Technical report

IN-006/2020

Incident involving a Boeing 767-375ER aircraft operated by Air Canada, registration C-GHOZ, at Madrid-Adolfo Suárez Airport (Madrid) on 03 February 2020

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

MINISTRY OF TRANSPORT, MOBILITY AND URBAN AGENDA

SUBSECRETARY

CIVIL AVIATION ACCIDENT AND INCIDENT INVESTIGATION COMMISSION

NOTICE

This report is a technical document that reflects the point of view of the Civil Aviation Accident and Incident Investigation Commission regarding the circumstances of the accident object of the investigation, its probable causes and its consequences.

In accordance with the provisions in Article 5.4.1 of Annexe 13 of the International Civil Aviation Convention; and with Articles 5.6 of Regulation (EU) No 996/2010 of the European Parliament and of the Council of 20 October 2010; Article 15 of Law 21/2003 on Air Safety; and Articles 1 and 21.2 of RD 389/1998, this investigation is exclusively of a technical nature, and its objective is the prevention of future aviation accidents and incidents by issuing, if necessary, safety recommendations to prevent their recurrence. The investigation is not intended to attribute any blame or liability, nor to prejudge any decisions that may be taken by the judicial authorities. Therefore, and according to the laws detailed above, the investigation was carried out using procedures not necessarily subject to the guarantees and rights by which evidence should be governed in a judicial process.

Consequently, the use of this report for any purpose other than the prevention of future accidents may lead to erroneous conclusions or interpretations.

CONTENTS

ABBREVIATIONS

ACC……………………….Air control centre
AESA ....Spain's National Aviation Safety Agency
AGL.............................. Above ground level
ATC .... Air traffic control
ATPL(A) ....Airline transport pilot license (aircraft)
CGA ....Airport management centre
COAM ....Movement area operations coordinator
ECAO............................Operational air traffic squadron
FDR...............................Flight data recorder
FOD ....Foreign object debris
fpm................................Feet per minute
h....................................Hours
IFR ....Instrumental flight rules
kg ....Kilogrammes
km ....Kilometres
kt ....Knots
L....................................Left (runway identification)
LECM ....Callsign for Madrid air control centre
LECU ....Callsign for Madrid-Cuatro Vientos Airport
LEMD Callsign for Adolfo Suárez Madrid-Barajas Airport
LEMDAIN ....Callsign for the initial approach sector of Madrid TMA, North configuration
LEMDDWN-WNN..........Callsign for the integrated Westerly take-offs and North-West sector of Madrid TMA, North configuration
m...................................Metres
MCT .... Maximum continuous thrust
MHz……………………….Megahertz
MLG ....Main landing gear
min ....Minutes
mm................................Millimetres
MTOW........................... Maximum take-off weight
NLG...............................Nose landing gear
NM ....Nautical mile

OJTI……………………….On-the-job-training-instructor (for controllers)
p/n................................Part number
PDC ....Pre-departure check
PF ....Pilot flying
PNF..............................Pilot not flying
psi ....Pounds per square inch
R ....Right (runway identification)
s ....Second(s)
s/n ....Serial number
SSEI.............................Spanish Rescue and Firefighting Service
SPP..............................Runway and Apron Service
CC................................Cabin crew
TOAM...........................Movement area operations technician
TOCA...........................Acceleration altitude
TOGA...........................Take-off/Go-around power
UTC..............................Coordinated universal time
WOW ....Weight on wheels

SYNOPSIS

Owner and operator:	Air Canada
Aircraft:	Boeing 767-375ER, registration C-GHOZ
Date and time of incident:	Monday, 03 February 2020, 14:58 local time[1]
Site of accident:	Madrid-Adolfo Suárez Airport
Persons on board:	Crew: 8, uninjured
	Passengers: 130, uninjured
Type of flight:	Commercial air transport - International - With passengers
Flight rules:	IFR
Phase of flight:	Take-off
Date of approval:	30 June 2021

Summary of accident:

On Monday, 03 February 2020, the Boeing 767-375 aircraft, registration C-GHOZ, operated by Air Canada with flight number ACA837, departed from Madrid-Adolfo Suárez Airport (Spain) destined for Toronto Pearson Airport. (Canada). At 14:58:03, two seconds before lift off, the wheel number 5 (the left rear wheel on the left main landing gear) experienced a tyre burst and thrown tread. During the incident, several tyre fragments were ingested by the left engine (number 1), causing internal damage.

The crew continued with the take-off, shut down the left engine and declared an emergency at 700 ft AGL while still on the runway heading. After several conversations with ATC, the aircraft was instructed to fly to the southeast of the airport, where, in order to land with less weight, it flew holding patterns at 5,000 ft and then 8,000 ft to consume fuel. During this holding period, a military aircraft from the Torrejón de Ardoz Air Force base was mobilised to verify the location and extent of the damage to the landing gear.

By 18:56, the aircraft had consumed sufficient fuel to land and began its approach to runway 32L at Madrid-Adolfo Suárez Airport. The aircraft landed without incident and came to a halt on the runway at 19:08, where it remained until the temperature of the landing gear brakes had been reduced using fans. The aircraft finally exited the runway without assistance at 19:55, and at 20:11, the passengers disembarked normally. Nobody on board was injured during the incident.

The investigation has determined that the incident involving the C-GHOZ aircraft was caused by the presence of a sharp foreign object (FOD) on runway 36L at Madrid-Adolfo Suárez Airport, which punctured tyre number 5 on its left main landing gear and resulted in the explosion of the tyre and other secondary failures.

[1] All times used in this report are local time, as extracted from the flight data recorder (FDR). There is a 5 second lag between the ATC times and those recorded in the FDR. Therefore, the FDR time is 5 seconds ahead of the ATC time.

The report contains 4 safety recommendations: Three are addressed to ENAIRE as the air navigation service provider for the units involved, and one to AENA, as the runway and apron inspection service provider at Madrid-Adolfo Suárez Airport.

1. FACTUAL INFORMATION

1.1. History of the flight

On Monday, 03 February 2020, the Boeing 767-375 aircraft, registration C-GHOZ, operated by Air Canada with flight number ACA837, departed from Madrid-Adolfo Suárez Airport (Spain) destined for Toronto Pearson Airport. (Canada).

There were 138 people on board: 2 pilots (commander and co-pilot), 6 cabin crew and 130 passengers. The flight's departure was delayed by 2 hours due to a drone being detected in the proximity of Madrid Airport, which forced the airfield to close. Once resolved, the airport re-opened following an inspection of the runways. At 14:40:27, the aircraft, which weighed 168.4 tonnes (less than the MTOW of 183.8 tonnes), taxied from parking stand 72. It was fourth in the departure sequence. The taxi took 17 minutes; then, at 14:57:21, it began its take-off run from runway 36L, with take-off thrust and flaps 5 for the ZMR5L instrument departure. The take-off reference speeds were 158 kt (V_1), 160 kt (V_r) and 166 kt (V_2).

At 14:58:00, the aircraft reached V_1 (158 kt), and at 14:58:03, two seconds before rotation, the tyre on the left rear wheel of the main landing gear burst (tyre number 5). The footage from the airport's surveillance cameras allowed to confirm that the left engine ingested several of the shredded tyre tread fragments and, together with the data from the flight data recorder (FDR), to reconstruct the following sequence of events, where t=+0 s is the moment the tyre burst (14:58:03).

t=+0 s tyre burst and fragments ingested by the left engine (14:58:03)

t=+1.2 s first flame (14:58:04)

t=+2 s rotation begins (nose landing gear sensor in AIR mode) and second flame (14:58:05)

Figure 1. Sequence between 14:58:03 (explosion) and 14:58:05 (rotation begins)

Figure 2. Tyre number 5 piece and ingestion by the engine (14:58:03, t=+0 s)

The aircraft continued with the take-off while simultaneously initiating the process to shut down the left engine and declaring an emergency due to an engine failure:

t=+36 s	A/T (autothrottle) disconnected
t=+39 s	thrust lever pulled back
t=+50 s	distress call: "*MAYDAY MAYDAY MAYDAY with engine failure*"
t=+62 s	engine fuel cut-off valve closed

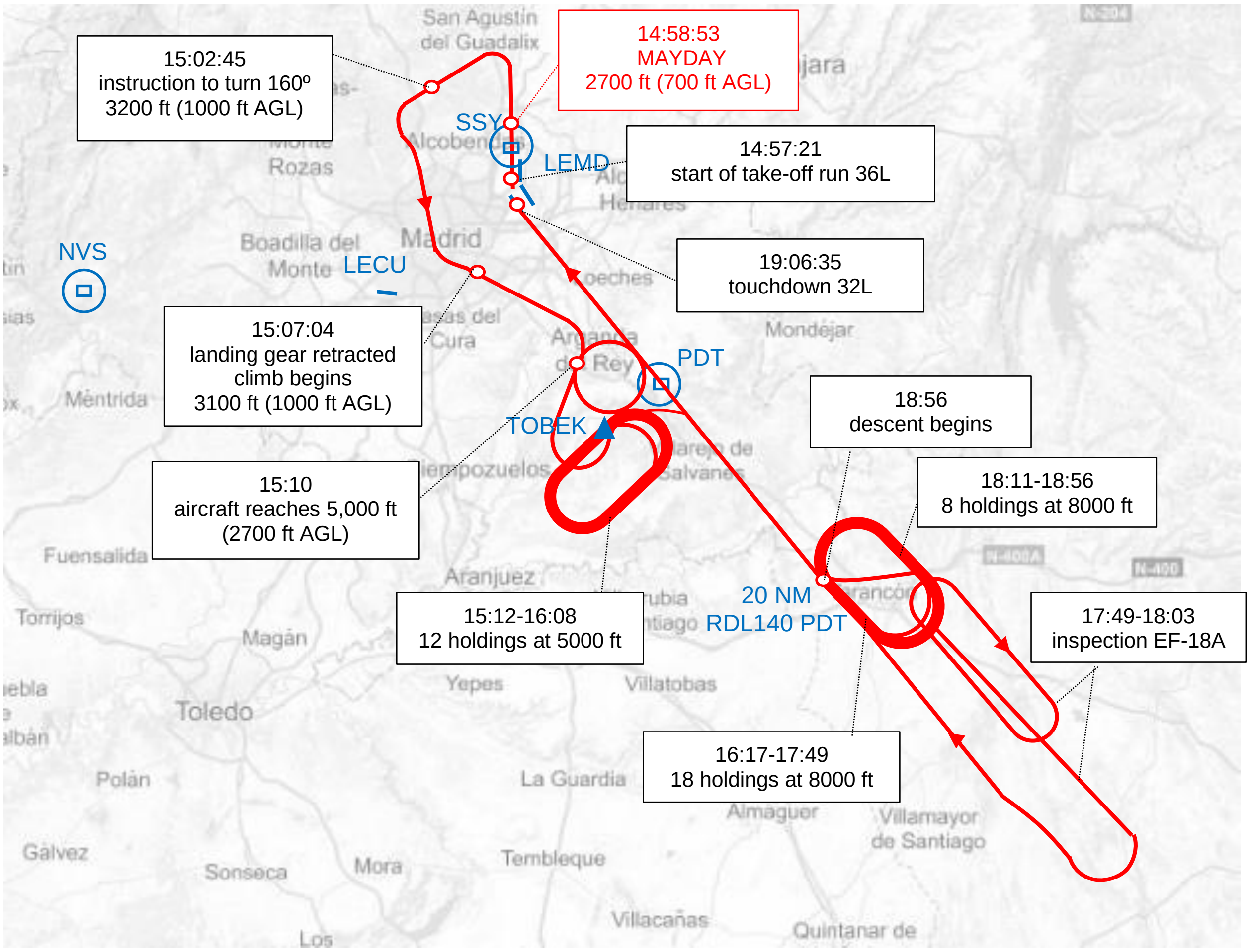


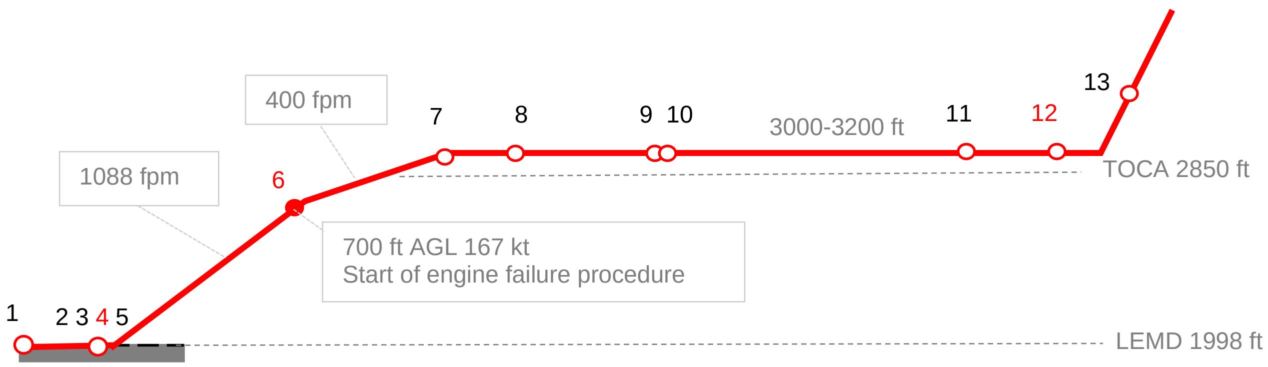
Figure 3. Complete trajectory

The aircraft remained on the runway heading until it climbed above the acceleration altitude (2,850 ft). It then levelled at 3,000 ft (1,000 ft AGL) and subsequently turned southeast towards DVOR/DME NVS (hereinafter NVS). On the sector towards NVS, the aircraft carried out a series of communications with ATC, during which the crew confirmed that one of the landing gear tyres had exploded, that they were flying with one engine, that they were having problems retracting the landing gear and climbing and requesting radar vectors to descend to a lower altitude.

At 15:02:45, when the aircraft was at 1,000 ft AGL (3,200 ft of altitude) above the town of Tres Cantos, ATC instructed the aircraft to turn south (160º). For the next 5 minutes, it maintained 3,100 ft altitude (1,000 ft AGL), increased its speed and retracted the flaps while flying over the centre of Madrid.

At 15:06:00, the aircraft requested a zone to hold in but could not specify how long they would need to do so.

At 15:07:04, the crew managed to retract the landing gear and began to climb above 3,100 ft altitude (1,000 ft AGL), notifying ATC of their actions.



