kt variable direction) with visibility in excess of 10 km and a temperature of 16 ºC. There were no significant changes for the rest of the flight[29].

1.5. Aids to navigation and communications

At the time of the incident the aircraft had been airborne for 10 minutes (07:32:37, point 1 in figures 4 and 5), and was climbing on a southerly heading under the responsibility of the Madrid Control Center on a frequency of 136.100 MHz. The emergency was declared at 07:43:15 (point 2 in figures 4 and 5) by the captain: "RYR2011 we have to descend MAYDAY MAYDAY MAYDAY".

Twenty-three seconds later the aircraft repeated the emergency declaration, requested to descend once again and asked for heading 150: "RYR2011 requesting heading one five zero, we have to descend further one hundred, MAYDAY MAYDAY MAYDAY". ATC cleared the change in heading to 150º and a series of exchanges took place to determine the intentions of the crew:

- ATC asked if they were returning to Madrid, which the captain confirmed.
- ATC gave them a new course to intercept the ILS, believing they were returning directly. The captain only acknowledged the heading. ATC repeated the instruction, which is when the captain requested to maintain altitude (07:45:53, point 3 in figures 4 and 5). At that point they were at 12,116 ft.
- ATC requested confirmation that they were stopping the descent at FL100 and the captain asked for a slightly lower level. The controller cleared him to descend at his discretion, bearing in mind the radar minimum of 4,000 ft. The captain asked for confirmation of the authorized altitude. The controller repeated the instruction and finally, at 07:46:34 (point 4 in figures 4 and 5), at 10,585 ft, the captain reported they would initially be descending to 6,000 ft and that they had to maintain altitude.

At 07:47:21 (point 5 in figures 4 and 5), the captain requested a 360º (they were at 9,557 ft), which they started at 07:48:49 (point 6 in figures 4 and 5). They exchanged

[29] METAR LEMD 090530Z VRB01KT CAVOK 16/14 Q1019 NOSIG=
METAR LEMD 090630Z VRB01KT CAVOK 17/14 Q1019 NOSIG=

eight further messages with ATC by 07:49:49 to confirm the 360°, that it would be a left turn and whether they would complete it. In the message from 07:49:49 (point 7 in figures 4 and 5), the captain informed that they would be ready for the approach in 5-10 minutes. During all this time the crew was doing the CABIN ALTITUDE WARNING and EMERGENCY DESCENT checklists.

When they finished the 360°, at 07:52:25 (point 8 in figures 4 and 5), the controller cleared them to descend to 4000 ft and asked if they could turn right to heading 040. At 07:52:57 ATC again asked how much time they would need to complete the approach, with the captain confirming the 5-10 minute estimate. At 07:53:15 they were cleared to heading 200. At 07:56:22 (point 9 in figures 4 and 5) on heading 200, ATC again asked if they were ready to turn, with the captain again replying in a few minutes. At 07:59:50 (point 10 in figures 4 and 5), three minutes later, ATC again asked if they were ready to turn. This time the reply from the captain was affirmative, and ATC cleared them to turn to heading 010 and intercept and follow the runway 33L localizer.

The aircraft intercepted the localizer about seven miles out and completed the approach without incident.

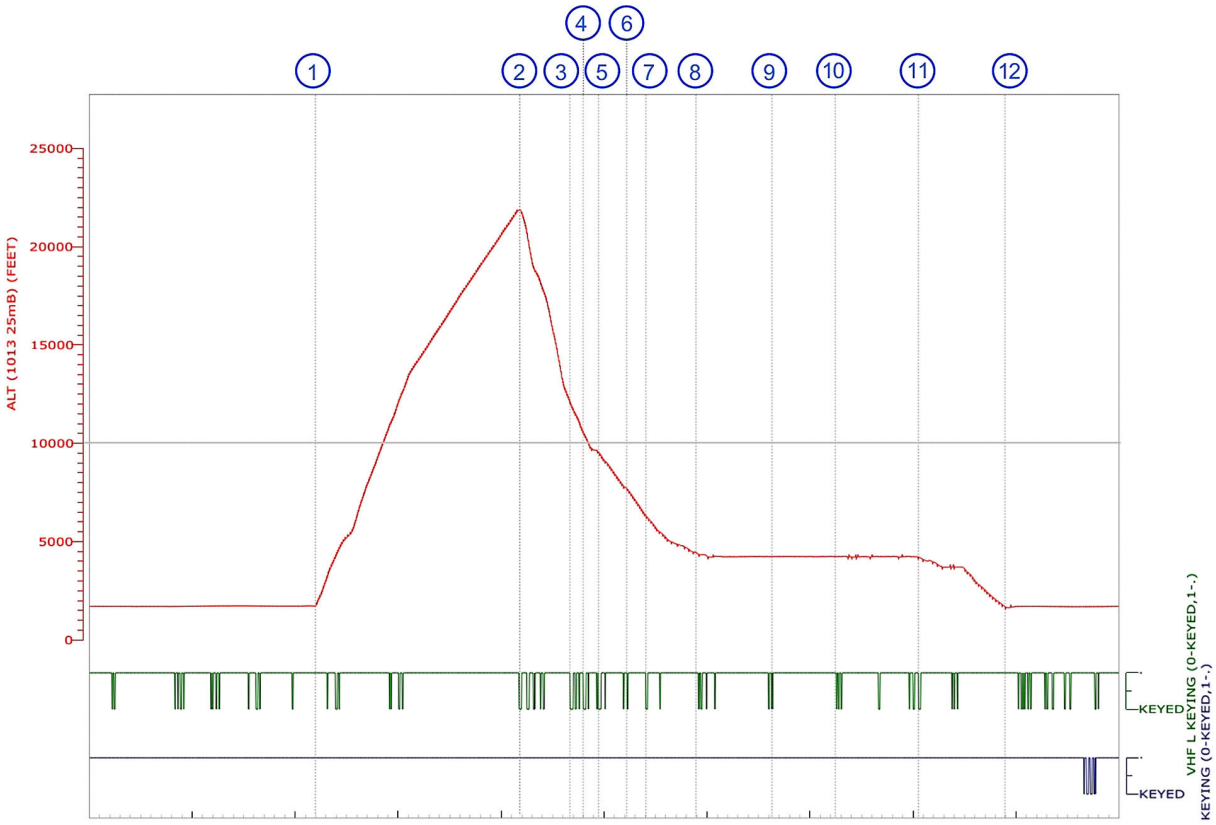

Figure 4. Aircraft's altitude and crew's communications with ATC

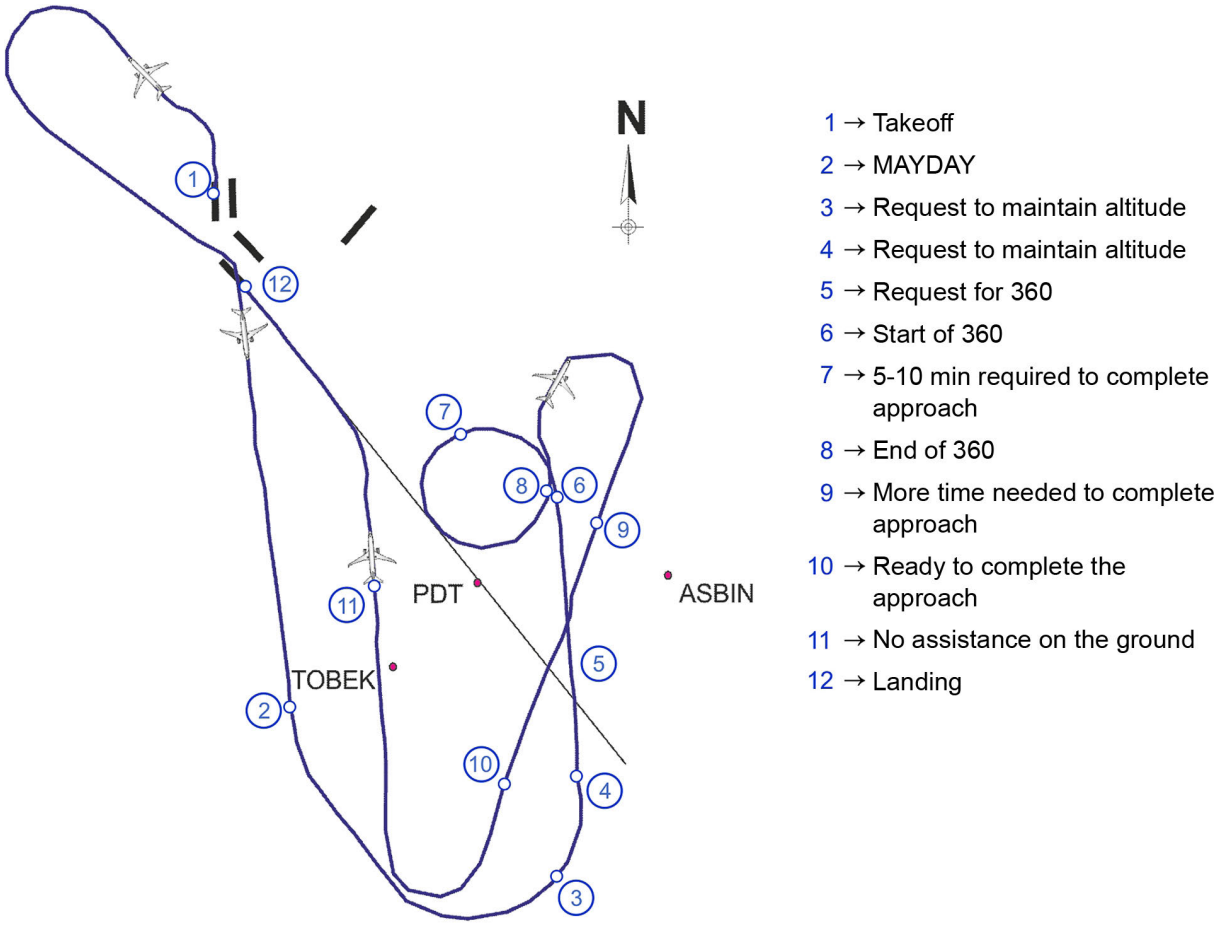

Figure 5. Aircraft's flight path

At 08:03:59 (point 11 in figures 4 and 5) the captain informed ATC that they did not require assistance. This information was conveyed to the tower controller to which they would be transferred later. Despite this, said controller, after clearing them to land, again asked the aircraft if they requested any assistance and the nature of the problem. This was the first time that the crew reported the nature of the problem, which they described as a "depressurization". The landing took place at 08:08:37 (point 12 in figures 4 and 5).