1	14:57:21		take-off run initiated 36L LEMD TOGA + flaps 5	
2	14:58:00		V_1 (158 kt)	
3	14:58:01		V_r (160 kt)	
4	14:58:03	t=0 s	EVENT 168 kt	
5	14:58:05	t=+2 s	V_{LOF} 171 kt	
	14:58:20	t=+17 s	400 ft AGL – 167 kt	
6	14:58:39	t=+36 s	Procedure initiated	700 ft AGL 167 kt
7	14:59:24	t=+1 min 21 s	Start of level segment at 3,000-3,200 ft and increase speed	
8	15:01:10	t=+3 min 07 s	Failed attempt to retract landing gear	3,000 ft - 190 kt
9	15:03:30	t=+5 min27 s	MCT	3,000 ft -210 kt
10	15:03:44	t=+5 min 41 s	retraction to flap 1 (V_{ref30}+40)	3,200 ft - 216 kt
11	15:06:16	t=+8 min 13 s	retraction to flap 0 (V_{ref30}+60)	3,200 ft - 230 kt
12	15:07:04	t=+9 min 01 s	landing gear retracted	3,200 ft - 230 kt
13	15:08:33	t=+10 min	climb to 5,000 ft (V_{ref30}+80)	240 kt

Figure 4. Diagram of the ascent profile (not to scale)

At 15:10, the aircraft reached an altitude of 5,000 ft and was instructed to head towards TOBEK, where it would maintain that altitude and fly 12 holdings, between 15:12 and 16:08. Having completed the holdings over this point, the crew confirmed they would need 3 more hours of flight to offload weight and that they could do so at any navigation point.

At 16:08, the aircraft left TOBEK to go to mile 20 of the 140 radial from DVOR/DME PDT (hereinafter PDT), placing it 36 NM from the runway, where it would fly 18 holdings at an altitude of 8,000 ft, between 16:17 and 17:49.

At 17:49, the aircraft departed the area towards the southeast so that the Air Force EF-18A aircraft mobilised from the Torrejón base could inspect the condition of the landing gear. The inspection took place between 17:49 and 18:03 and confirmed the extent and location of the damage. At 18:03, the crew retracted the landing gear and flaps that had been extended for inspection and returned to the previous area to complete a further 8 holdings at 8,000 ft.

At 18:56, the aircraft began its approach to runway 32L from the 8,000 ft altitude it had been holding at and 36 NM on the final approach to the aforementioned runway.

The crew extended the landing gear at 19:03.

Touchdown (WOW sensors in ON mode) was recorded at 19:06:35, with flaps 20 and a weight of 142.9 tonnes. Two minutes later, the aircraft had come to a halt on the runway, and the airport's Rescue and Firefighting Service began cooling the brakes with fans.

The passengers remained on board for almost an hour, until at 19:55, the aircraft began taxiing under its own power to leave the runway. At 19:59, it reached its parking stand (parking stands 1 and 2), and at 20:11, the passengers disembarked normally, with nobody on board having sustained any injuries during the incident.

Figure 5. Left main landing gear (seen from behind) after the landing

1.2. Injuries to persons

Injuries	Crew	Passengers	Total in the aircraft	Others
Fatalities				
Serious				
Minor				
Unharmed	8	130	138	
TOTAL	8	130	138	

1.3. Damage to the aircraft

The aircraft sustained significant damage to the left main gear (wheel number 5, panel and tilt sensor) and left engine (engine interior and exterior fairings). The fairing of flap number 3 and various panels located above the left main gear sustained minor impacts.

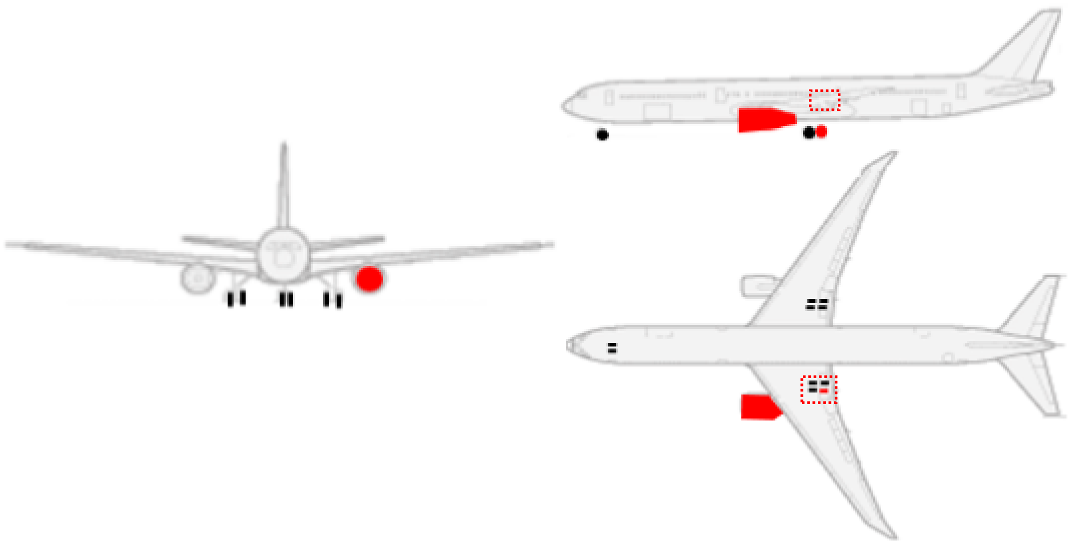


Figure 6. Damage to the aircraft

1.4. Other damage

None.

1.5. Personnel information

1.5.1 Information about the aircraft's personnel

The commander was 52 years old. He had a valid ATPL(A) license with a valid B767 rating. He had an accumulated total flight experience of 25,000 h, of which 13,349:50 h were with Air Canada. He had 1,300 h of flight experience on the B767.

The co-pilot was 35 years old. He had a valid ATPL(A) license with a valid B767 rating. He had an accumulated total flight experience of 6500 h, of which 619:34 h were with Air Canada. He had 619:34 h of flight experience on the B767.

The service director was 52 years old and had 31 years of experience with Air Canada.

The entire flight crew (two pilots and six cabin crew) had slept in a hotel in the centre of Madrid the night before the incident. They were picked up from the hotel at 11:45 and transferred to the airport, arriving at approximately 12:10.

1.5.2 Information about the control tower personnel

Two ATC units intervened in the incident: the Madrid-Barajas Adolfo Suárez control tower and the Madrid ACC, with different sectors managed by each of them. They are listed according to their order of interaction with the aircraft during the event:

1. At the time of take-off, there were two people in the Madrid-Barajas Adolfo Suárez control tower: an instructor local controller (OJTI) and a trainee local controller.

   The instructor local controller, LCL36L, was 47 years old and had an air traffic controller license issued by AESA on 16 August 2000. He had 15 years of experience at the unit and valid aerodrome control rating unit endorsements in force until 06 October 2020.

   The trainee local controller, LCL36L, was 40 years old and had an air traffic controller license issued by AESA on 01 June 2010. On the day of the incident, she did not yet have the required unit endorsements as he had not completed her unit training.

2. At the Madrid ACC LEMDDWN-WNN Integrated Sector, there were 2 people: an executive controller and a planning controller.

   The executive controller was 64 years old and had an air traffic controller license issued by AESA on 15 September 1983. He had 10 years of experience at the unit and valid aerodrome control rating unit endorsements in force until 18 May 2020.

   The planning controller was 57 years old and had an air traffic controller license issued by AESA on 15 February 1993. He had 8 years of experience at the unit and valid aerodrome control rating unit endorsements in force until 10 May 2020.

3. At the Madrid ACC LEMDAIN Sector, there were 2 people: an executive controller and a planning controller.

   The executive controller was 45 years old and had an air traffic controller license issued by AESA on 18 December 2002. He had 10 years of experience at the unit and valid aerodrome control rating unit endorsements in force until 04 February 2021.

   The planning controller was 52 years old and had an air traffic controller license issued by AESA on 15 September 1998. He had 10 years of experience at the unit and valid aerodrome control rating unit endorsements in force until 16 October 2020.

4. The executive controller for the Madrid ACC LEMDAIN Sector was relieved during the incident.

   The new executive controller was 60 years old and had an air traffic controller license issued by AESA on 30 June 1997. He had 10 years of experience at the unit and valid aerodrome control rating unit endorsements in force until 23 May 2020.

5. At Madrid ACC, frequency 130.8 MHz[2], there was an executive controller.

   The executive controller was 51 years old and had an air traffic controller license issued by AESA on 06 July 2000. He had 8 years of experience at the unit and valid aerodrome control rating unit endorsements in force until 02 October 2020.

6. At the Madrid ACC LEMDAIN Sector, there was an executive controller.

   The executive controller was 48 years old and had an air traffic controller license issued by AESA on 20 December 2002. He had less than one year of experience at the unit and valid aerodrome control rating unit endorsements in force until 10 April 2020.

7. At the Madrid ACC LEMDAIN Sector, there was an executive controller.

   The executive controller was 57 years old and had an air traffic controller license issued by AESA on 17 June 1987. He had 10 years of experience at the unit and valid aerodrome control rating unit endorsements in force until 09 October 2020.

8. At the time of landing, there were two people in the Madrid-Barajas Adolfo Suárez control tower: a local controller LCL32L and a ground movement controller.

   The local controller, LCL32L, was 50 years old and had an air traffic controller license issued by AESA on 26 May 2006. He had 8 years of experience at the unit and valid aerodrome control rating unit endorsements in force until 02 January 2021.

   The ground movement controller was 47 years old and had an air traffic controller license issued by AESA on 07 April 1998. He had 12 years of experience at the unit and valid aerodrome control rating unit endorsements in force until 24 November 2020.

1.5.3 Information about the airport personnel

The personnel on duty for the Madrid-Adolfo Suárez airport runway and apron service that carried out the pre-flight inspection of runway 36L were as follows:

The Movement Area Operations Coordinator (COAM) was 56 years old. He had 30 years of runway inspection experience: the first 10 years as a TOAM and 20 years as a COAM.

The movement area operations technician (TOAM) was 53 years old. He had 11 years of experience as a TOAM.

1.6. Aircraft information

The Boeing 767-375ER model aircraft, registration C-GHOZ, s/n 24087, operated by Air Canada, had a total of 58,889:42 flight hours and 10,099 cycles. It had two General Electric CF6-80C2 engines. The left engine (number 1), s/n 702775, had accumulated 102,022 h and 17,592 cycles.

[2] This frequency does not belong to a specific sector. It is a frequency available for contingencies in the Madrid TMA (AIP ENR 2.1-25).

The right (number 2), s/n 702385, had accumulated 113,204 h and 6,561 cycles. The aircraft was not equipped with a quick fuel-dumping system.

The flight involved in the incident was the aircraft's second flight that day, having previously flown the reverse Toronto-Madrid route. That flight took 6 hours and 49 minutes, landing in Madrid at 12:11 without incident.

1.6.1 Weight of the aircraft during the flight

The maximum operating weights for this aircraft were as follows:

- Maximum take-off weight (MTOW): 183,800 kg.
- Maximum landing weight (MLW): 145149 kg.

On take-off:

- Weight without fuel: 116,700 kg.
- Weight of the fuel[3]: 51,752 kg.
- Weight on take-off: 168,452 kg.

On landing:

- Weight of the fuel: 26,223 kg.
- Weight on landing: 142,923 kg.

1.6.2 Condition of the aircraft before take-off

The aircraft underwent a PDC (pre-departure check) in Madrid prior to take-off. The PDC did not identify any abnormalities in the landing gear. The inspection included (*item 5, Aircraft exterior*):

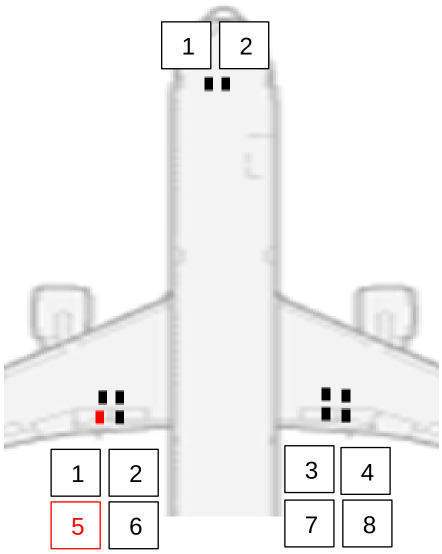
- *(1) Check main nose gear tyres for inflation pressure.*
- *(2) Visually inspect main and nose gear wheels for condition and integrity.*
- *(3) Inspect main and nose gear tyres for wear.*

The results of the PDC performed prior to flight ACA837 did not record any anomaly or defect related to the condition of the landing gear, and the pressure measurement for wheel number 5 was 220 psi, which is within the normal pressure range stipulated in the maintenance manual.

The review of the maintenance documentation (*defect detail reports, aircraft journey log, pre-departure check, routine check*) did not identify any landing-gear-related components or systems that had been inoperative, deferred, or experienced any previous problems that might have been relevant to the incident on take-off.

[3] Fuel weight values at take-off and landing obtained from the FDR.

1.6.3 Wheel no. 5



Each of the main landing gear legs comprises 4 wheels arranged in tandem: two front and two rear. They are identified according to the criteria shown in the diagram, which indicates that wheel number 5, which exploded during take-off, is the left rear wheel of the left main gear.

At the time of the incident, the tyre on wheel number 5 had undergone 3 retreading processes (R03[4]) and 40 life cycles. It had p/n 020-807-0 and s/n 7251R00109.

1.6.4 Structure of the wheel

To provide a better understanding of the information presented in the following sections, it is included a brief description of the structure of the main gear wheels below.

The wheel comprises two aluminium alloy rims that house the tyre. Each of these three parts (rims and tyre) have an independent operating life. This means that a tyre can be installed on different rims and, therefore, on different aircraft.

In addition to the inflation valve, the two rims are fitted with devices to prevent the tyre from bursting[5]. These devices consist of:

- a pressure relief valve located in the outer rim, which acts at between 25.8 and 31.0 bar to completely release the pressure inside the tyre.
- three fuse plugs located in the inner rim, which act at 183ºC to melt a eutectic material and release the pressure inside the tyre.

The tyre is composed of:

- the body of the tyre (carcass or casing), which refers to all of the tyre apart from the tread. It comprises a series of obliquely superimposed plies that provide resistance and uniformly distribute loads.
- the tread is the part of the tyre that comes into contact with the ground. This is the part of the tyre that undergoes retreading processes.

[4] The number of retreading processes is printed on the tyre itself.
[5] The certification regulations require these devices to be fitted. The relevant European regulation on the matter is CS 25,731 Wheels.

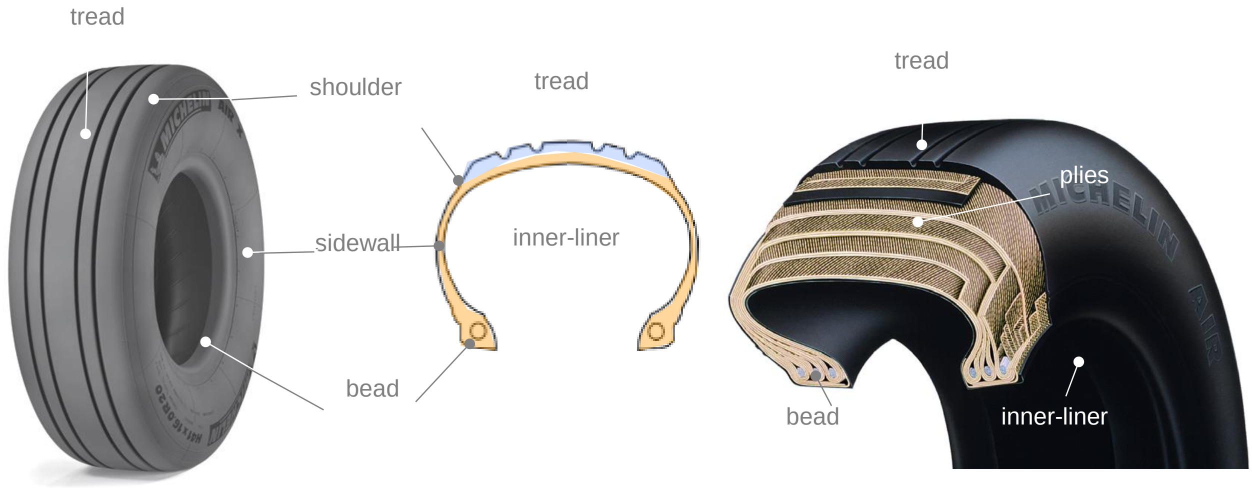


Figure 7. Zones and internal structure of the tyre

The tread has 4 grooves to help identify the level of wear and evacuate heat and channel water. The grooves are identified according to their proximity to the tyre face with the serial number. The tyre faces are identified as OSS (Opposite Serial number Side) and SS (Serial number Side).

On Michelin tyres, s/n is indicated only on one side of the casing. Other markings, such as p/n, size, etc, are duplicated on both sidewalls of the tyre. The specific retread markings (including a repetition of the s/n and the retread level) are located on one shoulder of the tyre. To facilitate the tyre reconstruction and analysis processes, it is virtually divided into 12 identical sectors identified on the opposite serial number side, starting with the inner-liner seal, as shown in the diagram.

1.6.5 Services used during the stopover in Madrid

On arrival from Toronto at 12:11, the aircraft parked at stand 72. It was connected to the passenger boarding bridge (12:21 to 14:16) and the 400 Hz service (12:31 to 14:15), during which time no incidents were recorded.

1.6.6 Take-off procedure from runway 36L: ZMR5L

The aircraft used the ZMR5L instrument departure take-off procedure published in the AIP. The operator was using the Jeppesen chart, which is shown in figure 8 with any relevant information highlighted:

- Climb to SSY[6] on magnetic course 001ºM at or above 2,400 ft, turn left, maximum speed 205 kt.
- At MD039, at or above 5,200 ft, turn left, maximum speed 210 kt.
- At MD044, at or above 7,600 ft, turn left.
- At DISKO, at or above 12,000 ft.
- At ZMR, at or above 13,000 ft.

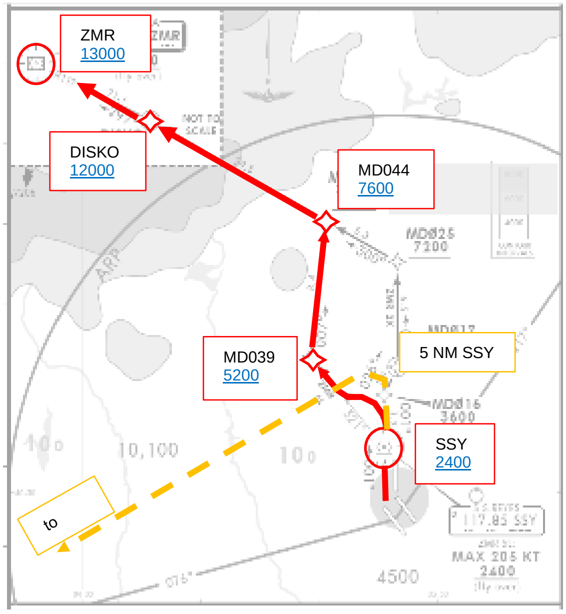


Figure 8. Take-off procedures

1.6.7 Take-off procedure from runway 36L in the event of an engine failure

In the event of an engine failure on take-off while carrying out instrument departure ZMR5L from runway 36L, the operator had an established procedure to follow, which has been represented in figure 8 by a dashed orange line, together with the standard departure (in solid red):

- If the engine failure occurs within a radius of 5 NM from SSY, continue as indicated in the SID until 5 NM SSY is reached.
- Turn left to proceed straight to NVS and hold as requested.

> If engine failure prior to a radius of D5.0 SSY or D9.4 BRA, continue as per SID until D5.0 SSY or D9.4 BRA, then LEFT turn and proceed direct to NVS VOR and hold as published.

1.7. Meteorological information

On take-off[7], the meteorological conditions were as follows: sunny day, no cloud cover, maximum visibility and 1 kt wind speed from a 170º direction. The temperature was 17°C and the QNH was 1,030 hPa.

[6] DVOR/DME SSY (hereinafter SSY) is situated approximately 1 NM from the end of runway 36L.

[7] METAR at 14:00 UTC (15:00 local time).

On landing[8], the conditions remained similar: 5 kt wind from a variable direction between 150º-210º, maximum visibility, no cloud cover, 14ºC and QNH 1,029 hPa.

1.8. Aids to navigation

All the navigation and landing aids, as well as the on board instruments, were operational and working correctly. The radar information, radio communications and flight recorder data have been included in section 1.11 to provide a more complete overview of the flight.

1.9. Communications

To aid the investigation, communications between the different control units and the aircraft were analysed. They cover the entire flight, and the most relevant information has been extracted and included in section 1.11. The cockpit voice recorder was operational and working correctly, but due to the duration of the flight, only the recording of the period immediately before the end of the flight remained. Conversations in the cabin at the time of the incident were overwritten by the CVR as it records in a continuous loops, and it was unable to analyse them.

1.10. Aerodrome information

Madrid-Adolfo Suárez Airport has an elevation of 609 m (1,998 ft) and four designated runways (two parallel runway strips). The runways used by the incident aircraft were 36L (DIM: 4,179 m) for take-off and 32L (DIM: 3,988 m) for landing.

1.10.1 Runway inspection procedure at LEMD

Madrid-Adolfo Suárez Airport has an established runway inspection procedure detailed in document PO-38, “Inspections of runways, taxiways and the apron by the Runway and Apron Service”. Version 3, which was in force at the time of the event, was dated 30/08/2019. The following information deemed relevant to the investigation has been extracted from the procedure:

- *Runway inspections are intended to detect any anomaly that may compromise the efficiency and/or safety of operations.*
- *Runway inspections will be carried out by the Runway and Apron Service.*
- *The inspections must be carried out with two Runway and Apron Service vehicles (positioned on either side of the centreline), travelling at an approximate speed and, as far as possible, not exceeding 60 km/h, to facilitate the detection of any incident.*
- *Inspections will be carried out while travelling along the runway in the opposite direction to its usage at that time.*
- *Each vehicle will be positioned approximately 5 m from the centreline.*
- *The inspections are intended to check the runway for:*
  - *any screws, tools or parts.*
  - *loose materials that could be ingested by aircraft engines.*
- *There are two types of inspections: scheduled and additional.*
- *A total of 4 daily scheduled inspections are programmed for each runway:*

[8] METAR at 18:00 UTC (19:00 local time).

- *1st inspection: 06:00 to 07:00.*
- *2nd inspection of the DEPARTURE runway: 13:00 to 13:30.*
- *3rd inspection of the DEPARTURE runway: 17:30 to 18:00.*
- *4th inspection: 22:30 to 23:30.*

- *Additional inspections may be motivated by accidents or incidents and after any unusual airport conditions.*

The procedure has defined records, which must be completed and signed by the COAM, as the person responsible for the inspection. These records are completed for each of the sections into which each runway is divided (for example, HEAD 36L-Z6). The annotations made should assess the CLEANLINESS, POTHOLES and OBJECTS of the runway using a code GOOD-NORMAL-BAD and YES-NO.

The vehicles used to carry out the inspections are pick-up type vehicles. Specifically, those used for the pre-take-off inspection were vehicles P19 and P20, a Nissan Navara (TOAM) and Ford Ranger (COAM), respectively.

Figure 9. Vehicles used to inspect runway 36L

1.10.2 Pre-take-off runway inspections

The airport had been closed to traffic due to the presence of a drone in the vicinity. After resolving the situation, operations resumed following an inspection of the runways, which coincided with the second scheduled inspection of the day. Specifically, the inspection began at 14:06[9], 50 minutes before activity resumed on runway 36L. According to the records, the inspection did not detect any objects.

1.10.3 Prior take-offs on runway 36L

After the runway inspection at 14:06, and prior to the take-off of flight ACA837, there were three departures:

[9] Although it did not influence the event, the time at which the record of this inspection was signed did not coincide with the actual time at which the inspection was carried out.

- 14:51: Take-off of aircraft RYR5468.
- 14:53: Take-off of aircraft RYR5995.
- 14:56: Take-off of aircraft IBE6403.
- 14:58: Take-off of the incident aircraft ACA837.

The surveillance cameras recorded the three previous take-offs. The footage confirmed that the three aircraft completed their take-off runs without incident. None of them reported having any problems with their landing gear. It was confirmed that their take-off runs were longer than that made by the ACA837 flight.

1.10.4 Inspection of runway 36L after take-off

The Runway and Apron Service inspected runway 36L again after the aircraft declared an emergency. Records show that a vehicle entered the runway at 15:04 and that two minutes later, at 15:06, it informed TWR of the presence of multiple pieces of wheel and debris and requested the services of a sweeper. By 17:45, the runway had been cleaned, all the debris had been removed, and it was declared operational again.

The debris was scattered over approximately 1,400 m of the runway, along the area shown in figure 10, and consisted of:

- a multitude of wheel fragments of different sizes: the smallest measuring a few centimetres in thickness and length and the largest being over a metre in length.
- material (honeycomb) that was later identified as belonging to the engine cowling (nose cowl inlet).

Figure 10. Dispersion of debris on runway 36L

1.10.5 Inspection of runway 32L after landing

After the aircraft exited runway 32L at 19:55, an additional inspection of the runway and the route to the parking stand was carried out. The inspection found several pieces of tyre debris. Runway 32L was declared operational again at 20:03.

1.10.6 Effects of the emergency on the airport's operations

The airport’s operation was affected in different ways as the information on the status of the emergency traffic was updated. The affected runways were 36L due to runway contamination after take-off and 32L because it was the runway chosen for landing. The developments were as follows:

During the initial minutes after take-off before commencing the holding pattern:

- Pending the imminent landing of the aircraft and anticipating a possible runway excursion, the area near the end of runway 32L was cleared of taxiing traffic.
- Due to the contamination of runway 36L, the traffic waiting to take off on 36L was re-routed to 36R.
- The only runway in service for take-off was 36R, and the arrival traffic landed on runway 32R, leaving runway 32L reserved for flight ACA837.

When flight ACA837 decided to hold at TOBEK but did not know how long they would need to do so:

- The only runway in service for take-off was 36R, as 36L was in the process of being cleaned. The situation led to an accumulation of up to 20 aircraft taxiing towards 36R for take-off. Therefore, control took measures to reduce the take-off parameter from 40 to 10 aircraft per hour in some sections. The number was increased again later.
- The only runway in operation for landing was 32R.

When flight ACA837 confirmed that it needed to continue holding for 3 h:

- The take-off parameter was again reduced to avoid an accumulation of traffic taxiing to runway 36R. After half an hour, it went back up to 40 aircraft per hour. Runway 36L was still being inspected and cleaned.
- Runway 32L was opened for landings.
- The airport was operating with one runway for take-offs and two runways for landings.

When the inspection and cleaning of runway 36L were completed:

- Runway 36L was re-opened for take-offs.
- After receiving confirmation at 18:02 that the aircraft would be in flight for an additional 90 minutes, the airport operated with all four runways open.

Before the approach:

- Taxiing was diverted away from the area around the end of runway 32L.

After landing:

- Runway 32L was inoperative due to being occupied by the aircraft. Runway 32R was operational for arrivals.
- Runway 36L was closed for take-offs to avoid departure traffic taxiing in the area near the aircraft. Runway 36R was the only one open for take-offs.

The airport returned to normal operating conditions with all four runways open at 20:03. During the period affected by the emergency, regulations were established to manage arrival traffic in 4 time slots, and 3 aircraft were diverted to the airports at Valencia and Zaragoza.

1.11. Flight recorders

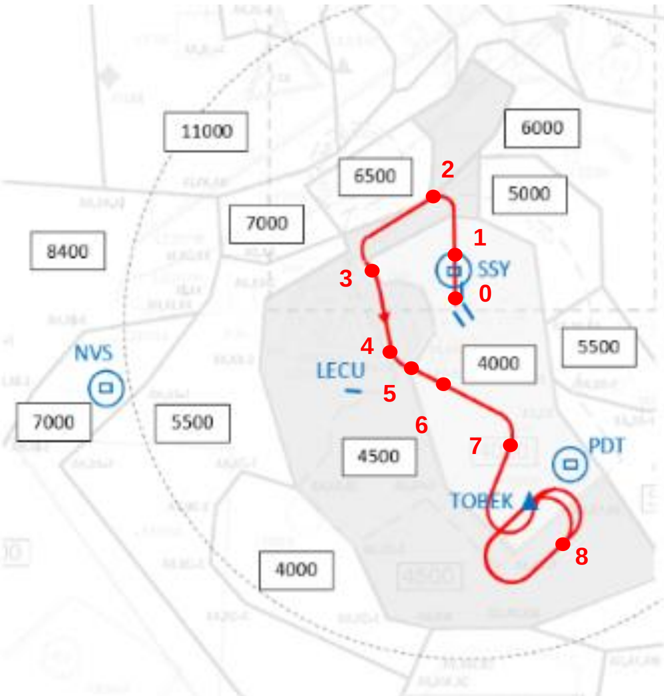
The data obtained from the flight recorders[10] and air traffic services was compiled and combined. From the start of the take-off run to the end of the landing run, the flight lasted 4 h 11 min. From

[10] Flight data recorder: p/n 980-4700-042, s/n SSFDR-10221.
Cockpit voice recorder: p/n 980-6022-021, s/n 120-04321.

the start of taxiing for take-off to the end of taxiing on arrival, it lasted for 5 h 19 min. The full trajectory has been included in section 1.1.

This section focuses on the first 18 minutes of the flight, during which time the aircraft was flying below the minimum ATC surveillance altitudes over Madrid, and the pilots applied the emergency procedures. After that period, the aircraft was able to retract its landing gear and climb, which meant the remainder of the flight proceeded without significant events.

Figure 11 shows the aircraft's trajectory on the ATC surveillance minimum altitude chart, which details the minimum altitudes for each area the aircraft flew over.



(0) 14:57:21 take-off run initiated
(1) 14:58:39 Damaged engine procedure initiated (items 1, 2 3)
(2) 15:01:10 Failed attempt to retract the landing gear. 3200 ft (1000 ft AGL)
(3) 15:04:45 Madrid overfly. 3100 ft (1000 ft AGL)
(4) 15:06:22 First information about the presence of wheel debris on the runway. 3100 ft (1000 ft AGL)
(5) 15:07:04 Landing gear retracted. 3100 ft (1000 ft AGL)
(6) 15:08:04 Aircraft above minimum ATC surveillance altitude. 4100 ft (2000 ft AGL)
(7) 15:10:00 Aircraft reaches 5,000 ft
(8) 15:15:03 Items 4, 7 & 8 of the damaged engine procedure

Figure 11. Trajectory until 15:23 above the ATC surveillance minimum altitude chart

<u>Taxi (17 min):</u>

14:40:27 Start of taxi from parking stand 72 to 36L runway head.