From the start of the incident until the aircraft came to a stop, there were five frequency changes (127.100, 127.500, 118.150, 121.975 and 121.85 MHz), three in the air and two on the ground.

ATC gave priority to the aircraft to land, clearing traffic from the area and letting the aircraft remain on hold as long as requested by the crew. Figures 4 and 5 show the flightpath taken, the changes in altitude and communications by the captain (in green) and first officer (in blue) with ATC throughout the flight.

1.6. Flight recorders

Installed on the aircraft were a Honeywell solid-state flight data recorder (FDR), P/N 980-4700-042 and S/N 17825, which had recorded 15 full flights, and a Honeywell cockpit voice recorder (CVR), P/N 980-6022-001 and S/N 13563, with four channels, one lasting two hours and one minute and three lasting 30 minutes. In addition to the information on the FDR, the information on the quick access recorder (QAR) was also used to analyze the incident since the FDR did not contain information on the pressurization system, whereas the QAR did[30].

On the incident flight the cabin pressure controller in use was CPC 1, with CPC 2 in standby. An analysis of the flight data and of the 15 previous flights showed that the pressurization and air conditioning systems had functioned normally. The FDR did not record any CABIN ALTITUDE alerts above 10,000 ft, nor were any heard on the CVR[31].

At 07:32:00 the aircraft was on the ground prior to takeoff, and the outflow valve was in a 110º position, meaning it was open. The cabin pressure was 13.8 psi. At 07:32:02 (point 1 in figure 6), just as the takeoff run was started, the outflow valve started to close. One second later the mode of operation of CPC 1 went from "ground" to "takeoff".

Three seconds after the rotation, "climb" mode was activated on CPC 1. The outflow valve's position was 51°. The climb continued until 07:43:15, when the crew declared an emergency (point 2 in figure 6). At that time the pressure in the cabin was 12.8 psi, 1 psi less than on the ground. The outflow valve was in position 10.82º and the differential pressure was 5.7 psi. The flight mode on CPC 1 changed from "climb" to "abort".

At 07:44:16 (point 3 in figure 6) the outflow valve started to fully close, reaching its closed position (–0.55º) three seconds later, where it remained until the airplane landed. CPC 1 went from in use to standby. From that moment on the pressure in the cabin started to increase (decrease in cabin altitude), as did the differential pressure and the change in pressure (from –500 slfpm[32] to –3,000 slfpm).

At 07:45:20 (point 4 in figure 6) the cabin pressure was 14.69 psi, equivalent to the pressure at sea level.

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[30] The QAR recorded the cabin pressure (used to calculate the cabin altitude), the variation in cabin pressure (cabin rate), the pressure differential between the cabin and the outside, the position of the outflow valve, the CPC computer in use and the computer's flight mode.

[31] Visual and aural alerts are activated to alert the crew whenever the cabin altitude exceeds 10,000 ft. The acoustic CABIN ALTITUDE alert is the same as that of the TAKEOFF WARNING SYSTEM. The former can only take place in flight and the latter on the ground. The visual alerts on this airplane were separate.

[32] Slfpm: sea level feet per minute.

At 07:48:26 (point 5 in figure 6), with the aircraft at 8,968 ft, the cabin pressure was 19.613 psi and the differential pressure reached its maximum value of 8.75 psi. The opening of the relief valves caused the cabin rate to drop from –3,000 fpm to –1,000 fpm. From then until the landing, the differential pressure held at around 8.75 psi, with changes in the cabin rate being recorded due to the opening of the relief valves.

When the aircraft landed in Madrid at 08:07:37 (point 6 in figure 6), the outflow valve was still closed and the cabin pressure was 22.36 psi. While taxiing on the ground, more significant fluctuations were recorded in differential pressure and in cabin rate.

At 08:14:27 (point 7 in figure 6), after taxiing on the ground for six minutes, the cabin pressure was 22.59 psi and the captain complained of an ear ache. There had been a change in cabin rate of 5,000 slfpm. Two seconds later, at 08:14:29, the captain turned off the air conditioning packs.

At 08:14:42 (point 8 in figure 6), after a comment by the captain that the cabin pressure was over 10,000 ft[33], they started opening the outflow valve, which started to depressurize the cabin, a process that was completed at 08:16:09 (point 9 in figure 6), when the inside and outside pressures equalized. The valve did not open fully, only slowly opening to the 39° position.

During the cabin depressurization process, the maximum recorded cabin rate was 6,350 slfpm, which lasted 59 seconds.

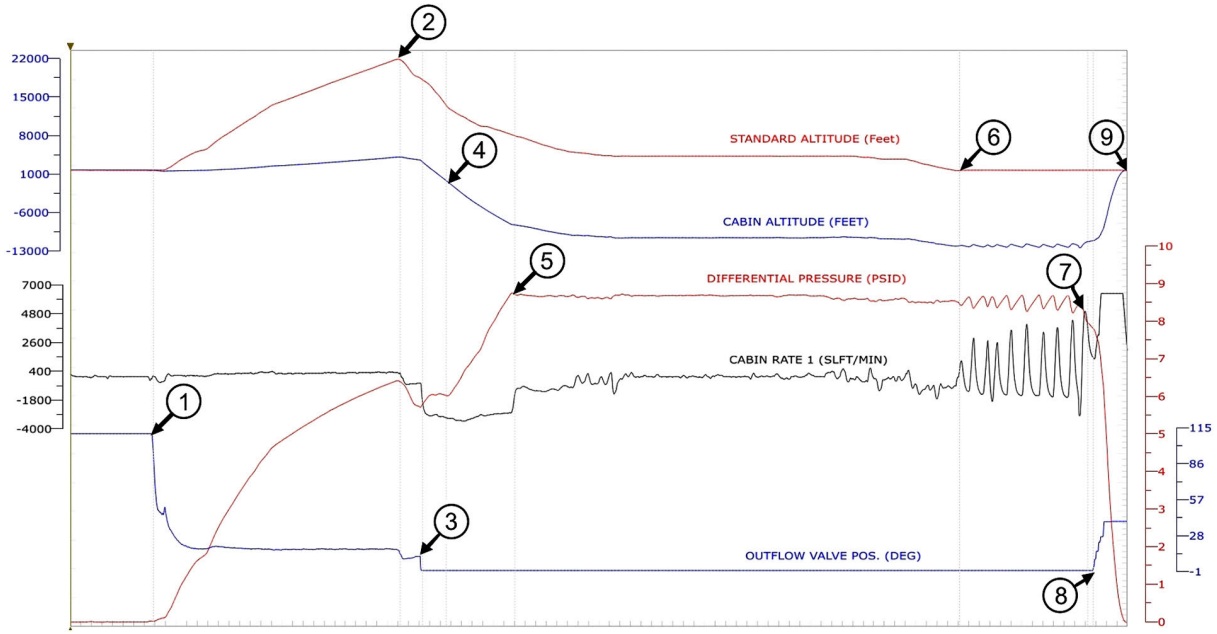

Figure 6. Pressurization system parameters during the flight

[33] They were at an overpressure equivalent to an altitude of –11,224 ft, where the negative sign indicates below sea level.

1.6.1. *Communications involving the pressurization system*

The complete flight, and thus the emergency, were recorded on one of the CVR channels, specifically the two-hour and one-minute channel associated with the area microphone, which also records background noise. The first 23 minutes of the recording included the Land Verify Test, which had been performed the night before. The recording of the incident flight started 23 minutes in, by which time the crew had already identified the problem with the TAKEOFF CONFIG, since within one minute of starting the recording, the captain can be heard asking for a mechanic to change the weight and fix this problem.

As part of the flight preparations, the crew went over the emergencies. This included a review by the captain of the cabin depressurization using the following actions[34]:

> "... we come back to Madrid. Once airborne and the altitude above ten thousand feet if we have the intermittent warning horn, which is not working yet, we'll immediately don the oxygen mask regulator one hundred percent, establish crew communication, do the rapid depressurization checklist and we must good verify cabin altitude establish below ten thousand feet before removing the oxygen masks".

They reviewed the instrument departure authorized by ATC, the information on the FMS (flight management system) and the pushback and taxi procedures. They then did the SAFETY INSPECTION and BEFORE START checklists. As part of the latter, the first officer was heard identifying the "STAB TRIM CUTOUT", with the captain replying "NORMAL"[35].

The remaining conversations between the crew members involved the flight. After engine start-up and takeoff, the background noise in the recording increased. They did the BEFORE TAXI checklist, requested to taxi and did the BEFORE TAKEOFF CHECKS. All of the checklists were requested by the captain and communications with ATC were handled by the first officer.

For the first ten minutes of the flight the crew was heard doing a checklist, responding to alerts involving SPEED TRIM FAIL and the autopilot, which they could not engage, with the first officer reading the relevant item on the checklist. Ten minutes after takeoff a ding was heard in the cockpit indicating a call from the purser, during which the captain is heard saying, "Hello, hello, yeah, ok", followed by instructing the first officer

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[34] Ryanair Operations Manual. Initial emergency briefing. Captain (always, first flight of the day only):
Whenever the intermittent warning horn sounds in flight, at an airplane flight altitude above 10,000 ft MSL:
- Immediately don oxygen masks and set regulators to 100%
- Establish crew communications.
- Do the CABIN ALTITUDE Warning or Rapid Depressurization non-normal checklist.