<u>Take-off run:</u>

14:57:13 Take-off clearance collation with flap 5.
14:57:16 Action on the throttle lever.
14:57:21 Start of take-off run on runway 36L (aircraft begins to move).
14:57:25 A/T MODE ENGAGED.
14:58:00 158 kt of CAS corresponding to V_1.

<u>Event (t=+0 s) at the end of the take-off run:</u>

14:58:03 (t=+0 s) Tyre number 5 explodes. 168 kt of CAS. Aircraft still on take-off run.
14:58:04 (t=+1 s) Anomalies in parameters:

- N1 Engine 1 decreases: 107% to 94%.
- Vibrations in engine 1 increase up to the value (scalar) of 5.
- Increase in longitudinal and lateral accelerations.

- Momentary change in heading to the left.

14:58:05 (t=+2 s) Lift off. 171 kt of CAS.

14:58:06 (t=+3 s) N1 engine 1 Increase up to 118%, lasting for more than half a minute. Aircraft at 8 ft AGL.

Aircraft on runway heading and start of engine shutdown procedure (t=+36 s):

14:58:37 Call from TWR to aircraft to transfer it. There was no reply from the aircraft.

14:58:39 (t=+36 s) A/T MODE NOT ENGAGED[11]. 2,633 ft.

14:58:41 MASTER CAUTION ON (stayed on for 3 min and 34 s, until 15:02:15).

14:58:42 (t=+39 s) Engine 1 throttle lever pulled back[12]. Aircraft reaches 2,651 ft (653 ft AGL). Engine vibrations reduce to 1.

14:58:48 Second call from TWR to aircraft to transfer it: *"ACA837 contact departure 124.230 bye-bye*". There was no reply from the aircraft.

14:58:53 (t=+50 s) 1st communication from flight ACA837 with TWR after take-off: "*Negative negative*. *MAYDAY MAYDAY MAYDAY with engine failure, stand by*".
The aircraft was at 700 ft AGL and 171 kt of CAS. Immediately, TWR contacted ACC to notify them that the ACA flight it had been going to transfer had an engine failure and cancelled the next take-off to clear runway 36L.

14:59:05 (t=+62 s) Engine 1 fuel CUT OFF[13]. 2,781 ft and 172 kt of CAS.

14:59:24 2nd communication from flight ACA837 to TWR. Aircraft at 2,900 ft (900 ft AGL) on runway heading: "*OK, ACA837, we have left engine failure, secured, requesting radar vectors*".
TWR acknowledged receipt of the engine failure notification replying, "*engine failure understood*", and instructed them to contact the next sector, DWN-WNN. TWR then immediately diverted the traffic waiting to take off on 36L to 36R to keep the runway available in the event of an eventual landing of flight ACA837.

Aircraft turns west towards NVS:

15:00:44 1st contact with the DWN-WNN sector. The aircraft was at 3,000 ft and 5 NM from SSY[14] and informed them of their emergency and intentions: "*with engine failure, just climbing 3,000 ft, left turn to NVS[15]*". The controller asked them whether they were able to climb to 5,000 ft[16]. The response from ACA837 was, "*we are trying, we are trying, stand by*".
The controller took steps to separate flight ACA837 from a nearby traffic, to which he reported that the ACA "*is trying to climb but can't at the moment*".
TWR confirmed to the airport management centre that they had the "*ACA837 with engine failure on take-off*" and also called the Rescue and Firefighting Service (SSEI), informing them that "*the traffic that has just taken off on RWY36L is declaring an emergency due to engine failure, traffic ACA837*".

15:01:10 (t=+3 min 07 s) Actuation on the landing gear UP lever, but the landing gear did not retract. After 4 s, the lever returned to the DOWN position.

15:02:28 Aircraft established at 3,200 ft (1,000 ft AGL) heading towards NVS. After a new communication from the controller asking if they could climb or preferred to

[11] Action number 1 of the "ENGINE FIRE or Engine Severe Damage or Separation" procedure. See section 1.16.12.
[12] Action number 2 of the "ENGINE FIRE or Engine Severe Damage or Separation" procedure. See section 1.16.12.
[13] Action number 3 of the "ENGINE FIRE or Engine Severe Damage or Separation" procedure. See section 1.16.12.
[14] According to the engine failure on take-off procedure. See section 1.6.7.
[15] The left turn to NVS is the specified procedure for an engine failure on take-off from runway 36L. See section 1.6.7.
[16] The aircraft was in an area with a minimum ATC surveillance altitude of 4,500 ft and bordering a 6,500 ft area.

maintain visual contact with the ground, the aircraft reported the following: *"We had a tyre explosion, the gear will not retract; we are single-engine. Please give us radar vectors to the lower area"*

Instruction to turn south:

15:02:45 The aircraft was instructed to turn to a heading of 160º, which would take them to the area with the lowest radar altitude. At this point, they were above Tres Cantos at 3,200 ft of altitude and 1,000 ft AGL.
Following this instruction, the ACC informed the Cuatro Vientos TWR that the ACA was heading towards its area at 3,000 ft, that it could not climb and that it was not known what it was going to do, intending to prevent conflicts with other in-flight traffic at the same altitude as the ACA.

15:03:30 (t=+5 min 27 s) Thrust modification from TOGA to MCT.

15:03:44 (t= +5 min 41 s) Flaps 1. 216 kt of CAS and 3,200 ft.

15:04:11 PAPA1 calls TWR to offer to check the runway. PAPA1 was cleared to enter the runway.

Madrid overflight:

15:04:45 Aircraft on 168º heading, at 3,100 ft (1,000 ft AGL), at 227 kt of GS with the landing gear extended, entering Madrid (at this point, it was over the M-40 motorway, above the Pitis metro station).

15:05:23 Instruction from the DWN-WNN sector to change heading to 140º. At that point, the aircraft was over the Antonio Machado station, maintaining 1,000 ft AGL. The heading acknowledgement was mistaken (120º instead of 140º) and not corrected by the controller. The aircraft again notified that it could not climb, that the landing gear was stuck, and they only had one engine. The controller asked them about their intentions (landing or holding), and the crew replied that they preferred to wait because they had multiple emergencies to deal with. ATC again insisted on the need to ascend to 4,000 ft[17] and the aircraft repeated that they were trying but couldn't because of the landing gear and engine issues.
While these communications were taking place (a period that lasted until 15:06:19), the aircraft was flying over the centre of Madrid at 1,000 ft AGL and 243 kt of GS, following the line that connects the Canal, Sevilla and Atocha metro stations.

15:06:16 (t=+8 min 13 s) Flaps 0 (UP). 230 kt of CAS and 3,200 ft.

15:06:22 (t=+8 min 19 s) Call from PAPA1 to TWR reporting the presence of "*pieces of wheel, rubber, and a lot of debris all over the runway*." TWR immediately transferred this information to the DWN-WNN sector.

15:06:38 Aircraft on a 120º heading at 3,100 ft in an area with a 4,000 ft minimum ATC surveillance altitude.

Retraction of landing gear and start of ascent:

15:07:04 (t=+9 min 01 s) Actuation on the landing gear lever[18] and successful retraction of the landing gear. Confirmation of landing gear up and locked. The aircraft was over Vallecas at 1,000 ft AGL on a 120º heading. They began to climb and notified ATC

[17] The aircraft was in an area with a 4,500 ft minimum ATC surveillance altitude.

[18] The recorder does not distinguish between the UP and OFF position, registering only UP/OFF. According to the pilot's statement, the procedure used to retract the landing gear required them firstly to position it in UP and then in OFF (the Gear Lever Will Not Move Up procedure, section 1.16.13).

that they had managed to retract the landing gear and could now ascend. ATC again requested they ascend to 5,000 ft and turn to 200º.

15:08:04 Aircraft at 4,100 ft, for the first time above the minimum ATC surveillance altitude for the area (4,000 ft).

15:08:26 (t=+10 min 23 s) Communication from the aircraft to ATC re-confirming the emergency and providing more data: "*engine failure, left side. Also left side gear, we are blown at least one tyre*".

15:09:12 Flying over Arganda del Rey, at 4,800 ft and climbing.

<u>Aircraft established at 5,000 ft:</u>

15:10:00 Aircraft at 5,000 ft altitude and on a 200º heading. The DWN-WNN sector informed the Cuatro Vientos TWR that the aircraft could now ascend, was at 5,000 ft and not occupying LECU airspace. Instruction to go to TOBEK, the initial approach fix for the approach to LEMD, and fly holdings around said point until ready to land. At this time, the aircraft had not specified how much time it would need to perform its checks.

15:12:37 Connection of A/P 2 and start of the holding circuits.

15:15:03 (t=+17 min) Actuation on the ENGINE FIRE SWITCH[19], which moved to the PULLED position in the recorder. Aircraft in a holding pattern above TOBEK at 5,000 ft.

15:15:28 (t=+17 min 25 s) Actuation on the APU[20], reflected in the recorder by an increase in the EGT temperature of the APU.

15:15:33 (t=+17 min 30 s) TWR asks SPP about the possibility of confirming whether the wreckage belongs to the ACA837 aircraft or the one that preceded it. The ground personnel were unable to say.

<u>Confirmation of the waiting time:</u>

While holding at TOBEK, the aircraft gave varying indications about the waiting time they would need: initially it was 15-20 min (15:22:36), then 1 hour (15:44:26) and finally 3 hours (15:57:22). Given this information, the controller of the AIN sector, to whom the aircraft had been transferred:

- coordinated with Torrejón and the other sectors to allow entries to Madrid with sufficient separation from the ACA837, and
- decided to move the aircraft away from TOBEK (IAF) so as not to interfere in the approach operation to LEMD and ascend it to 8,000 ft. He decided to take the ACA837 to a DVOR/DME PDT reference point (hold 20 NM south of PDT, on radial 165 and later on radial 140). The instructions required several communications to correctly confirm the references they had been given and the waiting times in the different sectors.

<u>Aircraft established at 8000 ft:</u>

At 16:08 (t=+1h 10 min), the BAW maintenance technician confirmed that the engine and tyre debris belonged to flight ACA837. At 16:17:26, the aircraft reached 8,000 ft and the hold fix

[19] Action number 4 of the "ENGINE FIRE or Engine Severe Damage or Separation" procedure. See section 1.16.12.
[20] Actions numbers 7 and 8 of the "ENGINE FIRE or Engine Severe Damage or Separation" procedure. See section 1.16.12.

located at 20 NM on radial 140 of PDT, where it entered a holding pattern at that altitude. At 16:41:29, the aircraft was transferred to the 130.8 MHz frequency available for contingencies in the Madrid TMA.

16:41:57 (t=+1h 43 min 54 s) The controller informed the aircraft about the parts on the runway and the crew asked if it was possible to determine whether they belonged to the main or forward landing gear. ATC sent photos of the parts that had been collected to the crew and, in addition, had the initiative to deploy an EF-18A from the Torrejón base to carry out a visual inspection of the condition of the landing gear.

At 17:25, the CVR recording begins. At that point, the crew could be heard going over what had happened during take-off and completing the flight documentation with data on weight, passengers, etc.

At 17:30, the aircraft confirmed to ATC that it would be landing in two hours.

Deployment of the EF-18A:

Control coordinated with ECAO to arrange for one of the EF-18A military aircraft with flights scheduled for that afternoon, to be deployed. The type of flight it would have to perform with the ACA837 was similar to a scramble mission. It was initially in contact with ECAO then later transferred to civil control in order to communicate with the ACA aircraft.

The inspection, conducted between 17:49 and 18:03, required the ACA's gear and flaps to be extended. The military aircraft positioned itself under both sides of the ACA aircraft and inspected the main and nose landing gear. He confirmed the damage to one of the left-landing-gear wheels and that the remaining 3 left wheels and the right and forward landing gear appeared to be fine. The EF-18A pilot took several photos, two of which are shown in figure 12. After completing the inspection, the landing gear was retracted and locked correctly.

Figure 12. Photographs taken by EF-18A

The CVR recorded the pilots preparing for the flight with EF-18A and the two passenger announcements made by the captain before and after its approach. In this last announcement, he informed the passengers that they had lost a wheel while taking off and that they would be flying for an additional hour to burn fuel. All the passenger announcements were made in English by the commander and repeated in French, by the service director, and Spanish by a cabin crew member.

At 18:13, the aircraft confirmed to ATC that they would use runway 32L and required emergency vehicles upon arrival on the runway.

At 18:15, and for 5 minutes, the CVR recorded a conversation between the commander and the service director on the flight deck. They discussed the reality of the situation they were in (left engine out and damage to a landing gear wheel), the intentions for the landing and the risks associated with it in terms of a possible fire on the left side of the aircraft.

Approach and landing:

18:33:21	The aircraft notified control of the expected landing time and their decision to land on runway 32L as it was the longest. From that moment on, the pilots were heard confirming and reviewing data and conducting the landing briefing, in which they verbalised their intentions to stop on the runway and request an inspection of the aircraft by the emergency services on the ground. The crew reviewed several lists, including the pre-descent and single-engine landing checklists. They also re-checked the engine fire list and their calculations related to the expected weight on landing. The turning of pages could also be heard. At the end of this review, the commander was heard asking the co-pilot if he had any suggestions or comments regarding anything they had discussed.
18:51:00	The commander confirmed with the service director that the cabin was secured and made another passenger announcement to advise them that once they landed in Madrid, they would see lights from the emergency vehicles that would be approaching to check the condition of the aircraft.
18:53:21	After re-checking the pre-descent checklist and confirming that it was complete, the co-pilot informed ATC that they were ready to commence the approach. He received clearance for 32L ILSZ with QNH1029. Shortly afterwards, he was transferred to the AIN sector, to whom he again advised that they were in a single-engine emergency.
18:59:00	Cabin lights dimmed.
19:00:06	Aircraft at 20 NM, 5,000 ft and aligned with runway 32L.
19:01:06	Aircraft at 16 NM over PDT. Connection of A/P1 and AP/3 (A/P 2 was already connected). Locator armed.
19:03:06	The aircraft extended the landing gear. Flaps 20[21]. Landing checklist reviewed, and speeds checked again. The aircraft contacted TWR LEMD, and the controller informed him about an engineered materials arresting system (EMAS) at the end of the runway, in addition to the official length of the runway. After receiving clearance to land, the aircraft indicated that in the event of a go-around, they would ascend on the runway heading to 5,000 ft.
19:05:32	Aircraft at 1,000 ft and callout of 1,000 ft.

[21] Action number 13 of the “ENGINE FIRE or Engine Severe Damage or Separation” procedure. See section 1.16.12.

19:06:03 Aircraft at 500 ft, callout 500 ft and confirmation from the co-pilot that the aircraft was stable.

19:06:14 Aircraft at 300 ft and request from the commander to disconnect the autopilot.

19:06:36 The aircraft touched down and registered GROUND mode in the landing gear sensors. At 19:06:38, the deployment of the reverse thrust was recorded for 25 seconds. The AUTOBRAKE was not used. Left engine vibration increased to 5 during the landing roll-out.

19:07:32 Aircraft stopped on runway. At 19:08, the crew could be heard completing the after landing checklist, and at 19:09:13, the high brake temperature light was registered by the FDR. Firefighters immediately approached the aircraft along with maintenance personnel to assess the condition of the brakes. The temperature measurement taken by the fire service was 475ºC and the cockpit measurement reported by the crew was 8[22]. It was decided that fans should be used to cool the brakes, a process that lasted almost an hour. While this took place, the passengers remained on board, with the commander making another announcement about the situation at 19:19.

19:30:24 End of the CVR. In the last communications recorded at 19:25, the crew could be heard deciding that, if there wasn't too much shimmy, they would taxi under their own steam to the parking stand, but if there was, they would request to be towed.

19:55:00 The aircraft began taxiing under its own steam to its parking stand.

20:11:00 The passengers disembark.

Other data:

The 5 previous flights stored in the FDR were reviewed in search of operating conditions that could have caused an overload on the tyre. Specifically, weight parameters, closed ground turning regimes, take-off and taxi speeds, taxiing durations, vertical, lateral and longitudinal accelerations and brake usage. All values were within normal parameters.

1.12. Aircraft wreckage and impact information

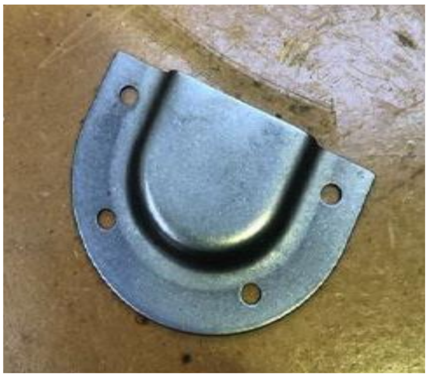
The aircraft landed normally and managed to taxi to its final parking position. The damage affected the left main landing gear, the inside of the left engine, various landing gear panels and the underside of the left wing and left engine. There were no perforations or damages to the fuselage or any of the aircraft's systems (tanks, hydraulic system, or electrical system), nor were there any fluid losses. The control surfaces remained operational.

Wheel no. 5:

Wheel no. 5 was still attached to the landing gear. Around 60% of its total tyre surface material (casing and tread) had disappeared entirely, with the bead visible in some places. In the remaining 40%, the casing was intact, but the tread had disappeared. Detached tyre fragments were recovered from both the take-off and landing runways, as well as the interior of the engine.

[22] The BRAKE TEMP indicator illuminates in the cockpit when the brake temperature is in the high range, i.e., between 5 to 9 on a scale of 0 to 9. The normal temperature range is between 3 and 4.

Of all the pieces collected, only one was identified as not belonging to the aircraft. This piece, shown in the image, was metallic and measured 45*35*6 mm. Its condition was unaltered and shiny, ruling out its involvement in the event.



The sizes of the recovered fragments varied: the largest was 132x40 cm, and the smallest was 1x1 cm. The thickness of the pieces also varied: some were made up of just the tread or casing, and others contained the entire tyre section. Some of the fragments had cuts that would have been caused by the engine blades. All the recovered items were preserved for further investigation (section 1.16). The remaining wheels on the left main gear (numbers 1, 2 and 6) were fully intact.

Figure 13. Remains of wheel no. 5

<u>Tilt sensor:</u>

The left-landing-gear tilt proximity sensor (*prox sensor target bracket)* had shifted, modifying the gap between the sensor and the target beyond tolerable levels.

Rubber marks:

Black impact marks were identified at different points between the left main gear and the engine. The direction of all the markings indicated that the pieces came from behind and travelled towards the front (from the landing gear to the engine). The areas displaying evidence of impact were:

1. left main gear panel
2. underside of the left wing
3. right panel of the thrust reverse
4. right fan cowl
5. nose cowl inlet

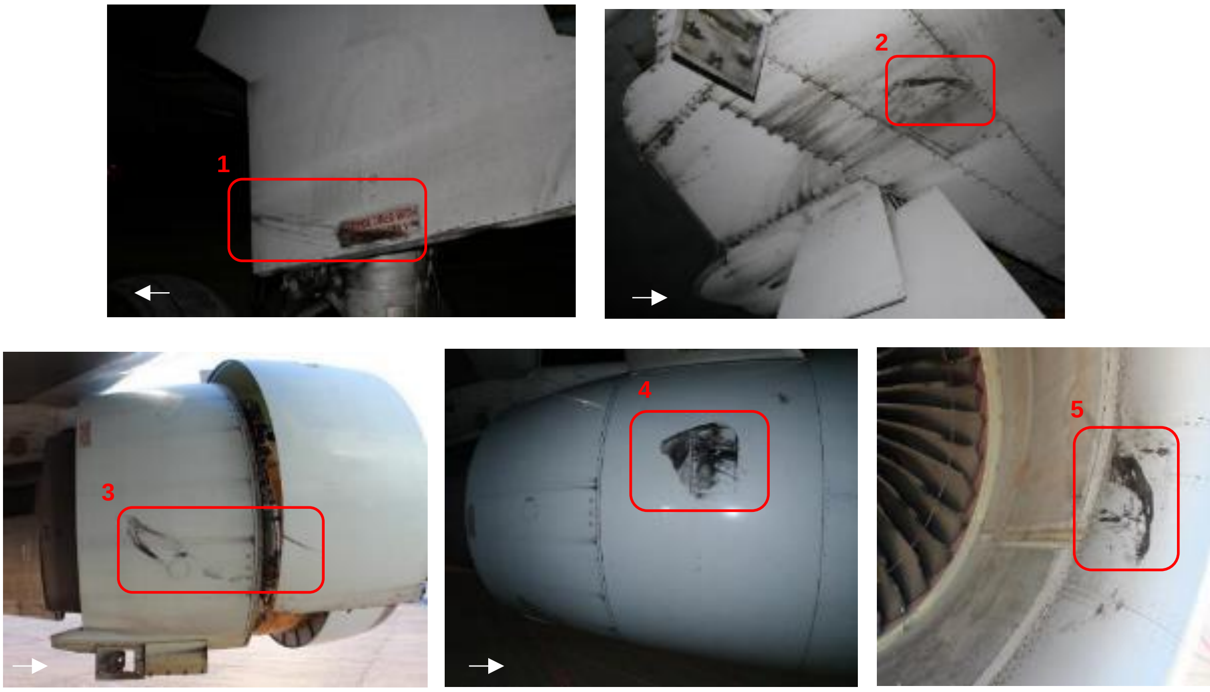


Figure 14. Rubber marks (travelling in the direction of the white arrow: towards the front of the aircraft)

Perforations:

Two small holes (4*4 cm) were identified in the number 3 fairing flap support and the thrust reverser panel. They were both made in a forward direction from the back (landing gear) to the front (engine). The nose cowl inlet had another small hole produced from the inside of the engine to the outside.

Left engine:

The subsequent boroscopic inspection of the engine revealed the following internal damage:

- Fan/booster module: the fan and fan track were significantly damaged, with the coating material having disappeared from the fan inlet and damage all the fan blades. The 2nd stage blades of the low-pressure compressor (LPC) displayed minor scratches and traces of ingested material. The 5th stage LPC blades displayed markings indicating the displacement of ingested material, and one of them had a dent on the trailing edge. Further remains of ingested material were found in the booster, and there was minor damage (minor tip curl) to some blades.

Figure 15. Damage to the fan

- Core module: Ingested debris were found in the 1st stage of the HPC. All 14 stages of the HPC had marks made by the passage of tyre debris, impact marks and scratches. In some stages, impacts were also identified on the leading and/or trailing edge (1, 4, 5 and 6). Stage 8 displayed deformations and dents within tolerable limits. Finally, more severe cuts or nicks were found in stages 7, 11, 12 and 13, with one of the cuts in stage 11 being beyond tolerable limits. The combustion chamber had no damage or obstruction in any of the ducts. Also, no defects were found in the stage 1 HPT guide blades. None of the stators had been damaged.
- High-pressure turbine module (HPT module): The 1st stage of the HPT displayed evidence of object ingestion. The other stages presented no significant defects.
- Low-pressure turbine module (LPT module): the 1st stage LPT blades were slightly eroded. The guide vanes in this stage had cracks beyond tolerable limits. The 2nd stage LPT blades displayed evidence of object ingestion. Stages 3, 4 and 5 were in good condition.

Cockpit:

The cockpit was accessed after landing and the following aspects were deemed of interest to the investigation: the left-engine fire switch was pulled, the NO AUTOLAND indicator and GROUND PROXIMITY FLAP switch were in OVRD.

1.13. Medical and pathological information

The medical services were awaiting the passengers on arrival. None of the 138 people on board required medical assistance.

1.14. Fire

There was no fire.

1.15. Survival aspects

In this incident, the survival aspects are related only to the management of the emergency by the airport. The absence of an emergency evacuation and any damage to the cabin compartment that could have affected the survival of the passengers meant that no further analysis was required.

The Airport Emergency Plan was implemented in two phases:

- 14:58: Call from the aircraft notifying the emergency using the term MAYDAY.
- 15:00: Local aeronautical alarm.

  This phase began with the sounding of the siren in the TWR and the initiation of communications between TWR, the CGA and the SSEI. In these communications, the emergency was transmitted in the following terms: "*ACA837 with engine failure on take-off" and "declaring an emergency due to engine failure and returning to the field*". At 15:25, the service executive received confirmation that the aircraft had declared MAYDAY and raised the alarm level to general. Up until that point, the only services activated were for the inspection and cleaning of runway 36L.

- 15:29: General aeronautical alarm. This phase was implemented according to Madrid airport's emergency plan.
- 20:02: Local aeronautical alarm after the aircraft taxied off the runway without assistance. During this period, the passengers and crew disembarked safely and without injuries via the normal exit stairs.
- 20:15: Local alarm deactivation process initiated.
- 20:25: End of the emergency.

1.16. Tests and research

1.16.1 Information provided by the flight crew: commander and co-pilot

The captain and co-pilot were interviewed the morning after the event. They both provided similar information describing the following sequence of events:

With regard to taxiing to the runway:

- It was the first flight of the day for the whole crew. They had slept in the same hotel, and a bus had picked them up to take them to the airport.
- The pre-flight inspection was carried out by maintenance.
- The commander was the PF while taxiing, and the co-pilot took the controls at the head of the runway for take-off.
- There were no abnormal cockpit indications prior to rotation.
- They had no recollection of seeing anything on the runway during the take-off run.

With regard to the rotation and initial ascent:

- During the rotation, the following occurred:

  - the sound of an explosion (a bang) to the rear left side
  - vibration in the column
  - shimmy)
- After this, they noticed the smell of burning rubber but no smoke. The smell disappeared quickly. With regard to the smell, they indicated that they didn't know if it was coming from the engine or from a fire in the landing gear.
- Immediately afterwards, the N1 of the left engine increased above maximum, indicating overspeed. The commander also reported seeing excessive vibrations in that engine. There was no indication of engine fire at any time.
- Given such indications, they carried out the ENGINE FAILURE procedure, shutting down and securing the left engine.
- They tried and failed to raise the landing gear as soon as they had a positive rate of climb (they believe it was at 400 ft). They were unsure why.

With regard to the remainder of the flight:

- They turned left and requested vectors.
- They were directed south and, on that sector of the flight, they succeeded in retracting the landing gear using the landing gear lock override switch.
- They entered a holding pattern to consume fuel. While doing so, they took turns as PF.
- During the flight, there were no warnings of problems with any system.
- ATC informed them that they had found traces of rubber on the runway and, while waiting, offered them the possibility of having an EF-18A carry out a visual inspection from the air.
- They emphasised that there was excellent coordination with the service director throughout the flight, who, at one point, confirmed the presence of rubber marks on the engine.
- The passengers were very compliant despite not having an entertainment system, and the service director did not inform them of any passenger-related issues.
- All communications with the passengers and the service director were made by the commander.
- The commander carried out the approach and landing as PF. They had no problems with the landing.

1.16.2 Information provided by the service director

The service director was interviewed the day after the event. The information of interest to the investigation was as follows:

Specifically related to the event:

- Before the incident, everything was as expected: the arrival at the airport, the briefing with the cabin crew and pilots and boarding.
- At the end of the take-off, run she heard a "bang" and felt things moving underneath her (her position was L1, located in the front left-hand jump seat).
- They immediately noticed a strong smell of rubber and, in addition, that the plane had a low rate of ascent; it was struggling to climb.
- She immediately received calls from four cabin crew members who confirmed the smell of rubber. In addition to the smell, the crew member in position 0L by the left wing informed

her that he could see a mark on the left engine[23] and that a passenger in that area said the engine was moving.

While climbing:

- During the ascent she called the cockpit to report the smell and the mark on the engine. The flight crew confirmed that they would call him later.
- Meanwhile, she made an announcement to the passengers in French and Spanish.
- Shortly afterwards, the smell disappeared, and everything became “very normal”: there were no vibrations, everything was “smooth”, and there was no noise.

During flight:

- She received the call from the commander and entered the flight deck. They explained that they had a problem with a landing gear wheel, that they had lost an engine and needed to follow a holding procedure. The service director asked the commander to make an announcement to the passengers. This first communication occurred at approximately 15:13.
- He called all the cabin crew to his post and briefed them on the situation. They reviewed the ABNORMAL LANDING procedure.
- While in the holding pattern, the service director made a second passenger announcement repeating the information the commander had previously transmitted.
- She requested permission to provide a service to the passengers, who were served drinks and snacks.
- There was regular communication between the service director and the commander, who, at all times, kept them informed. In fact, when the pilots received confirmation from ATC that they had found traces of rubber on the runway, the captain transmitted the information to the service director, although not to the passengers, so as not to alarm them.
- Before the EF-18A approached, the commander made another passenger announcement to let them know what would happen.
- He informed them about the expected holding times and flight progress. He also told them that, in principle, there would be no evacuation. When they received the 30-minutes-to-landing-notification, they stopped the service.
- They received the notice to prepare the cabin for landing, which took place without incident.

During the landing:

- They rolled down the runway before coming to a stop.
- She made an announcement reminding the passengers to remain seated and dimmed the lights to accustom them to the outside light (it was night-time) in case an evacuation was ordered.
- The commander made a new announcement informing them about what was going to happen next: the appearance of the firefighters and the need to lower the brake temperatures.
- Everything went as planned, and they eventually disembarked following routine procedures.
- They held a debriefing at the hotel: first among the cabin crew and then with the pilots.

[23] The mark was the one identified as number 4 in figure 14.

- The service director highlighted the fact that all the commander's passenger announcements were extremely reassuring, with precise information and a highly appropriate choice of terminology.

1.16.3 Tests carried out on the landing gear

The landing gear tilt sensor was reset after the incident. The landing gear was subjected to 4 extension and retraction cycles with satisfactory results.