Both pilots must verify on the overhead Cabin Altitude panel that the cabin altitude is stabilized at or below 10,000 ft before removing oxygen masks.

[35] Item 20 on the list is: "STAB TRIM CUTOUT SWITCHES... NORMAL".

to "Stop the altitude" and the emergency declaration. The start of the CABIN ALTITUDE WARNING checklist could not be heard because it was only recorded on the 2 hour area channel, and the background noise only allowed identifying the noise of the masks when they activated. The FDR did, however, record the manipulation of the outflow valve (step 4 on the checklist) a minute after the emergency was declared. The start of the 30 minute channels coincided with the following communications[36]:

First officer: 07:49:08 *Ahh the... if the cabin altitude exceeds or is expected to exceed fourteen thousand feet pax oxygen switch is on, go to the emergency descent checklist on page zero point one. Cabin altitude warning or rapid depressurization non normal checklist completed.*

Ok... emergency descent checklist. Are you ready for the checklist? Yeah? Emergency descent checklist. Non normal.

Condition. One or more of these occur. Cabin altitude cannot be controlled when the airplane is above fourteen thousand feet a rapid descent.

The EMERGENCY DESCENT checklist was interrupted by calls from ATC, which were answered by the captain. During descent, the captain suggested to removed masks due to they were at 10,000 ft "OK. We are at ten thousand feet, I suggest you to remove your mask, check and...". The checklist was interrupted two more times by calls from ATC and finally the first officer announced "The emergency descent non-normal checklist complete".

At 07:53:05 the captain started to review their situation, speed, position and intentions. He called ATC again and, after that, called the purser to hold the NITS briefing ("Hello? This is your NITS briefing. Nature: the aircraft was not pressurized, I do not know why. Intention: go back to Madrid. Time 5 minutes. No specials, normal landing. Do you have anything in the cabin?"). The purser, who had removed his mask for the briefing, reported that everything was calm and asked if they could remove their masks. The captain replied to keep them on. After finishing, he continued with the first officer (07:54:58):

Captain: "OK, I am back to you" So, PIOSEE[37]. Problem, unpressurization.

First officer: Yes.

Captain: *Information, we have... we didn't have this configuration warning because, I suppose, because of the problem we had on the ground.*

[36] Literally at the end of point 5 on the CABIN ALTITUDE WARNING checklist and the start of the EMERGENCY DESCENT checklist. See section 1.10.2.

[37] The PIOSEE is a decision-making model used by the operator's flight and cabin crews. The word stands for Problem, Information, Options, Select, Execute, Evaluate. The model involves identifying the exact nature of the problem, gathering all of the relevant information, identifying all of the associated options and risks, selecting the best way to solve the problem, carrying out the solution and regularly evaluating the effects of the plan. The use of this model is periodically trained on and evaluated by the operator, as specified in Part D of its Operations Manual.

They reviewed the go-around procedure and the fuel they had used, and did the checklists and the DESCENT CHECKS, as part of which the crew was heard changing the value for the altitude of Barajas on the pressurization panel, "Pressurization... landing altitude 2,000", which is how it was found after the incident (figure 2).

They made no further comments on the pressurization system. After landing, they were busy with the taxiing instructions and coordinating the deplaning of the passengers with the operator. While taxiing, the captain was heard saying, with the first officer assenting:

Captain: *I saw the packs on and the pressurization…It was pressurizing on the ground.*
What is this now? My ear!! Do you feel it?
Look, the aircraft altitude is up ten thousand. We cannot open the doors like this.
Yes, but slowly slowly slowly (referring to the outflow valve)
Yeah, but now up to this up.
No, it's normal, it's increasing. What's going on?

Once the airplane came to a stop, the maintenance shift leader went into the cockpit. Before opening the CVR circuit breaker, the last recorded conversations were heard, with the captain explaining to the mechanic what had happened (08:18:47): *We started from the air, I'm sure hundred per cent this was on, on and... you know when we put them on we always see this is going a little bit down so it is pressurizing on the ground. I always check that. It was fine, no? And the after takeoff so the autopilot was not working and the initially...*

> *... we had speed trim failure, we did the checklist and then I give him control about 15,000 ft and standing up to verify any CB (circuit breaker) you know, for the autopilot or something. Cabin called me and said that they don't feel good and in meantime I didn't feel good, so...*

1.7. Medical and pathological information

The airport's medical service attended 16 individuals, including four flight attendants. They were diagnosed with otorrhagia (hemorrhaging through the ear), epistaxis (bleeding from the nose) and panic attacks. During the evaluation process, the medical service described the passengers as being "standing and alert", and did not detect any symptoms indicative of hypoxia or intoxication.

Two of the passengers were taken to the emergency room at the Ramón y Cajal Hospital where they were treated for "otalgia (ear ache) after airplane depressurization", as a result of which they were seen by an otorhinolaryngologist. The two passengers were

diagnosed with otic barotrauma (physical damage caused by a pressure difference between the middle and outer ear). One was advised not to fly for 72 h and the other for 7 days.

The pilots did not report to the airport's medical service. In the case of the captain, he went to his doctor a week after the incident for a check-up. At the time of the check-up the doctor did not find any problems, and he concluded that the symptoms being reported by the captain were consistent with hypoxia. The first officer went for a medical check-up two days after the incident, the results of which were satisfactory.

1.8. Survival aspects

After the Madrid control center received the crew's emergency declaration at 07:43, the Madrid tower informed the Airport Management Center (AMC) that flight RYR2011 was returning. The AMC activated the local alarm from 07:49 until 08:23. The airport handled the emergency in three phases.

Local alarm activation phase

At 07:49 the groups affected, as described in the Emergency Manual, were activated. The Rescue and Firefighting Service (RFFS) was activated and the remaining units affected were informed but not mobilized[38]. At 07:56 the tower provided updated information to the AMC about the aircraft, which was 20 NM out and would be landing on 33L. From the time it landed until it stopped at its parking stand, the RFFS informed the AMC that the oxygen masks in the plane had been released due to a pressurization problem. There were no problems accessing the airplane and the two doors used to disembark the passengers were opened without any problems. The handling agent was ready when the aircraft landed and there were no delays in providing assistance in terms of ramp operations or passengers.

Medical attention phase

At 08:22, with the aircraft stopped, the operator requested medical services onboard as one of the passengers was very agitated and bleeding from the mouth. The AMC notified the airport's medical service for terminals 123[39], located in T2, which had already been notified but that at the time was responding to another emergency in T1. While en route

[38] Apron Management Service, Signalmen, Ryanair, the handling company Swissport, Flight Safety Office, T123 Airport Medical Service, Civil Guard, National Police Force, Airport Security, Airport Press Office and Aena's Network Control Center.

[39] There are three medical services (SMA) at the Madrid-Barajas Airport, identified by the area they cover: SMA T123, SMA T4 and SMA T4S.

to the aircraft they were informed of an additional three passengers needing medical attention. One, who had a history of serious cardiovascular problems, was taken in a mobile intensive care ambulance to the medical service. The other individuals were taken there in a handling company bus. At 08:45 the passengers who needed medical attention arrived at the medical service office in T2, followed later by more passengers. The medical service was supplemented with personnel from the T4S medical service. A total of 16 people received medical attention, 12 passengers and 4 flight attendants, who reported to the medical service at 11:00. Four passengers were advised to be seen by an otorhinolaryngologist in the emergency room at the Ramón y Cajal Hospital, though none exhibited urgent symptoms. These passengers were taken there in a taxi provided by the handling company Swissport. The medical services at the airport were concluded at 11:31.

Flight recovery phase

Passengers who so desired were placed on another of the operator's flights, parked in remote stand 32, at 11:05.

1.9. Tests and research

1.9.1. *Captain's statement*

He arrived at the airport an hour before the flight. He had had breakfast at the hotel and did not have anything at the office or on the airplane. He held the briefing with all the crew in the office. He walked the 200 m from the office to the stand where the airplane was parked. The maintenance check was done and the aircraft's Technical Log Book was already signed. It was the first flight of the day.

He did the pre-flight checks and saw that the T/O CONFIG (aural warning) was not working. He called a mechanic, who realized that a circuit breaker was tripped. They reset it and it worked properly. The passengers were boarded without any problems and they taxied to the 36L threshold. He was the pilot flying.

At approximately 1,000 ft the SPEED TRIM and MASTER CAUTION lights turned on, the latter of which continued turning on throughout the flight. At 5,000 ft they tried to engage the autopilot unsuccessfully. They continued flying until they reached 10,000 ft. The readings from the pressurization system were normal both before takeoff and in the checks done at 10,000 ft.

After doing the checks at 10,000 ft, the captain passed control to the first officer. They checked the QRH for the procedures involved with A/P FAIL TO ENGAGE and SPEED TRIM FAIL. The captain stood up to check the aft circuit breaker panel, convinced that a tripped circuit breaker was keeping the autopilot from engaging. He knew that if the

autopilot was unavailable, they would have to return to Madrid due to RVSM airspace requirements to fly to the Canaries.

At FL200, while he was still standing, he received a call from the purser. This surprised him because they never called so early. The purser told him they were not feeling well, that they felt strange and asked if the pressurization was alright. This call confirmed his own feeling and he immediately ordered the first officer to halt the climb. He had not mentioned anything to the first officer but he was already feeling unwell. The captain described the feeling as "some kind of nausea that made it hard to concentrate. Thinking was hard". It took him about a day until he started feeling better.

The captain took over the controls, they donned their oxygen masks and manually activated the passengers' masks. When he looked at the cabin altitude reading, he saw it was abnormal but he could not recall the exact value. They issued a MAYDAY to ATC and made an emergency descent, returning to Madrid-Barajas. The oxygen mask made him feel somewhat better but not fully. They removed them at 10,000 ft and continued the descent without them. He transferred control to the first officer and called the purser to hold a NITS briefing, after which he made an announcement to the passengers explaining their situation.