1.16.4 Previous similar incidents

It was collected information on events with similarities to the ACA837 incident in terms of the following parameters: retreading level, tyre p/n, operator, date and location of recent maintenance, type of failure, wheel position and damage to the aircraft. Information was compiled on a total of 7 similar incidents involving B767 and B777 aircraft equipped with Michelin tyres between 2008 and 2019:

- Retread levels ranged from R00 (new) to R04.
- The failure modes varied: there was one event involving a partial thrown tread detachment, two involving complete thrown tread, three burst (one of them on landing), and one burst and thrown tread separation during take-off (as in the ACA837 incident).
- Three of the events involved damage to the left rear outer wheel.
- The damage sustained as a result of the wheel failures was as follows: in two events, wheel parts were ingested by the engine, in another two, the damage was limited to the landing gear, and in one, the flaps were damaged.
- As for the cause of these incidents, in four of them, the cause could not be determined; in two, FOD was considered a possibility and only in one of them was FOD confirmed as the cause. In this single confirmed case, the object that had produced the failure had a circular 35 mm in diameter shape.

1.16.5 Records for wheel number 5

At the time of the incident, the number 5 wheel tyre had a total of 3 retreads (R03), 40 life cycles, p/n 020-807-0 and s/n 7251R00109. It had been manufactured (R00) on 13/09/2017 by Michelin at its factory in Norwood, United States, after which it had the following activity recorded:

- 31/12/2017: fitted on an Air Canada aircraft.
- 26/02/2018: disassembly after 191 cycles due to wear.
- 20/07/2018: first retread (R01) at Michelin's Norwood factory.
- 29/08/2018: fitted on an Air Canada aircraft.
- 01/12/2018: disassembly after 208 cycles due to wear and the exposure of a ply.
- 28/01/2019: second retread (R02) at Michelin's Norwood factory.
- 30/03/2019: fitted on an Air Canada aircraft.
- 19/07/2019: disassembly after 227 cycles due to wear.
- 02/12/2019: third retread (R03) at Michelin's Norwood factory.

- 16/01/2020: fitted in position no. 5 of the C-GHOZ aircraft.
- 03/02/2020: incident in Madrid at 40 cycles.

1.16.6 Records for the other wheels on the left main landing gear

It was reviewed the history of the left main gear wheels, identifying that wheel number 6 had been replaced on 30/01/2020, three days before the event. It was removed due to the presence of two cuts. To determine whether these cuts could have also affected wheel number 5, it was retrieved the information on wheel number 6. However, due to the size of the cuts (approximately 1 cm), it was ruled out the possibility that they could have affected wheel no.5.

Figure 16. Cuts on wheel number 6 (paired with no. 5), produced on 30/01/2020

1.16.7 Records of the inflation pressures

The following table shows the inflation pressures for all the landing gear wheels on the C-GHOZ aircraft since wheel number 5 was installed on 16/01/2020, after its last retread. These values have been obtained from the PDCs (pre-departure checks).

Date	Location	NLG (psi)		MLG (psi)							
		1	2	1	2	3	4	5	6	7	8
18/01/2020	Amsterdam	175	175	220	225	220	215	**220**	220	220	220
20/01/2020	Toronto	170	170	215	220	210	215	**220**	220	210	215
22/01/2020	Toronto	167	167	217	217	217	217	**215**	217	217	217
23/01/2020	Toronto	180	180	218	218	218	218	**218**	218	218	218
26/01/2020	Toronto	178	178	221	220	217	220	**221**	220	220	221
31/01/2020	Toronto	175	175	225	220	220	220	**225**	225	220	220
02/02/2020	Toronto	170	170	220	220	220	225	**225**	226	220	224
03/02/2020	Toronto	180	180	230	220	230	230	**230**	230	230	230
03/02/2020	Madrid	170	170	225	220	225	225	**220**	220	220	220

Figure 17. Landing gear pressures since 18/01/2020

1.16.8 Review of the manufacturing and retreading processes

It was reviewed the records for the initial manufacturing process and subsequent tyre repairs; specifically, the last retreading carried out 40 cycles before the event. This review included the shearography tests carried out before and after the retreading process to confirm that the tyre is suitable for retreading and, once the process is finished, check for unbonding areas inside the tyre that could lead to future integrity issues. This documentary and graphic review did not reveal any non-conformities or anomalies.

1.16.9 Condition of the other wheels on the left main gear

The remaining 3 wheels on the left main gear (numbers 1, 2 and 6) were preserved for inspection. None of them showed any signs of damage or imperfections that could have been related to the failure of wheel number 5. They were all fully intact.

1.16.10 Inspection of the valves and fuses on the rims

The condition of the inflation valve, the pressure relief valve on the outer rim and the three temperature fuses on the inner rim were checked. They were found to be in good condition, and none of these devices had been activated during the event.

1.16.11 Reconstruction of the fragments of tyre number 5

General inspection of the fragments:

Reconstruction of the fragments of tyre number 5 used the references in section 1.6.4 (tyre sectors and zones within the tyre section). The process involved several phases. In the first phase, it was conducted a general inspection of all the recovered parts, as a consequence of which it was determined that the tread detachment was a secondary effect of the breakage of the tyre casing.

Matching the fragments to sectors:

The second phase was focused on identifying which pieces belonged to the inner plies of the tyre casing and which belonged to the outermost plies of the casing. In addition, each of the tyre casing fragments were matched to their sector. This reconstruction process revealed that all the pieces belonged to sectors 4 to 12, and none of them were from sectors 1, 2 and 3.

Analysis of types of breakages:

Subsequently, it was analysed the way they had ruptured. An X-pattern breakages were clearly identifiable, following the overlap angles of the plies. There were two types of breakage:

- The fragments belonging to sector 7 displayed direct ruptures in all the plies. In these breakages, all the ruptures were perpendicular to the tyre surface.
- The fragments belonging to sectors 4, 5, 6, 8, 9, 10, 11 and 12 displayed tapered ruptures. In these breakages, the plies had ruptured in a staggered and gradual way, showing a progression from ply to ply.

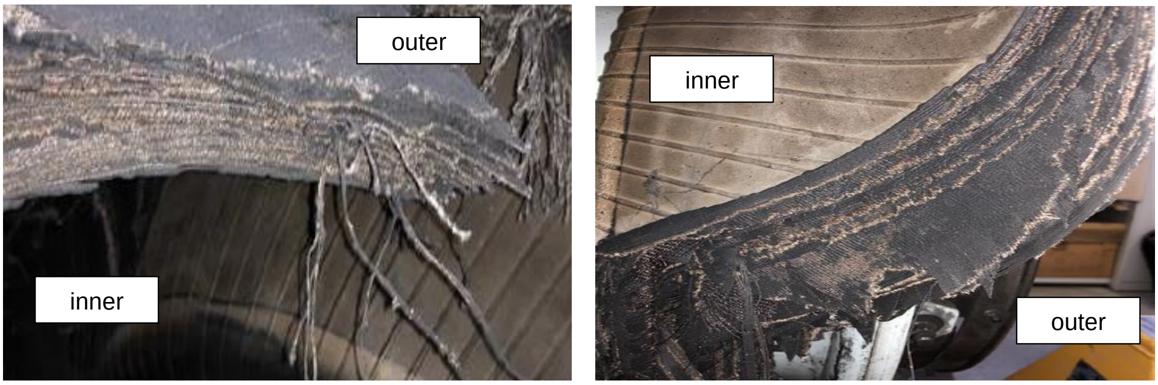


Figure 18. Direct ruptures (left) and tapered (right) in the casing of tyre no. 5

The following graphic representation of the fragments' rupture layers (internal in blue and external in green, in figure 20) and their position on the tyre, shows that in the direct rupture zones, the fracture lines between the pieces were closer together, whereas in the staggered fracture zones, the fracture lines were separated.

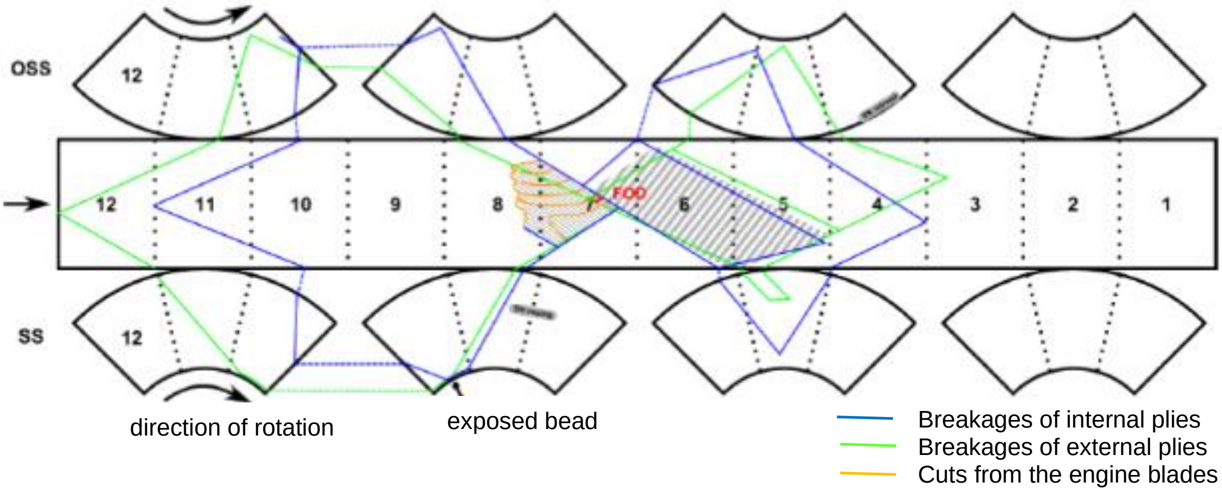


Figure 19. Reconstruction of tyre number 5

Sector 7:

The next phase focused on the fragments belonging to sector number 7, which was the only one with direct ruptures and indicated, therefore, that the failure began in that area. The analysis focused on two pieces, described as A and B. Both were contiguous and belonged to the central zone of sector 7:

- Piece A: belonged to sector 7 and a small portion of sector 8. It was made up of 8 small fragments with very sharp cuts in a different direction to those that followed the path of the plies. These 8 pieces fitted together to form a single piece that had been ingested by the engine and cut by its blades.

- Piece B: belonged to sectors 7, 6 and a small portion of 5. This piece had no cuts and hadn't been ingested by the engine. Associated with piece B were 4 tread fragments, which have been superimposed over piece B in the left-hand image in figure 21.

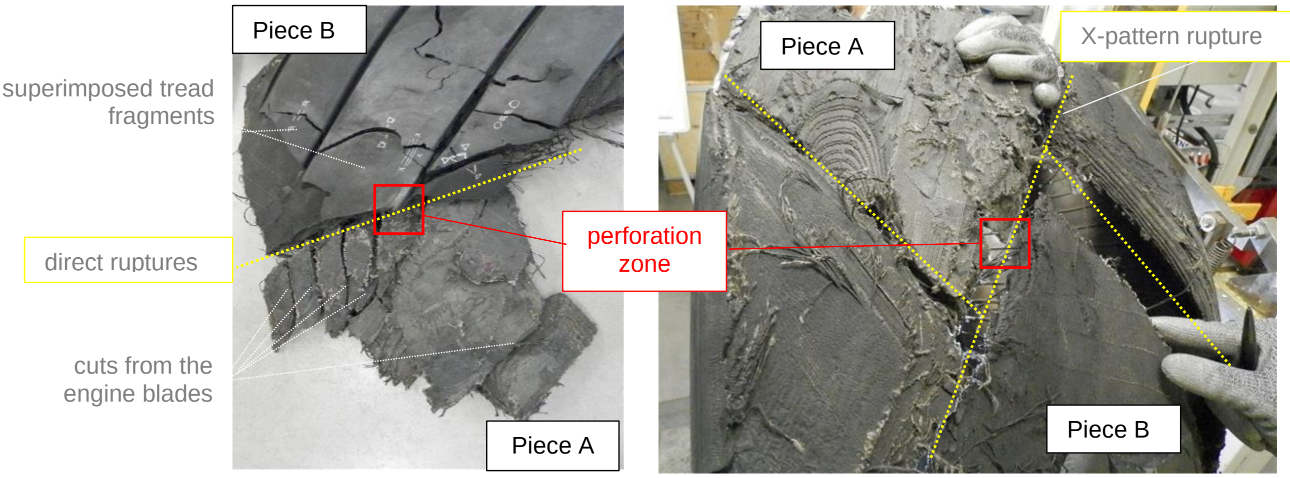


Figure 20. Pieces A and B from sector 7 viewed from the exterior

Figure 21 shows the superposition of pieces A and B, the direct rupture zones between the two pieces and the reconstruction of section 7, which also shows the X-pattern rupture.

A detailed observation of the pieces revealed perforation marks in the tread and almost all the plies of the tyre casing around the join between pieces A and B. These perforation marks were found in pieces A and B and in one of the tread fragments that had separated from part B.

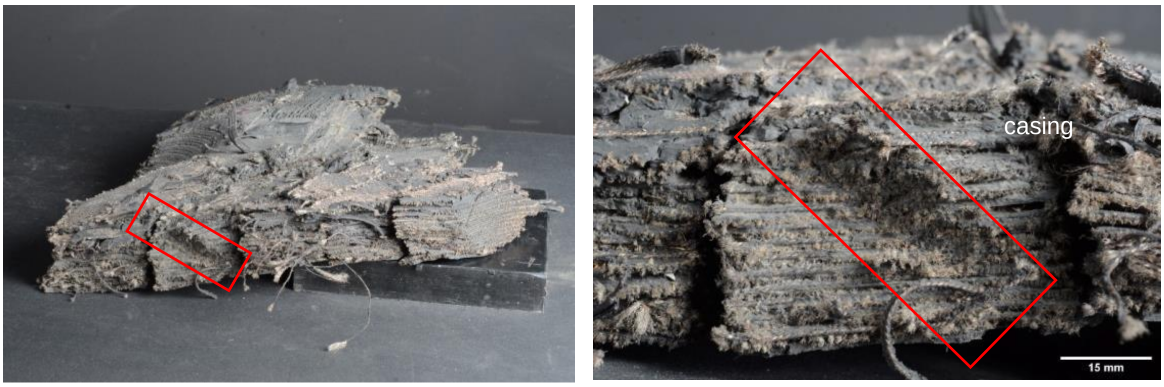


Figure 21. Perforation in piece A (casing)

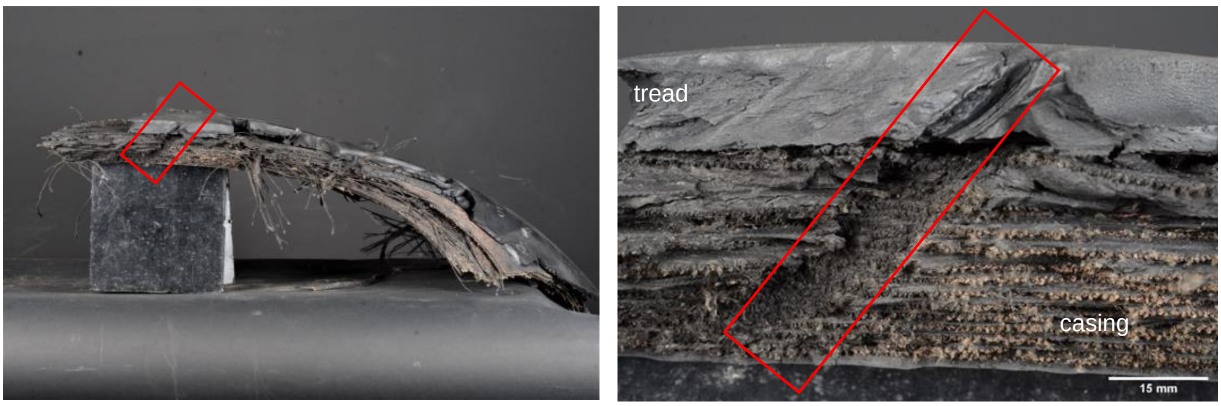


Figure 22. Perforation in piece B (casing and tread)

Microscopic analysis of the perforation zone:

The last phase consisted of analysing the perforation zone detected between pieces A and B using a scanning electron microscope (SEM). It was used for different purposes: for the piece A and B fragments of the tyre casing, it was used to determine the breakage patterns of the filaments that make up the plies; and for the piece B tread fragment, it was used to determine the direction of perforation. The results were as follows:

- The study of piece A revealed multiple damaged filaments, probably due to being ingested by the engine, for which it was unable to determine the failure mode. In the remaining filaments, it was identified two types of breakages: tension breakages[24] and crushing breakages.[25]
- The study of the casing section of piece B revealed crushing breakages in the perforation area and tension breakages in the areas outside the perforation area.
- The study of the tread section of piece B showed the rubber was clearly deformed towards the centre of the piece.