Once they were completely stabilized on the ILS, the captain again took the controls and continued until the end of the flight. The landing on runway 33L was uneventful. While taxiing, the cabin started to pressurize to 15,000 ft. He opened the outflow valve before turning off the engines.

He had never felt nauseous during a flight, even an acrobatic flight. It took him several days to recover.

1.9.2. *First officer's statement*

He arrived at the airport two hours prior. He had had breakfast at home and had a coffee at the office before the flight. He did not have anything on the flight. He did the walk-around check of the aircraft. The pressurization system readings had been normal during the pre-flight checks. The "ten checks"[40] also included a check of the pressurization readings, which were normal. Between FL100 and FL150 the captain transferred the controls to him. Shortly before the call from the purser he already felt sick. The feeling "wasn't one of illness but of a lack of energy and disorientation". He felt as if "at some point in the flight, without realizing it, I had lost energy and brain capacity. I felt disoriented. I felt absolutely dead". He attributed to it being very early. The captain, after speaking with the purser, told him to stop the climb and to deploy the masks. For him it was a "shock". He thought the captain had seen something that he had not.

[40] Checks at 10,000 ft.

He did not recall what cabin altitude he had seen at the time of the incident. He did recall that, after landing, at the parking stand the cabin altitude was 15,000 ft. They opened the outflow valve very slowly. It took him over a day to recover.

1.9.3. *Purser's statement*

They held a normal briefing in the office. The flight departed on time with a taxi phase lasting 10-15 minutes. The takeoff was normal and within five minutes they received the all clear to stand up. He went to check the content of the bars while the number 4 flight attendant (FA) went forward to get the newspapers ready.

Shortly afterward he started getting a headache. He felt a little dizzy counting the bar and he especially felt uncoordinated. The number 2 FA approached him looking pale and tired, as if he could not get enough air. He asked him how he was, and he confirmed he was not feeling well. After talking about how he felt he thought he was losing consciousness for a few seconds. He asked FA 4, who was with the newspapers, who also confirmed she felt very strange. FA 2 was looking worse and he started shaking. He was still pale. He asked FA 4 again and confirmed that something was wrong. He identified the symptoms as hypoxia and knew that, since they were climbing, he had 2-5 minutes to notify the cockpit before losing consciousness. He decided to call the captain and tell him the airplane was depressurizing and that they were exhibiting symptoms of hypoxia.

He immediately felt the airplane stop climbing and heard the pilots' oxygen masks activate. A few seconds later the passengers' masks dropped. He looked at his hands but did not see his nails turn blue. The masks worked perfectly. The cabin was secure. They had not yet taken out the carts. He felt better with the oxygen masks. There was no emergency descent announcement but it was not necessary as he could feel they were descending.

The passengers were calm. Some were sleeping due to the early hour and continued with their seat belts fastened. Nobody reported feeling anything strange.

The descent was normal, not abrupt. When the airplane stopped descending and leveled off, he called the cockpit twice without receiving an answer. He took off his mask to go in and make sure they were alright, as required by procedure, and he received a call from the captain telling him they had suffered a depressurization. They held a NITS briefing and the captain told him they would be landing in Madrid in 5-10 minutes. The purser gathered the FAs to relay this information and noticed they were a little better and calm. He next heard the captain inform the passengers of their situation and of their intention to land in Barajas in six minutes. The captain's announcement was in English, which he then translated into Spanish.

They landed normally and exited the runway. While taxiing they started to feel an ache in their ears and many passengers covered them with their hands. After stopping the

engines it took them over two minutes to open the doors, more than usual. There was no problem opening the doors and the passengers exited the aircraft via the front and rear left doors. Emergency services were waiting for them. Four passengers remained onboard and were treated there by the airport's medical service. Handling company personnel were there waiting and took charge of the passengers.

They went to the office with the pilots where they held a debriefing with the base FA coordinator. They then went to the medical service to have their ear aches treated. By that time he felt well. They were notified they were being given the day off.

He did not hear air rushing out the doors nor feel that the temperature was off during the flight. He had not had anything on the airplane and had only drunk one coffee in the office prior to the flight. He had never before felt nauseous on a flight.

1.9.4. *Statement from FA 2*

He arrived at the airport about an hour before the flight. They walked to the airplane after the briefing with the crew. He was seated in the left rear of the airplane. It appeared to him that it took a little longer than usual for them to be "released" [41]. He headed forward to help with the service and felt strange while walking there, noticing that "something wasn't right", but attributed it to the early hour. When he got to the front of the cabin the purser was standing straight, opening boxes, and FA 4 was with the newspapers.

He sat next to the purser and discussed how he felt. The purser asked FA 4, and after confirming that all three were feeling the same, called the pilots. At that moment he felt as if "my mind had gone, like having a slab in the brain, like having lost all my abilities. My body weighed a thousand kilos". He called back to FAs 3 and 4 to tell them to sit.

He had experienced turbulence, an onboard fire, an evacuation and heart attacks, but no incidents involving a depressurization. He had never felt nauseous during a flight. They took their oxygen masks off when the airplane leveled off, shortly before landing.

1.9.5. *Statement from FA 4*

Her position was at the front of the airplane, along with the purser. She did not feel anything strange during the flight and when they were released, she got up and started selling newspapers. While doing this, the purser asked her if she felt alright, to which she replied yes, though when asked again later she did feel strange. She asked FA 3

[41] Permission from the captain to stand up from their seats and start their duties.

how she felt. She finished handing out newspapers and realized she felt something in her stomach, "like when you land in Barajas in the summer with the heat". She was in the rear of the airplane and sat next to FA 3. They then received a call from FA 2 telling them to sit. Her ears felt normal while they were taxiing.

1.9.6. *Statement from the night shift leader*

The shift leader on the night of 6-7 September was an Irish national. It was his first day on his shift in Madrid after his allocated rest days. He had arrived in Madrid at around 16:00 and at 19:00 he reported to work. He had been working for the operator for seven years, two as a shift leader. That night they had 14-15 airplanes and a shift of seven people. He recalled that shift was busy.

He did not do the daily inspection, but the Land Verify Test since the captain of the previous flight had told him about a problem they had had. When he did this test, the mechanic who had done the RAMP 1 was also in the cockpit. He usually took the aircraft's Technical Log Book to the office to check that everything was alright and to log the actions taken. That day he forgot. He was in a hurry because there were other airplanes and, as the shift leader, he was constantly receiving calls.

1.9.7. *Statement from the morning shift leader*

The morning shift leader on 7 September was a Spanish national. He had been at that job for four years, but working for another operator. At the conclusion of the contract with another operator he went to work for the operator on 1 September, doing the same job as for the previous four years. He had 12 years of experience on the B737.

Before takeoff, the captain called them to change the weight and to fix a configuration problem that was being caused by a tripped aural warning circuit breaker for the landing gear. They reset it and it worked. They should have logged it but they did not. When the airplane made an emergency return, he went out to the airplane. When the captain informed him of the problem with the autopilot, he immediately saw that the STAB TRIM was in CUTOUT.

1.9.8. *Cabin altitude readings below zero*

The cabin altitude indicator (1 in figure 3) is a round gauge with altitude marks every thousand feet from 0 (0 ft) to 50 (50,000 ft). This gauge is not designed to show altitudes less than zero. According to information from Boeing, there have been cases where the needle moved counterclockwise to read between 50 and 40. In this incident, the crew saw the needle above the 10 ("the altitude is up to ten thousand") when the

cabin pressure was 21.71 psi[42]. They were then heard saying that the needle was below 10 ("we are at ten thousand feet") when the cabin pressure was 20.4 psi[43].

1.9.9. *Medical aspects of the incident*

Hypoxia is a lack of oxygen to the body's cells and tissues. It can be caused by several reasons, with commercial aviation being the most frequent cause of a lack of oxygen in breathed air (hypobaric hypoxia), changes in how much oxygen is transported by the blood (anemic hypoxia, such as carbon monoxide poisoning), or poisoning by substances that keep cells from using oxygen (histotoxic hypoxia).

In the event of hypobaric hypoxia, the use of oxygen masks leads to immediate improvement, but in the event of hypoxia by poisoning (either from CO or other substances), this is not the case and the recovery time often depends on each individual's characteristics. The symptoms of hypoxia are many and not every individual exhibits the same ones. Their intensity also varies depending on many aspects, though in general they tend to compromise intellectual functions, leading to sluggish thinking, inexact calculations, poor judgment, memory loss and delayed reaction time. Other signs (cyanosis, hyperventilation, shaking, a lack of muscle coordination) and symptoms (dizziness, difficulty breathing and, on rare occasions, headaches, nausea and vomiting) may appear depending on the seriousness of the situation, though discomfort or pain are rare, the opposite being more common. The symptoms reported by the crew were headaches, inability to concentrate, dizziness, lack of coordination, difficulty thinking, listlessness, a feeling of disorientation, shaking and difficulty breathing.

The initial evaluation of the incident by CIMA (Aerospace Medicine Teaching Center) was that the symptoms reported were consistent with hypoxia, though a hypobaric hypoxia could be ruled out due to three factors: the limited time the aircraft was exposed to altitudes above 10,000 ft; the fact that the symptoms did not completely disappear when oxygen was supplied and the fact that the cabin altitude remained well below the established 10,000 ft threshold for hypoxia at all times.

The investigation thus focused on the possible presence of some substance that could have caused the symptoms in the crew. This hypoxia by poisoning scenario considered:

- The ability to detect these substances, and
- identifying the possible substances present on an aircraft that do not produce obvious signs of their presence (smoke, odor or irritation)[44].