The measurements taken for piece B (figure 24) showed that the perforation was approximately 1.5 mm wide and extended for about 70 mm (7 cm) through the tread and casing on an almost wholly oblique path relative to the tyre surface.

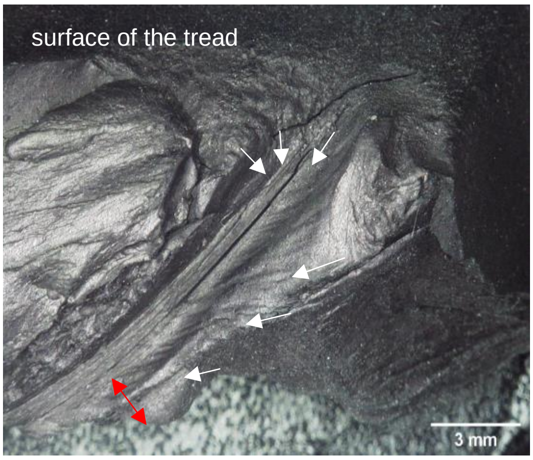


Figure 23. Deformation of the material in the tread of piece B

[24] Tension breakages are ductile and generally due to forces that exceed the strength of the filament. Typically, these breakages occur after a localised rupture of a few filaments (either due to fatigue, compression or external cuts and perforations). This then affects the other filaments in the vicinity, which cannot withstand the extra load in the damaged area.
[25] Crushing breakages are typically found when an external object has exerted pressure on the plies.

1.16.12 Landing gear retracting procedure

The Air Canada Quick Reference Manual (QRH) specifies the following procedure for retracting the landing gear.

Gear Lever Will Not Move Up

Condition: The landing gear lever cannot move to UP.

1 Landing gear lever LOCK OVRD switch . . . . Push and hold

2 Landing gear lever . . . . UP

After landing gear retraction is complete:

Landing gear lever . . . . OFF

■ ■ ■ ■

The procedure inhibits the landing gear lock using the LOCK OVERRIDE SWITCH located next to the landing gear actuation lever. Under normal conditions, the main landing gear tilts after take-off, causing the tilt sensors to release the gear lock, allowing retraction. This was the procedure used by the crew during the incident.

The *Limitations-Landing Gear* section of the Aircraft Operating Manual (AOM) establishes a maximum of 270 KIAS when operating the landing gear. This speed is the maximum speed the aircraft can fly at with its landing gear extended.

Lastly, the aircraft also has an option to extend the landing gear in an emergency, using the ALTERNATE GEAR EXTENDED SWITCH. This last option can be used when flying up to a maximum of 250 KIAS and is irreversible, i.e. it does not allow for the landing gear to be retracted. The pilots did not need to use this procedure during the incident.

1.16.13 Engine failure procedure

The Air Canada Quick Reference Manual (QRH) specifies the following procedures in the event of severe engine damage. The steps applicable to flight ACA837 have been marked in red, taking into account that there were no indications of fire in the engine, no vibrations after shutting down the engine, and they hadn’t needed to apply antifreeze to the wings.

ENGINE FIRE
or
Engine Severe Damage or Separation

Messages: L ENGINE FIRE R ENGINE FIRE

Condition: One or more of these occur:
- Engine fire warning
- Airframe vibrations with abnormal engine indications
- Engine separation

1 A/T ARM switch . . . . OFF

2 Thrust lever
(affected side) . . . . .Confirm . . . . Idle

3 FUEL CONTROL switch
(affected side) . . . . .Confirm . . . . CUTOFF

4 Engine fire switch
(affected side) . . . . .Confirm . . . . Pull

5 **If** the engine fire warning light is illuminated:

Engine fire switch
(affected side) . . . . Rotate to the stop and hold for 1 second

If after 30 seconds the engine fire warning light stays illuminated:

Engine fire switch
(affected side) . . . . Rotate to the other stop and hold for 1 second

- -

6 **If** high airframe vibration occurs and continues after engine shutdown:

Without delay, reduce airspeed and descend to a safe altitude which results in an acceptable vibration level.

If high airframe vibration returns and further airspeed reduction and descent are not practical, increasing the airspeed may reduce the vibration.

▼ Continued on next page ▼

▼ ENGINE FIRE or Engine Severe Damage or Separation continued ▼

7 Choose one:

◆APU is **available**:

▶▶**Go to step 8**

◆APU is **not** available:

▶▶**Go to step 9**

8 APU selector . . . . START, then ON

9 Transponder mode selector . . . . TA ONLY

10 Plan to land at the nearest suitable airport.

11 **If** wing anti–ice required:

PACK control selector (affected side) . . . . OFF

ISLN switch (affected side) . . . . On

When wing anti–ice no longer required:

L and R ISLN switches . . . . Off

12 GND PROX FLAP OVRD switch . . . . OVRD

13 Use flaps 20 and VREF 20 for landing.

14 Use flaps 5 for go-around.

15 Check the Non-Normal Configuration Landing Distance tables for Engine Failure or Shutdown in the Performance Inflight-QRH chapter, or other approved source.

16 Do **not** accomplish the following checklists:

ENGINE BOTTLE

ENGINE OVERHEAT

ENGINE SHUTDOWN

PACK OFF

17 **Checklist Complete Except Deferred Items**

Deferred Items

Pre-Descent Checklist
Landing data . . . . **VREF 20**

Landing Checklist
Flaps **20**

■ ■ ■ ■

1.16.14 Procedure in the event of a wheel failure

While there are no defined procedures for a wheel failure as such, there is some information provided on the situation. Specifically, the following information is included within the *Abnormals-Landing Gear* chapter of the AOM:

TIRE FAILURE DURING OR AFTER TAKE-OFF

If the crew suspects a tire failure during take-off, the ATS facility serving the departing airport should be advised of the potential for tire pieces remaining on the runway. The crew should consider continuing to the destination unless there is an indication that other damage has occurred (non-normal engine indications, engine vibrations, hydraulic system failures or leaks etc).

Continuing to the destination allows the airplane weight to be reduced normally, and provide the crew an opportunity to plan and coordinate their arrival and landing when the workload is low.

LANDING ON A FLAT TIRE

The 767 is designed so that the landing gear and remaining tire(s) have adequate strength to accommodate a flat nose gear tire or main gear tire. When the pilot is aware of a flat tire prior to landing, use normal approach and flare techniques, avoid landing overweight and use the center of the runway. Use differential braking as required for directional control. With a single tire failure, towing is not necessary unless unusual vibration is noticed or other failures have occurred.

In the case of a flat nose wheel tire, slowly and gently lower the nose wheel to the runway while braking lightly. Runway length permitting, use idle reverse thrust. Autobrakes may be used at the lower settings. Once the nose gear is down, vibration levels may be affected by increasing or decreasing control column back pressure. Maintain nose gear contact with the runway.

Flat main gear tire(s) cause a general loss of braking effectiveness and a yawing moment toward the flat tire with light or no braking and a yawing moment away from the flat tire if the brakes are applied harder. Maximum use of reverse thrust is recommended. Do not use autobrakes.

1.16.15 Object detection tests

Following the analysis of the wheel failure, it was contacted Madrid-Adolfo Suárez Airport to assess the likelihood of detecting objects as small as those that affected flight ACA837 (1.5 mm in diameter by 7 cm long). According to the runway and apron service, their ability to detect small objects is obviously very limited and depends on several factors: the person who performs the inspection, the sun's position, the surface texture, the height and width of the object and its colour. Even though the service has previously detected objects of similarly small dimensions (a few centimetres), this would typically be because they produced a reflection or because, despite being small, they were several centimetres tall. As a general rule, detecting an object as small in diameter as the one involved in this event is considered quite unlikely.

Nevertheless, it was carried out a test by depositing similarly sized objects on the runway in similar light conditions to those on the day of the event. None of the objects were detected during the runway inspection.

1.17. Organisational and management information

1.17.1 The LECM Operating Manual

ENAIRE's defined Emergency Response Plans (S41-02-GUI-001-5.0), which establish guidelines and actions to be taken in the event of aircraft emergencies, are included in the LECM Operating Manual. According to the document, given that it would be impossible to list all the possible situations or emergencies that could occur, it intends to offer a list of actions to take in the event of the most frequently occurring emergencies. It provides guidelines for responding to a total of 27 different emergencies. For each emergency, it provides information about the situations that can arise, the things that might happen in the aircraft, the action that should be taken by ATC and the information that the pilot or controller may need.

Emergency no.12 deals with Engine Failure, Engine Failure/Flameout, and no.25 deals with Landing Gear Problems-Unsafe Indication-No Landing Gear, from which the references relevant to the runway inspection have been extracted:

- Procedure no.12: *“clear the runway”*
- Procedure no.12: *“after landing, a vehicle should be authorised to enter the runway (...) in order to inspect the aircraft”*
- Procedure no. 25: *“Clear the runway (...) keeping it free and secure”*

1.18. Additional information

1.18.1 FOD (Foreign Object Debris) risk management programme

FOD is defined in ICAO Annexe 14 as “an inanimate object within the movement area which has no operational or aeronautical function and which has the potential to be a hazard to aircraft operations”. The regulations define the need for the risks associated with the presence of FOD to be reduced or minimised through the implementation of a FOD risk management programme for those airports that wish to be certified under Commission Regulation (EU) No 139/2014. The programme specifies four phases (prevention, detection, removal and evaluation).

In addition to leading to high operating and maintenance costs, FOD can potentially damage aircraft during critical flight phases, resulting in personal and material damage. The Concorde crash at Charles De Gaulle airport was one of the most tragic accidents caused by FOD and led to substantial improvements in detection practices.

1.18.2 FOD detection methods

The visual inspection method is the most widely used detection method because it is the least costly (both in terms of machinery and operating costs). It uses the visual capacity of an operator who makes tours of the area to be inspected at a designated speed. The ability to detect small objects using this method will vary depending on the visibility, light conditions, characteristics of the object, speed and attention of the operator. In an attempt to improve detection procedures, detection technologies, known a continuous detection, are being developed. These technologies[26] use radar sensors (able to detect cylindrical objects measuring 3 cm thick by 3.8 cm in diameter) and electro-optics (able to detect 2 cm objects). These technologies allow for continuous object detection in all weather conditions but cost significantly more.

[26] FAA requirements.

At Madrid-Adolfo Suárez Airport, detection is carried out via visual inspections, and sweepers remove any FOD.

1.18.3 Studies on FOD (Foreign Object Debris)

Several studies and documents[27] were analysed to determine whether the object that caused the ACA837 failure was similar to the types of FOD typically found or whether, on the contrary, it was an exceptional case. The studies analysed contained the following relevant information:

- Origins of FOD: debris can be generated by personnel, airport infrastructures (pavements, lights, signals), the environment (animals, storms) and by aircraft and their equipment.
- Study carried out at Charles de Gaulle airport over the period of 1 year:
  - Composition: 60% were metal, 18% rubber.
  - Colour: almost 50% were dark.
  - Most frequent dimensions: 3*3 cm or smaller.
- Study of 116 FOD events reported to the ATSB over a period of 10 years:
  - 80% of the FOD cases had no operational consequences.
  - 20% had operational consequences (14% missed approach manoeuvre, 3% return to the airport after take-off, 2% interrupted take-off, 1% passenger disembarkation).
  - The most frequently reported FOD were produced by aircraft components (hatch pins, reversers, etc.), accounting for 33% of the events.
- Study on the location of FOD carried out by the CAA over a period of 10 months:
  - 55% on aprons
  - 30% on taxiways
  - 15% on runways

One of the most exhaustive studies on FOD at international airports was the one carried out by the FAA at Chicago O'Hare Airport. A total of 79 inspections (runways only) were performed over a period of 2 years, and the material found was classified, analysed, weighed and measured. The inspections were performed using three methods: visual inspections by operators, sweepers, and magnetic detectors. The study focused on hazardous FOD[28]:

- Hazardous FOD: objects larger than 2.5 cm, although the hazard may not be exclusively associated with the size or material: for example, small dense objects can be hazardous, while large paper or plastic objects are not.
- Size of hazardous FOD according to their largest dimension:
  - Small: under 3.8 cm.
  - Medium: between 3.8 and 7.6 cm.
  - Large: those whose largest dimension exceeds 7.6 cm.

[27] Carried out by the American Federal Aviation Administration (FAA), the United Kingdom Civil Aviation Authority (CAA), the Australian Transport Safety Bureau (ATSB) and Eurocontrol.
[28] Definition developed by CEAT (University of Illinois Center of Excellence for Airport Technology) based on reports from an American operator, informal reports from American airports and CEAT's research in FOD since 2004.

The study reached the following conclusions:

- As a proportion of the total FOD collected, hazardous FOD only accounted for a very small part.
- No. of hazardous FOD: 1,146 with a total weight of 244 kg.
- In terms of material and size
  - Small FOD were metal
  - Medium FOD were asphalt and concrete
  - Large FOD were tar, asphalt, concrete, and glass
- Hazardous FOD:
  - Small metal parts. These accounted for 60% of the hazardous FOD.
  - Larger fragments of asphalt, concrete and tar, the latter arising from the condition of the paving and being the most common.
  - Painted parts.

1.18.4 Aircraft performance

Based on the documentation provided by the operator, Air Canada[29], which, in turn, is based on information supplied by the manufacturer Boeing, several calculations were made in order to determine whether the aircraft performed was as expected during the initial minutes of the event. Taking into account the specific weight, temperature, altitude and pressure scenario of flight ACA837, with one inoperative engine and the landing gear extended, it was calculated the aircraft would be capable of maintaining level flight and/or achieving a residual climb rate of 100 fpm up until approximately 4,000 ft.