[42] Equivalent to a cabin altitude of –11,224 ft, where the negative sign indicates an altitude below sea level.
[43] Equivalent to a cabin altitude of –9,398 ft.
[44] The substances that can enter the cockpit from the engine bleed air are typically oil, hydraulic fluid or carbon monoxide. In the case of engine oil or hydraulic fluid, these generally have an odor and cause irritation, and they are thus easily detectable.

Based on information provided by CIMA, it is practically impossible to detect the presence of inhaled substances during a routine medical exam unless they are tested for specifically. In this incident no passengers had their blood tested. Those who were seen by a doctor complained of the last thing that affected them, which was the depressurization of the aircraft, and thus the medical analysis and the related tests all focused on this cause.

Considering how both the pilots and the flight attendands reported similar problems, the points in common were identified. The air conditioning system was working normally, meaning that the air breathed in by the pilots during the flight was supplied by left engine bleed air, this being the only point in common between the cockpit and the passenger cabin from the standpoint of the air conditioning system.

The maintenance actions specific to this engine were reviewed; specifically, the engine washings[45] on the night of 6 to 7 September. Neither the right nor left engine was washed that night. There were also no activities involving the airplane's air conditioning or air systems.

As part of the activities on the aircraft, the procedures and products used to clean the aircraft the night before the incident flight were reviewed. No products were detected that could have caused the symptoms reported by the crew; moreover, it was confirmed that only the passenger cabin was cleaned and that the cockpit was not affected by this activity. The last full internal cleaning was carried out on 2 August 2012.

Also ruled out were external washings of the aircraft that could allowed some substance to enter the aircraft through an improperly covered intake. The outside of the aircraft was not washed on the day before the flight, the last such activity having taken place on 4 August 2012.

The air breathed in the passenger cabin is sent through the cargo holds and recirculated. Although it would have explained the flight attendants' symptoms, but not the pilots', the aircraft's cargo manifest was reviewed to determine if some kind of substance could have contaminated the air in the cabin.

The fire extinguishing system for the engine, which uses Halon, was checked and verified to be free from leaks. The onboard extinguisher was also checked for small leaks that could have gone undetected. This was done by reviewing the weight of the extinguisher from 2009 until after the incident. There was no evidence of any leaks nor changes in the weight that could have accounted for the crew's symptoms.

Though extremely unlikely, the nitrogen generator system[46] (NGS) was checked for problems. None were found. The design of the system, and its location in an unpressurized area, makes it improbable that nitrogen can enter a pressurized area.

[45] Engine washings use substances that have reached the cockpit through the bleed air, and problems have been reported. These substances are usually detected by the itching or irritation they cause.

[46] This system provides nitrogen-rich air to the fuel tanks to prevent explosions.

Lastly, investigators considered the possibility that the contaminant could have entered the aircraft while it was on the ground. Aena kept a log of all the services used by the aircraft on 6 and 7 September and how long they were used. El operador had all of the services contracted (jet bridge, 400 Hz and air conditioning), of which the first two were used.

There were no faults reported with the jet bridge by the incident crew or by any other crews that used it on that day. There were also no problems logged in the jet bridge's maintenance records.

1.9.10. *Effect of flying in manual mode on the crew's symptoms*

Since hypoxia and motion sickness exhibit common symptoms[47], the potential effect that flying in manual mode could have had on the crew's symptoms was analyzed.

To do this, the manufacturer used Annex D of the ISO 2631-1 Standard[48], "Guide to the effects of vibration on the incidence of motion sickness", which provides a method for quantifying the effects of movement in a vehicle to motion sickness. This method yielded a comparison of this flight against other flights based on the principle that oscillating vertical accelerations at frequencies near 0.2 Hz (between 0.1 and 0.5 Hz) are most prone, according to studies, to causing motion sickness in humans. The vertical speed and acceleration of the incident flight from takeoff until FL210 were used, along with the same data from the previous flight (obtained from the QAR). The data from an additional 25 flights involving this aircraft model with the autopilot on and no turbulence were also used.

The method defines a parameter, the MSDV (motion sickness dosage value), which the ISO relates to the probability of suffering from motion sickness.

This study found that:

- The presence of vertical accelerations at a frequency that is known to induce motion sickness was 2.5 times higher on the incident flight than on the previous flight, especially in the initial phases of the takeoff.
- The takeoff on the incident flight was different from that of the other 25 flights analyzed, with MSDV values of 6.16 $m/s^{1.5}$, versus an average of 3.74 $m/s^{1.5}$.
- The MSDV for a B767 flight with severe turbulence yielded a value of 25 $m/s^{1.5}$.

[47] The symptoms of motion sickness are facial paleness and/or blushing, cold sweat, retching and vomiting. The main symptom is nausea. There are other symptoms: upset stomach, dizziness, yawning, hot flashes and salivation. There is a large amount of individual variability in terms of the sensitivity to the stimulus, the duration of the symptoms and their intensity.

[48] The ISO 2631 Standard is used internationally to evaluate human exposure to whole-body vibrations. Its purpose is to define methods for quantifying these vibrations as they relate to human health and well-being, the likelihood of sensing said vibrations and their effect on motion sickness (nausea).

1.9.11. *Aerotoxic syndrome*

Several studies[49] have been conducted on what is known as Aerotoxic Syndrome, which is used to describe the symptoms that various crews and passengers have reported in connection with contaminating agents to which they may have been exposed during a flight. The symptoms associated with the syndrome include disorientation, headache, weakness, nausea and coordination problems. Some of those affected experienced these symptoms over a long time period, while others reported rapid recoveries. Even so, no medical studies have clearly established a link between any potential contaminating agents present on an aircraft and the symptoms reported by those affected.

1.10. Additional information

1.10.1. *Checklists*

The non-normal checklists used by the crew to handle the alerts and the emergency were the following: SPEED TRIM FAIL, A/P DISENGAGE, CABIN ALTITUDE WARNING or Rapid Depressurization and EMERGENCY DESCENT

The Ryanair Operations Manual specifies the following in terms of using non-normal checklists:

- They must be used once the aircraft's flight path and configuration are established, except for those situations that require an immediate response (as in the case of the cabin altitude warning).
- The flight path must never be compromised.
- The memory items are critical steps that must be carried out before the checklist is read. Both pilots must execute the memory items applicable to their area without delay. The last step is marked with the separation symbol.
- The non-memory items are actions to be carried out while reading the checklist.
- The pilot flying asks for the checklist when the flight path is under control, never during critical phases of flight and after the memory items are complete.
- The pilot not flying reads the checklist title and condition out loud.
- When a checklist has memory items, the pilot not flying first verifies that each item has been done and reads this check out loud. The non-memory items are also read by the pilot not flying.

[49] Mohamed B. Abou-Donia. "Autoantibodies to nervous system-specific proteins are elevated in sera of flight crew members: biomarkers for nervous system injury".
Rober Harrison. "Exposure to aircraft bleed air contaminants among airline workers".
Chris Winder, Jean-Christophe Balouet. "Aerotoxic syndrome: adverse health effects following exposure to jet oil mist during commercial flights".
Professor Michael Bagshaw. "Health effects of contaminants in aircraft cabin air".

- Each checklist has a list complete symbol at the end. This symbol may be in the middle only when a list is divided into two or more alternatives.
- After finishing a non-normal checklist, the pilot not flying must state "non-normal checklist complete".

The symbols used in checklists are the following:

- Checklist complete.

- Redirection: with the words "Go to" redirecting to another checklist.

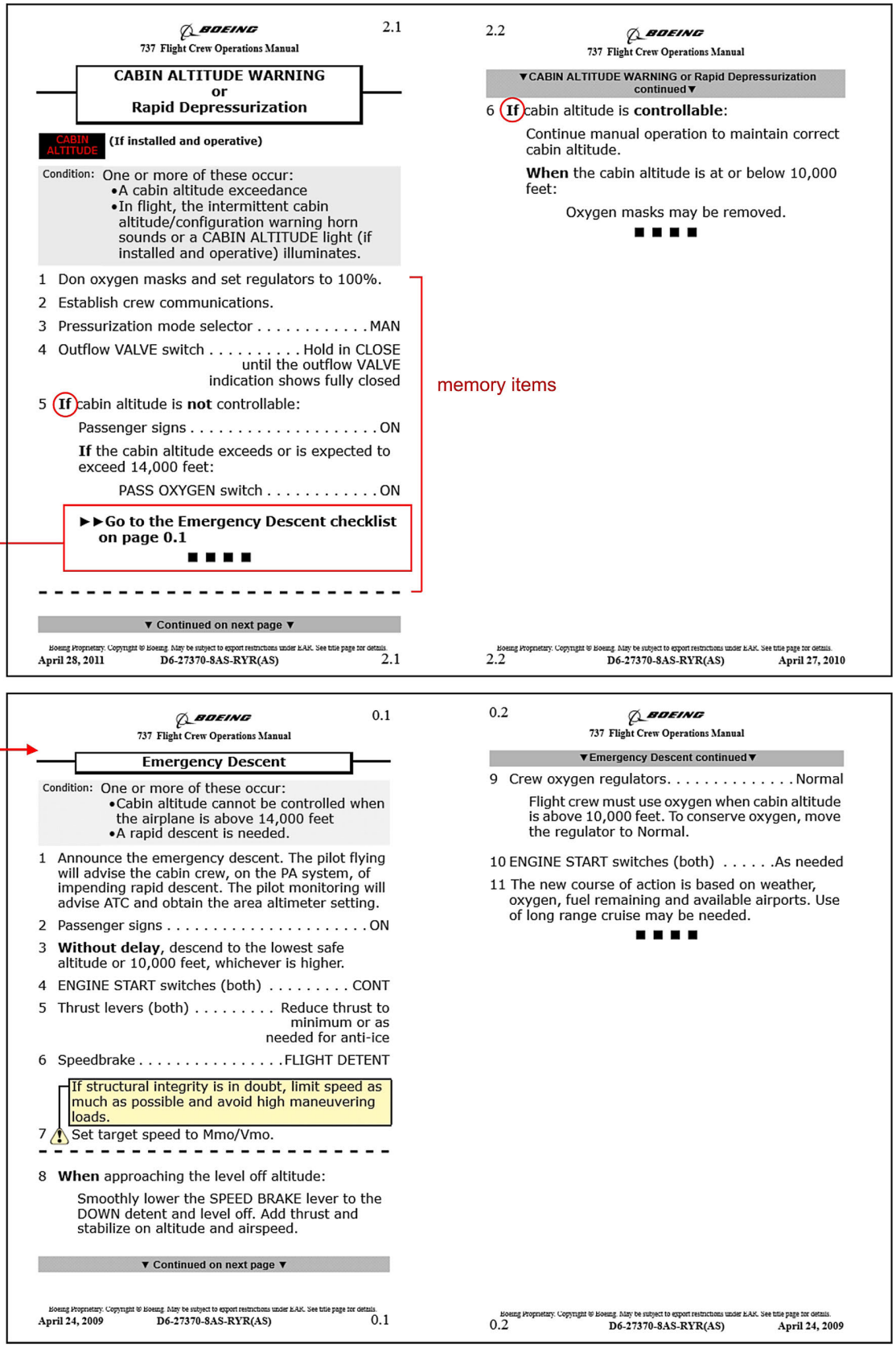
- Separation: separates the memory items from the rest.

- Decision: identifies possible options with the words "choose one:".

1.10.2. *CABIN ALTITUDE WARNING and EMERGENCY DESCENT checklists*

The checklist used by the crew after the emergency was the CABIN ALTITUDE WARNING, or Rapid Depressurization non-normal checklist. As used by crews, this checklist is two pages long (figure 8) and has six items, of which the first five are memory items (done without resorting to the QRH), and the fifth and sixth offer two options to choose from. The sixth is on a separate page and the fifth is part of the memory items.

Even though a decision point is present after item 4, the checklist uses the term "IF" instead of the decision symbol with the words "CHOOSE ONE". The reason for this, according to information provided by Boeing, is that human factors studies during the development of the checklists showed that crews had more problems memorizing "CHOOSE ONE" sequences than "IF" sequences. Thus, so as to make them easier to memorize, the memory items on checklists do not use the "CHOOSE ONE" formula, but rather "IF".



737 Flight Crew Operations Manual — 2.1

CABIN ALTITUDE WARNING or Rapid Depressurization

CABIN ALTITUDE (If installed and operative)

Condition: One or more of these occur:
- A cabin altitude exceedance
- In flight, the intermittent cabin altitude/configuration warning horn sounds or a CABIN ALTITUDE light (if installed and operative) illuminates.

1 Don oxygen masks and set regulators to 100%.

2 Establish crew communications.

3 Pressurization mode selector . . . . . MAN

4 Outflow VALVE switch . . . . . Hold in CLOSE until the outflow VALVE indication shows fully closed

5 **If** cabin altitude is **not** controllable:

Passenger signs . . . . . ON

If the cabin altitude exceeds or is expected to exceed 14,000 feet:

PASS OXYGEN switch . . . . . ON

►►Go to the Emergency Descent checklist on page 0.1

■ ■ ■ ■

▼ Continued on next page ▼

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memory items

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▼CABIN ALTITUDE WARNING or Rapid Depressurization continued▼

6 **If** cabin altitude is **controllable**:

Continue manual operation to maintain correct cabin altitude.

When the cabin altitude is at or below 10,000 feet:

Oxygen masks may be removed.

■ ■ ■ ■

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Emergency Descent

Condition: One or more of these occur:
- Cabin altitude cannot be controlled when the airplane is above 14,000 feet
- A rapid descent is needed.

1 Announce the emergency descent. The pilot flying will advise the cabin crew, on the PA system, of impending rapid descent. The pilot monitoring will advise ATC and obtain the area altimeter setting.

2 Passenger signs . . . . . ON

3 **Without delay**, descend to the lowest safe altitude or 10,000 feet, whichever is higher.

4 ENGINE START switches (both) . . . . . CONT

5 Thrust levers (both) . . . . . Reduce thrust to minimum or as needed for anti-ice

6 Speedbrake . . . . . FLIGHT DETENT

If structural integrity is in doubt, limit speed as much as possible and avoid high maneuvering loads.

7 ⚠ Set target speed to Mmo/Vmo.

8 **When** approaching the level off altitude:

Smoothly lower the SPEED BRAKE lever to the DOWN detent and level off. Add thrust and stabilize on altitude and airspeed.

▼ Continued on next page ▼

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0.2 — 737 Flight Crew Operations Manual

▼Emergency Descent continued▼

9 Crew oxygen regulators. . . . . Normal

Flight crew must use oxygen when cabin altitude is above 10,000 feet. To conserve oxygen, move the regulator to Normal.

10 ENGINE START switches (both) . . . . . As needed

11 The new course of action is based on weather, oxygen, fuel remaining and available airports. Use of long range cruise may be needed.

■ ■ ■ ■

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Figure 7. CABIN ALTITUDE WARNING and EMERGENCY DESCENT non-normal checklists

1.10.3. *Land Verify Test Procedure*

The Land Verify Test procedure carried out the night before the incident, in accordance with the Maintenance Manual, contains the following steps:

- (D) Prepare the aircraft for the test:
  - (2) Open the LANDING GEAR AURAL WARN CB and install a safety tag.
  - (3) Place the AUTOPILOT STAB TRIM SWITCH in the CUTOUT position.
- (F) Return the aircraft to its usual condition:
  - (2) Remove the tag and close the LANDING GEAR AURAL WARN CB.
  - (3) Place the AUTOPILOT STAB TRIM SWITCH in the NORMAL position.

1.10.4. *TAKEOFF CONFIG WARNING and CABIN ALTITUDE WARNING*

Aircraft EI-EKV featured a visual alert for the TAKEOFF CONFIG and a different one for the CABIN ALTITUDE[50]. In addition to this visual indicator, whenever either of these two conditions (cabin altitude above 10,000 ft or aircraft not properly configured) occurred, an intermittent warning horn sounded that was the same for both alerts.

The system is designed such that the TAKEOFF CONFIG warning can never occur in flight, meaning that the activation of the horn in flight must always be associated with an excessive cabin altitude. Despite these mutually exclusive conditions, this system, as described by the manufacturer in its Training Manual, can confuse crews and can even delay the start of the relevant procedure (CABIN ALTITUDE WARNING or Rapid Depressurization Non-normal checklist) [51].

The operator's manuals underscore this mutually exclusive condition and the fact that both alerts use the same aural warning.

[50] This differentiation did not always exist. It was implemented as a result of the HELIOS AIRWAYS accident, flight HCY522, Boeing 737-31S on 14 August 2005.

[51] After the HELIOS accident, changes were made to both the system and the procedures to avoid confusion regarding the type of emergency.

1.10.5. *Ryanair's actions after the incident*

After the incident, the operator took actions in the following areas:

- Remind crews and maintenance personnel of the need to document all incidents and activities involving aircraft in the Technical Log Book.
- Remind maintenance personnel of the need to leave aircraft properly configured after maintenance actions.
- Crew training in the following areas:

  – Depressurization and emergency descent.
  – Use of checklists.
  – Indications and operation of the pressurization in normal and manual modes.
  – Decision making.

- The incident crew underwent a Line Check and a Line Proficiency Check.
- Flight crews were trained on those cases in which a pilot can leave his/her seat.
- Flight attendants were reminded that they can never remove their oxygen masks until instructed to do so by the pilots.
- Consider the possible inclusion in the EMERGENCY DESCENT checklist of an aircraft depressurization procedure once the descent is completed.

2. ANALYSIS

The pressurization system on aircraft EI-EKV worked correctly during the incident flight. The system was working in automatic mode and during the taxi, takeoff and climb phases, and the cabin was pressurized according to a predefined profile. At the time of the incident, the cabin altitude was 3,774 ft. Then, without any contact between the cabin and cockpit, the purser contacted the cockpit and informed the captain that the cabin crew were feeling unwell. This confirmed his own feeling of being unwell. After the purser's call, the captain decided to declare an emergency, stop the climb, start the CABIN ALTITUDE WARNING procedure, although no such warning was received, and return to the Madrid-Barajas Airport.

The analysis of this incident considered the following aspects:

- The maintenance activity on the aircraft the day before that left it improperly configured, which was not detected or fully corrected prior to the flight.
- The problems with the aircraft that appeared at the start of the flight and that could have led the crew to mistrust their aircraft.
- The nature of the emergency: the lack of evidence for pressurization problems and for the presence of substances or elements in the aircraft that could have caused the symptoms in the crew.
- The handling of the emergency, with good and fast coordination between the cockpit and cabin, the immediate actions taken by the captain and the application of the CABIN ALTITUDE WARNING procedure.
- The handling of the rest of the flight, with the crew remaining calm and taking the time needed to configure the aircraft and ensure a safe landing, with the ensuing overpressurization and depressurization of the cabin.

2.1. Condition of the aircraft before the flight

A review of the aircraft's records and of the maintenance carried out on it did not indicate any events or problems similar to those present in the incident.

The day before the incident, the aircraft was subjected to a Land Verify Test by maintenance that was not logged anywhere. The base was transitioning from the previous maintenance organization to the current one, and the engineer who did the test had just arrived from Ireland. It was his first day as shift leader in Madrid and, he was constantly receiving calls, he said he was busy and he had to organize that nights work at the base.

In addition to not being logged, the test was not done in its entirety, as specified in the Maintenance Manual, which included restoring the aircraft's configuration and using tags on the circuit breaker, neither of which was done. Had these steps been done, it

would have helped to identify the incorrect position of the circuit breaker. The aircraft was left with an open circuit breaker in the panel behind the first officer's seat, and with a switch on the pedestal in the wrong position.

After this maintenance action, the aircraft was checked over by the mechanic who did the RAMP 1, by the crew that did the pre-flight checks, by the mechanic who was called in before the flight to solve the problem with the TAKEOFF CONFIG, and by the morning shift leader, who discovered the tripped circuit breaker. It is possible that if the test had been logged, the shift leader would have thought to look for other affected components. The switch was not detected on any of these four occasions even though the crew, as part of the BEFORE START checklist, reviewed the position of this very switch: "STAB TRIM CUTOUT... NORMAL". This item was read but not actually executed, and the switch remained in the CUTOUT position. Despite being in the pedestal, this switch is not usually operated by the crew.

Later, when the problems involving the autopilot and the SPEED TRIM FAIL occurred during the climb, the crew was unable to relate these faults to the switch on the pedestal. The non-normal checklists applicable to either case also did not instruct the crew to check any switch or circuit breaker in particular, since these warnings can be caused by a number of conditions.

2.2. The flight prior to the emergency declaration

Between the crew's arrival at the aircraft and the emergency declaration, there were a series of technical problems resulting from the maintenance activity carried out the night before. The aircraft was left with a tripped circuit breaker and with a switch in the cutout position. The former inhibited an aural warning and the latter prevented engaging the autopilot.

The first problem associated with the circuit breaker appeared when the crew started preparing the aircraft. The mechanic who reported to fix it told the crew that he was new on the job and that he did not know what the problem was. When the shift leader arrived, he quickly detected the open circuit breaker, but he left right away and the less experienced mechanic remained in the cockpit. The problem they had had involved the TAKEOFF CONFIG aural warning, which happened to be the same one that warned of a cabin altitude in excess of 10,000 ft. The crew was aware that this warning, the same as the one for the CABIN ALTITUDE, was not working on the ground. In fact the captain, while going over the emergencies, explicitly mentioned it: "If we have the intermittent warning horn, which is not working yet…" When later in the flight the crew felt sick, they thought of the problem they had had on the ground and assumed that the same thing was happening, that is, that the aural warning had failed again as had happened on the ground: "We didn't have this configuration warning because, I suppose, because of the problem we had on the ground".

One minute and 53 seconds after takeoff the problems with the second switch, which had not been restored after maintenance procedure the night before, started. The position of this switch caused the MASTER CAUTION to illuminate three times before the emergency declaration and made it impossible for the crew to engage the autopilot. In the ten minutes that had elapsed since taking off, the crew experienced one problem after another with the aircraft.

This series of events:

- Failure of the TAKEOFF CONFIG aural warning on the ground,
- Commonality between the CABIN ALTITUDE and TAKEOFF CONFIG aural warning,
- Having an inexperienced mechanic service the aircraft on the ground,
- Three MASTER CAUTIONs within ten minutes from takeoff, and
- The inability to engage the autopilot,

likely contributed to having the crew mistrust in the condition of their aircraft and to think that the excessive cabin altitude warning was not working.

2.3. The emergency

No evidence was found that the pressurization system was malfunctioning either during the incident flight nor during previous flights. The CABIN ALTITUDE WARNING was also not activated, as the conditions required for it never occurred. The feelings reported by the crew did not result from a lack of oxygen in the aircraft, since the cabin altitude never exceeded 10,000 ft and the aircraft was not exposed to flight altitudes above 10,000 ft for long enough to have caused hypobaric hypoxia. All of the options analyzed in terms of possible sources of contamination (external cleaning, internal cleaning, engine washings, pneumatic system, pressurization system, aircraft cargo, extinguishers in the cabin, engine extinguishing system and equipment used on the ground) gave no positive results. The checks and tests carried out after the incident showed that the aircraft was operating correctly and in proper condition, and the incident did not reoccur on subsequent flights.

The presence of inhaled contaminants is practically impossible to detect in routine medical exams, especially if they are not specifically tested for. In this case, the overpressurization and depressurization of the aircraft while taxiing resulted in the passengers being treated after the incident for the symptoms they had just experienced, that is, for barotrauma. The reports by the airport's medical service that these patients were "standing and alert" seems to indicate that if there had been some type of hypoxia due to contamination, it was not severe and the immediate use of the oxygen masks by the passengers helped to minimize the effects. Related to this hypothesis is the aero toxic syndrome, a recognized condition that is the subject of study and that presents similar conditions to those of this incident.

It was considered a third hypothesis in addition to hypoxia, namely motion sickness, as the flight was carried out without the autopilot engaged. The application of ISO 2631-1 showed that compared to a flight made with the autopilot engaged, the incident flight exhibited a higher number of vertical accelerations at a frequency that "induces nausea" (0.2 Hz), which seems logical. Flying in manual is not as stable as flying with the autopilot. However, a comparison of the incident flight against a flight with turbulence showed that it was more stable. Moreover, it is not normal for people who are used to flying in all types of weather conditions, including a captain with experience in acrobatic flights, to all feel dizzy at the same time during a flight, even if carried out in manual mode. It was very early, 7 in the morning, and weather conditions at the time indicated a "calm" atmosphere with no convective phenomena.

As a final possibility, it was considered the fact that the cabin crew reinforced one other's beliefs of thinking that the feeling of motion sickness was more intense than it actually was. The concern among the crew could have been reinforced by a weakening in the captain's physical condition caused by having stood up to check the circuit breaker panel. This possibility also remains unconfirmed but is considered unlikely, both given the experience of the captain and the rest of the crew, and because it would not explain the symptoms of the first officer, who remained seated.

In conclusion:

- The possibility of hypobaric hypoxia on the incident flight was ruled out.
- There was no evidence of contaminants that could have caused "hypoxia by poisoning", although
  - if it actually occurred, it was minor as its effects were not significant and it was immediately treated through rest and the use of oxygen;
  - it is difficult to detect through routine medical exams; and
  - the passengers and cabin crew were treated for the symptoms they exhibited due to the barotrauma, and did not at any time present symptoms consistent with poisoning of any type.

- Evidence was found of a larger number of vertical accelerations that could induce motion sickness in comparison to a flight made with the autopilot engaged, although:
  - compared to a flight with turbulence, this number was smaller;
  - it is not normal for people accustomed to flying professionally to all become nauseous at the same time in good weather conditions and doing different tasks, considering the variability in people's susceptibility to nausea;
  - the captain had experience in acrobatic flights, though he had stood up from his seat to check a panel.

Although no clear evidence exists to provide a certain explanation of what happened on the incident flight, the fact remains that several people (the two pilots and, to a

greater extent, FAs 1 and 2) who are used to flying on a routine basis, and with no previous contact, all agreed that they were experiencing the same physical discomfort. If in addition to the fact that the symptoms matched those of hypoxia, we consider the constant problems with the aircraft's climb, the inoperability of the CABIN ALTITUDE warning they discovered on the ground and that the crew was aware of, and the assistance provided by an inexperienced mechanic, it is understandable why the crew thought there was something wrong with the pressurization system and that their aircraft was unreliable.

2.4. The handling of the emergency

Regardless of the reason for the physical ailments suffered by the crew (hypoxia, nausea, suggestion or some combination of the three), within ten minutes of taking off the cabin crew thought that something was wrong and that what they were feeling was not normal. Before calling and alerting the cockpit crew, the purser checked with FAs 2 and 4, both of whom, especially FA 2, confirmed his suspicions. Following this confirmation the purser called the captain. This action by the cabin crew is regarded as highly appropriate, especially considering the consequences that a depressurization can have on flight safety.

The captain, too, used the call from the purser to confirm that something was wrong. The immediate order to stop the climb after the call suggests that he was already unwell and that his own condition must have been similar to that described by the purser.

It is not known whether he looked at the cabin altitude value, which at the moment read 3,774 ft. In their statements the captain and first officer reported having seen an abnormal reading, but they did not recall the exact value. Hypoxia diminishes one's cognitive abilities, and could have made it difficult for them to process the value or to remember it. In any case, the situation facing the captain at that moment was one in which the cabin and cockpit crews, with no previous communications between them, both reported feeling symptoms related to hypoxia. Furthermore, as the aural warning for cabin altitude warning had not worked on the ground, even had the cabin altitude readings been normal, the decision not to take any risks under those conditions was correct.

Thus, the captain's decision to stop the climb, declare a MAYDAY, deploy the oxygen masks and immediately start the CABIN ALTITUDE WARNING or Rapid Depressurization procedure was the best response to the situation they thought themselves in, due to the risk of incapacitation and loss of control posed by this emergency.

2.4.1. *Application of the CABIN ALTITUDE WARNING checklist*

The captain's immediate order to stop the climb after the call from the passenger cabin initially surprised the first officer who was relatively inexperienced. They had spoken

among themselves about how they felt before the purser's call, meaning that apart from his own physical condition, he had no additional information. The captain's actions were clear and immediate: to stop the climb and declare an emergency to ATC. Seconds later the pilots' and passengers' masks were deployed and the rest of the actions in the CABIN ALTITUDE WARNING, including closing the outflow valve, quickly followed.

The communications that followed show that the first officer read item 5 of the CABIN ALTITUDE WARNING checklist. The rest was spoken literally word by word from the checklist, meaning that the five memory items had been executed and they were reading the checklist, as specified in the operator's procedure for carrying out non-normal checklists.

The entry into this checklist was one of the critical moments in this incident, as it was then that the crew closed the outflow valve and kept it closed until the end of the flight, causing the subsequent overpressurization and depressurization of the cabin.

The checklist, as described in Section 1.10.2, included five memory items. Number 3 was to place the pressurization system in manual mode and 4 was to fully close the outflow valve, which the crew did. Item 5, despite being a memory item, gives the crew a choice between two options. The other option, item 6, which was the condition in effect in this incident, is not a memory item and is on a different page. Furthermore, there is a "checklist complete" and a redirection to another checklist after item 5. This means that crews memorize the cabin depressurization only in the event that the cabin altitude cannot be controlled.

In this case it is not known whether or not the crew attempted to verify if the cabin altitude was controllable or not, and thus determine if the correct option was item 5 or 6. But subsequent communications suggest they were sure that the first 5 steps (the memory items) were the ones that were applicable. The crew thought they had applied the procedure correctly and focused on the remaining tasks involved in the emergency: flying the aircraft, procedures, coordinating with ATC, informing the cabin crew and configuring the aircraft for a safe landing. That is why the captain was so surprised on touching down when he saw that the cabin was pressurized.

This mistake in applying the checklist is more significant in a crew that throughout the flight, not only before the incident but also afterwards, exhibited excellent discipline and adherence to every procedure and to flight management, identifying the start and end of each checklist, perfectly dealing with interruptions to checklists, prioritizing the aircraft's configuration rather than landing immediately and hastily, restarting checklists when interrupted and using the PIOSEE methodology after addressing the immediate emergency.

Throughout the flight, and especially after the emergency declaration, the captain clearly exercised his leadership role by taking the initiative, organizing and communicating all of his actions and intentions to the first officer, who was sure at all times of what he

had to do and of what the captain's intentions were ("I'm back to you", "you have controls", "you keep the controls and I make the aircraft ready for the 33"). The crew was focused on rigorously adhering to the checklists at all times and balanced the constant communications with ATC with the handling of the emergency.

The full management of the emergency comprised the use of the CABIN ALTITUDE WARNING checklist and, as directed by this checklist, of the EMERGENCY DESCENT checklist. It took the crew 6 minutes 3 seconds to complete the first one, and 3 minutes 40 seconds for the second one. The reason was the frequent communications with ATC that took place during the emergency, forcing the crew to interrupt the checklists. The captain handled communications with ATC (figure 4). From an ATC standpoint, the aircraft was in a busy traffic area, the approach to the Madrid-Barajas Airport, in a transitional phase of flight where handling emergency traffic required considerable coordination. In addition the crew, which were focused on the emergency they were attempting to manage, did not make their intentions clear, having to specify them with each call from ATC.

ATC's intention from the start was to give them landing priority by clearing them to descend and directing them to the airport. Within two minutes of the emergency declaration, ATC offered them the choice of heading directly to the airport. It was the captain, who was still carrying out the CABIN ALTITUDE WARNING checklist, who reported needing to maintain altitude. From then on, the captain's demands to ATC were frequent, as they needed more time to complete the approach. ATC did not wait until the captain called them when he was ready; rather, it was the controller who, on several occasions, asked about how much time they needed.

The crew followed ATC's instructions at all times. The only initiative they took was to stop the climb at the start of the emergency, an action they reported to ATC along with the emergency declaration. They did not start the descent until cleared to do so by ATC. ATC also facilitated the hold maneuvers for as long as required by the aircraft.

2.5. Management of the rest of the flight

As specified by the CABIN ALTITUDE WARNING procedure, the crew fully closed the outflow valve, as required by item 4 of the checklist. Since this procedure was not applicable, the valve was kept closed. In this case, the crew should have gone on to item 6 on the checklist, which specified operating the outflow valve in manual to control the cabin altitude.

Since the air conditioning packs remained in operation with the outflow valve closed, the cabin overpressurized. Within two minutes of the emergency declaration the cabin altitude was 0 ft, and the needle on the cabin altitude indicator would have been on 0. It is not known what happened to the cabin altitude reading after that and whether it continued to move counterclockwise, as it is not designed to indicate altitudes below

0 ft. The crew were busy doing the CABIN ALTITUDE WARNING and EMERGENCY DESCENT checklists, answering calls from ATC and manually flying the aircraft. Even though no reference to the cabin altitude was heard, during the descent, at 07:50:52, the captain interrupted the EMERGENCY DESCENT checklist to say, "We are at ten thousand feet, I suggest you to remove your mask…" This interruption took place with the aircraft at an approximate altitude of 6,000 ft and with a pressure of 20.4 psi, equivalent to a cabin altitude of –9,398 ft. In other words, the "ten thousand feet" referred to the cabin altitude, meaning that the captain must have been monitoring this parameter and waited until the needle crossed the 10 (10,000 ft) on the dial to interrupt the checklist and remove their masks. This also suggests that the needle was moving counterclockwise and the captain saw how the cabin altitude was falling.

While taxiing, the cabin was overpressurized and the pressure was fluctuating significantly, causing the ear discomfort felt by the passengers and crew. It was then that the captain made the next comment regarding the cabin altitude and reported seeing it above 10,000 ft.

These two altitude readings seem to indicate that the needle was approximately indicating the altitude as a positive value; in other words, if this continued for the rest of the flight, the cabin reading would have been at around 10,000 ft. Starting two minutes after the emergency declaration, the dial would not have been reliable, as it started indicating altitudes below 0 ft, though the crew had no way of knowing this. In contrast, when updating the purser on the situation in the passenger cabin during the NITS briefing, he informed him that everything was calm.

The captain's comments indicate that he did not understand what was happening. He was sure that they had applied the procedure correctly and did not understand why the cabin altitude was behaving that way.

It was then that the captain decided to turn off the air conditioning packs and operate the outflow valve to depressurize the cabin. This process lasted 1 minute and 27 seconds, a period in which the maximum cabin pressure change rate, 6,350 slfpm, was recorded by the system. It was this cabin depressurization process over this time period that caused the barotrauma in the passengers.

The differential pressure in the cabin also remained high during the flight, with the relief valves actuating upon reaching the setpoint designed to prevent structural damage to the aircraft. As concerns the pressurization system, it did not malfunction.

The airport's handling of the emergency was fast and proper. The services provided to the passengers and aircraft were adequate and the necessary services were activated.

The operator addressed all of the aspects analyzed in this incident, and as a result it is not necessary to issue any safety recommendations.

3. CONCLUSIONS

3.1. Findings

- The crew had valid licenses and medical certificates.
- The crew had rested the day before.
- Weather conditions were good and there were no convective phenomena.

Aircraft

- The aircraft had undergone unrecorded maintenance the night before that had resulted in a circuit breaker and switch being left in the wrong position.
- The incorrect position of the circuit breaker (LANDING GEAR AURAL WARNING CIRCUIT BREAKER) prevented the operation of the TAKEOFF CONFIG WARNING horn.
- The TAKEOFF CONFIG WARNING horn is the same that is used for the CABIN ALTITUDE WARNING.
- The circuit breaker's position was detected and corrected before takeoff.
- The incorrect position of the STAB TRIM switch prevented engaging the autopilot.
- The position of the switch was not detected before takeoff and resulted in the constant activation of the MASTER CAUTION during the flight.
- The MASTER CAUTION activated 20 times during the flight, three before the emergency declaration and 17 after.
- The airplane was flown in manual, without the autopilot.
- The maintenance base in Madrid was in a transition phase due to a change in the maintenance organization one week before the incident.
- The maintenance technician who serviced the aircraft the night before had just arrived in Madrid a few hours earlier.

Flight

- After the takeoff, the incorrect position of the STAB TRIM switch caused the MASTER CAUTION to activate three times and the autopilot could not be engaged.
- During the climb, the captain stood up to try to solve the problem with the autopilot.
- Ten minutes after takeoff, the cabin crew informed the captain that they felt unwell. The pilots also felt sick.
- The symptoms reported by the crew were consistent with hypoxia.
- The CABIN ALTITUDE WARNING did not activate and was working correctly, due to conditions for this warning to activate didn't exist.
- The maximum cabin altitude was 3,774 ft and the pressurization system on the aircraft worked correctly.
- The crew's actions were coordinated, fast and proper for the situation.
- The crew's decision to stop the climb, deploy the oxygen masks, declare an emergency and return to Madrid was proper for the situation they thought they were in.
- The crew declared an emergency, started the CABIN ALTITUDE WARNING procedure and returned to Madrid-Barajas.

- The possibility of hypobaric hypoxia has been ruled out.
- The outflow valve was kept closed from the declaration of the emergency until the end of the flight.
- Starting two minutes after the emergency declaration, the altitude cabin reading dropped below 0 ft.
- The cabin altitude indicator is not designed to show altitudes below 0 ft.
- While taxiing in Madrid high cabin pressure caused the relief valves to open because of the maximum differential pressure set point being reached.
- The crew did not understand what was happening with the cabin altitude during the taxi phase.
- The cabin depressurized from 22.59 psi to the pressure at Madrid-Barajas in 1 minute and 27 seconds. It is this process that caused the barotrauma in the passengers and the discomfort in the captain.

After the flight

- There was no emergency evacuation.
- A local alert was declared at the Madrid-Barajas Airport and the emergency response was adequate.
- Four passengers were treated on the airplane.
- The airport's medical service treated a total of 16 people, two of whom were taken to the Ramón y Cajal Hospital.
- The flight attendants were treated by the medical service. The pilots did not report to the airport's medical service.
- Air traffic control gave priority to the aircraft in landing and accommodated the holds it requested.

3.2. Causes

The cause of the symptoms reported by several members of the crew (the two pilots, and particularly by two of the four flight attendants) onboard aircraft EI-EKV could not be determined. The hypotheses considered to possibly explain said symptoms were hypoxia by poisoning, motion sickness, suggestion among members of the crew or a combination of the last two.

The following factors contributed to the incident and to the handling of the emergency:

- the crew's suspicion that the aircraft was malfunctioning, as evidenced by the constant problems since taking off, specifically the operation of the aural warning of the CABIN ALTITUDE WARNING, which had not worked prior to the flight, and
- the possible confusion in executing the CABIN ALTITUDE WARNING or Rapid Depressurization checklist due to:
  - including an option between two choices as part of memory item 5,
  - having a second option (item 6) on a different page, and
  - completing the checklist and redirecting to another as part of the memory items.