In addition, an aircraft operating with its landing gear extended generates an estimated 15 to 20% weight penalty. Applying this factor to flight ACA837 led to conclude that the incident took place with a landing gear-induced excess weight of between 11-20 tonnes, a condition that would have affected the aircraft’s performance.

Finally, in a similar scenario with the same weight, environmental conditions and engine failure but with the landing gear retracted, it was calculated that the aircraft would have been able to ascend to an altitude of 20,700 ft, where it could have maintained level flight and/or achieved a residual climb rate of 100 fpm.

1.19. Useful or effective investigation techniques

N/A.

[29] AOM Supplementary Techniques Landing Gear- engine inop – driftdown speed / level off altitude 100 fpm residual rate of climb.

2. ANALYSIS

On Monday, 03 February 2020, the Boeing 767-375 aircraft with registration CGHOZ took off from Madrid-Adolfo Suárez Airport (Spain) destination Toronto Pearson Airport (Canada), loaded with 51.7 tonnes of fuel. Two seconds before lift-off, the tyre on main-gear wheel number 5 failed. The crew continued the take-off, managing the appearance of various damages to the aircraft as a result of the tyre failure in addition to navigating.

After 4 h 11 min of flight to reduce the aircraft's weight, it landed safely at Madrid-Adolfo Suárez Airport with 26.2 tonnes of fuel on board. No one was injured during the incident.

The analysis of the event is focused on what caused the tyre failure and how the situation was managed from three different perspectives: the crew, the airport and ATC.

- 2.1: Origin of the event: failure of tyre number 5 on the main landing gear.
- 2.2: Presence of debris on runway 36L.
- 2.3: Management of the emergency by the crew.
- 2.4: Management of the emergency by ATC.
- 2.5: Management of the emergency by the airport.

2.1. Origin of the event: failure of tyre number 5 on the main landing gear

The incident involving the C-GHOZ aircraft was caused by the failure of tyre number 5 on its main landing gear at 14:58:03, two seconds before the lift-off at the end of the take-off run. Specifically, the tyre burst and subsequently threw its tread.

2.1.1 Perforation by an external object - FOD

The research carried out on the recovered tyre fragments confirmed, with certainty, that the tyre failed after being punctured by FOD[30]; in other words, by an external object with the following characteristics:

- The object was a sharp object, which penetrated from the outside in and managed to pierce through the tread and almost the whole of the tyre casing.
- At the moment it punctured the tyre, the object was at an inclined angle.
- It was approximately 1.5 mm wide and 70 mm long.

2.1.2 Breakage sequence

The breakages observed in each of the 9 recovered tyre sections (direct ruptures in section 7 and tapered ruptures in the other sections) made it possible to determine that the failure began in section 7. The presence of these direct ruptures, in which all the tyre casing's plies rupture simultaneously, indicates there must have a lot of energy involved. With this energy level in mind, it was possible to rule out a possible low-pressure condition in the tyre at the time of failure.

[30] FOD (foreign object debris).

Furthermore, these types of ruptures are “rapid” ruptures, understood as breakages that occur in less than one turn of the wheel.

Furthermore, the presence of tapered ruptures in the other sections and the increasing distance between the internal and external ply ruptures the further the distance from section 7 indicates there was less energy left in the wheel after a significant part of it had already been released during the initial breakage in section 7. Tapered ruptures are associated with a slower breakage process during more than one turn of the wheel, in which it is possible to observe the process of rupture layer by layer.

Another of the observations confirming the initial point of rupture is the fact that pieces A and B were projected in different directions. Piece A was projected forward and ingested by the engine, but piece B stayed on the runway.

Given that we did not find any discrepancies or discordant elements in the damage caused to the wheel, it was determined that it was sustained during a single event. Based on findings, the failure of tyre number 5 occurred in the following sequence:

- the perforation produced by the external object weakened the structure of the tyre and triggered the explosion,
- the perforation occurred while the tyre was pressurised at its nominal value,
- the explosion started in section 7, causing all the layers of the tyre to rupture in less than one turn of the wheel,
- during the rupture of section 7, energy was released instantaneously,
- the breakages then progressed on either side of section 7 with less energy than the initial explosion, producing tapered ruptures in a process that lasted through several turns of the wheel,
- finally, and as a consequence of all the above, the tread was thrown.

2.1.3 Factors ruled out in the tyre failure

In addition to perforation by an external object, it was analysed the possibility that other factors or conditions could have arisen and, by themselves or in combination with other elements, contributed to the tyre's failure. The information compiled made it possible to rule out the following conditions as influential in the event:

<u>Meteorological conditions:</u>

- There were no extreme crosswind conditions that could have affected the geometry of the tyre rubber while taxiing.
- Nor was the outside temperature high enough to affect the tyre temperature.

Condition and geometry of the taxiway and runway:

- It was ruled out the possibility that the abrasiveness of the taxiways and runways may have contributed to the incident.
- The geometry of the taxi route followed by the aircraft did not involve any excessively sharp turns or manoeuvring that would have required the wheel to pivot.

Performances of the flights prior to the incident:

- The accelerations recorded for the previous flights did not indicate any issues relating to prior excessive loads due to “hard landings”. Nor were there any excessive roll speeds or elevated brake temperatures.
- The weight and balance of the incident flight did not indicate favourable conditions for the landing gear overload.
- A review of the inflation pressures did not find any low-pressure issues in any of the landing gear wheels (both main and nose), thereby ruling out a possible overload on the other wheels. Likewise, it did not find any excess inflation pressures that could have caused the tyre to burst.
- The flight reports did not indicate any previous issues with any other part or system that could have affected the landing gear.
- Finally, and related to operational factors, we reviewed the time that elapsed between the landing of the previous flight and the take-off of the incident flight and ruled out the possibility that an insufficient cooling time may have contributed to an increase in the tyre's temperature.

Wheel manufacture, assembly and maintenance:

- The review of the wheel's build and maintenance history did not identify any problems or abnormalities. Specifically, the review of the last retread, 40 cycles before the event occurred, did not reveal any defects that could have weakened the internal structure of the wheel.
- Possible undetected damage associated with the cut and consequent replacement of wheel number 6 (its companion wheel) three days before the event was also ruled out.
- The valves and fuses on the rims of wheel number 5 were found to be in good condition and had not been activated during the event, ruling out the possibility that the failure had been produced by excess temperature, internal pressure, or a loss of pressure through the inflation valve.
- The condition of the other wheels on the right main gear (1, 2 and 6) ruled out a problem relating to the assembly or installation of the main gear as a whole.
- The review of previous incidences allowed us to rule out a repetitive manufacturing problem due to the prolonged periods between similar events.

2.1.4 Temporal relationship between the puncture and explosion of the tyre

The final collapse of a tyre does not necessarily occur immediately after a puncture in all cases of FOD damage. Depending on the depth of the puncture, the profile of the object and the energy of the object during the perforation, the internal damage will vary and therefore, the internal structure of the tyre will be more or less resistant. This can lead to situations where an object may have punctured an aircraft tyre at one point, but nothing happens until several landings and take-offs later.

In the C-GHOZ incident, the estimated shape, dimensions and angle of penetration of the object, as well as the evidence of high energy at the time of the breakage, indicates that the contact with the external object occurred towards the end of the take-off run from LEMD and produced an instantaneous tyre rupture.

The fact that the object affected the rear rather than front wheels is a relatively common phenomenon in the type of landing gear configuration fitted to the C-GHOZ (*multiple axle bogies*). In fact, the similar incidents studied follow this same pattern. The most feasible explanation for this phenomenon is that the object, initially lying on the runway, did not affect wheel number 1 because it did not have an adequate angle of penetration. However, wheel number 1 lifted and projected the object backwards, giving it the necessary position and energy to make contact with and penetrate wheel number 5.

2.1.5 Secondary damages to the tyre failure

The tyre failure in the C-GHOZ event was a fully pressurised explosion phenomenon at the moment when the aircraft had reached its maximum ground speed (end of the take-off run at 176 kt of GS and 168 kt of CAS). As a result, several pieces of the tyre were projected in various directions.

The most problematic issues that affected the remainder of the flight (damage to the left engine and tilt sensor) were produced by the tyre fragments and can therefore be categorised as secondary failures, ruling out prior anomalies in the aircraft.

The most significant of all the secondary failures was the one that affected the engine. Black rubber marks were observed on the lateral engine cowlings, confirming that several pieces of tyre fragment were projected forwards. The high speed of the wheel at the moment the tyre exploded gave the fragments enough energy to reach the engine's suction area and be ingested by it. The surveillance cameras also confirmed that at least one of the ingested fragments was large. The results of the engine inspection confirmed this, finding tyre remains in the first modules and ingestion marks and damage to all the modules. At an operational level, the consequences of this secondary damage were an increase in engine vibrations and N1, which forced the crew to shut it down and continue the flight with just one operative engine.

The second secondary failure to affect the flight of the C-GHOZ aircraft was caused by a tyre fragment that moved up and to the sides, damaging the landing gear tilt sensor. The effect on this system was minor, but sufficient to prevent the crew from being able to retract the landing gear on the initial climb. However, the landing gear sustained no further damage, and the crew subsequently overcame the problem by using the alternative landing gear actuation procedure to operate it.

No other parts were affected: the remaining left landing gear tyres, including the companion tyre (number 6), were not affected, the gear was able to retract and subsequently extend, the flaps operated without asymmetries, and the hydraulic systems and fuel tanks also escaped damage.

The only other damage found on the aircraft was superficial, in the form of small, shallow perforations and marks that did not influence the operation of the aircraft or any of its systems.

2.2. Presence of the object on runway 36L

The origin of the event was the perforation of tyre number 5 by a sharp 1.5 mm wide by 7 cm long object (FOD) on runway 36L at Madrid-Adolfo Suárez Airport.

The review of the operations on Runway 36L showed that 3 aircraft had used the runway since its last inspection. Given that their take-off runs were longer than that of flight ACA837, the three aircraft would also have travelled over the area where the object that affected the ACA837 was lying. This implies that either:

- The object was on runway 36L, was not detected in the runway inspection and did not affect the three previous aircraft.
- One of the three previously departing aircraft left the object on the runway.

The investigation has not been able to determine which of the two options occurred in the ACA837 incident, and based on the information on FOD compiled in section 1.18, both are considered equally possible.

<u>FOD detection impossibility:</u>

In relation to the capacity to detect an object with these characteristics, the main conclusion of the investigation is that, by using the visual inspection methods currently in force, it is practically impossible to detect them. Therefore, if it was on the runway during the prior inspection, there would have been no guarantees it would have been found and removed.

The review of the runway inspection procedures at Madrid Airport found that the processes, means to be used, and criteria to follow were fully and correctly defined. The personnel who carried out the inspections were also highly experienced, both in their time at the airport and in carrying out the activity. The problem stems from the fact that the inspections are visual and performed by one person, from a moving car that can travel up to 60 km/h and covers areas up to 30 m wide.

While these conditions do not limit the detection of objects with significant dimensions and volumes, they do limit the detection of smaller objects. Despite the fact that the Madrid Airport Runway and Apron Service had detected smaller objects in the past, the general conclusion is that visual inspection methods are not entirely effective because of the limited human capacity to spot them.

<u>Presence of hazardous FOD:</u>

The results of the FOD studies looked at during this investigation indicates the presence of FOD of the type that affected flight ACA837 is not unusual. The most common type of hazardous FOD are small, metallic objects with dimensions similar to the one that affected the ACA837. In fact, according to the classification used in one of the study, the FOD involved in the ACA837 event would be classed as a medium-sized hazardous FOD.

However, the studies also recognise that hazardous FOD only accounts for a small percentage of all the FOD found on runways and that in 80% of cases, they do not affect aircraft operations. This explains why the visual detection method is still the primary method used at most airports, including Madrid.

Taking into account both these considerations (the not-unusual presence of the FOD that affected ACA837 and the fact that FOD has a low probability of causing accidents), and given the economic implications it would entail, no recommendations will be issued regarding the use of continuous detection methods, even though they may have facilitated the detection of the FOD involved in the ACA837 incident at Madrid-Adolfo Suárez Airport. However, in regard to the visual detection methods currently in use, it is issued a safety recommendation to Madrid-Adolfo Suárez Airport, suggesting that it should study the possibility of improving its current inspection procedure.

2.3. Management of the emergency by the crew

The crew could not be sure the tyre had exploded until quite some time after it occurred, after the flight had stabilised, and they had addressed all the emergencies on board. In the cockpit, the event manifested itself through the secondary effects that the explosion produced: the crew had to deal with the engine failure immediately before rotation, followed by the problems retracting the landing gear.

The crew's description of the event was coherent and consistent with the data recorded by the FDR with regard to the tyre (increase in accelerations and momentary yaw to the left) and the engine (increase in vibration and N1).

<u>Decision to continue with the take-off:</u>

The appearance of the engine failure coincided with lift-off at 171 kt, well above V_1 (158 kt). Therefore, continuing with the take-off was the only feasible option and aborting it was no longer possible.

<u>Selecting and initiating the ENGINE SEVERE DAMAGE procedure:</u>

The effects on the engine were immediately noticeable (between 1 and 3 seconds after the tyre failure occurred), coinciding with the aircraft's lift-off. Although it was not possible to listen to the cockpit communications at that time, the FDR recorded swift action by the crew. Thirty-six seconds after the event occurred, the crew were already taking their first action by following the ENGINE SEVERE DAMAGE procedure, which means that in less than half a minute, the crew had evaluated the data from the engine and decided which procedure to apply.

The selected procedure is the same for three different situations: engine fire, severe damage, or separation. The circumstances described by the severe damage procedure (*airframe vibrations with abnormal engine indications*) matched the parameters the crew saw in the cockpit, and therefore, the procedure selected to manage the situation was correct.

Phases in the execution of the ENGINE SEVERE DAMAGE procedure:

The procedure contains 4 initial actions to be carried out from memory (*memory items*) followed by another 10 steps to perform. The FDR revealed that the procedure was carried out in two clearly time-separated phases:

- Actions 1, 2 and 3: executed immediately at 36, 39 and 62 seconds after the event.
- Actions 4, 7 and 8: executed 17 minutes after the event.

The first three actions were implemented extremely quickly and succeeded in eliminating the vibrations by pulling the thrust lever back and shutting off the fuel (actions 2 and 3). The engine's stabilisation was corroborated by the FDR, described by the flight and cabin crew in their statements and perceived by the flight crew during the flight, who informed ATC that the engine was “secured”. Action 4, (*engine fire switch pul*l) is one of the memory items and should have been carried out urgently but was postponed until 17 minutes later. Fortunately, this action had no consequences for flight safety because the crew had stabilised the left engine parameters by completing the first 3 actions, but it indicates that the procedure was not carried out in the correct time sequence.

The remaining actions could not be confirmed by the FDR (because there are no associated parameters). However, in the CVR, the crew mention the review of all the actions involved in the procedure before planning the landing, and action 12 was confirmed because the post-landing flight deck inspection confirmed the switch had been pulled.

Emergency declaration:

When the engine problems appeared, the aircraft was still in contact with TWR, who, on two occasions, called the aircraft for its transfer. These calls went unanswered because of the high workload in the cockpit generated by both the phase of the flight (initial climb) and the unfolding emergency; they came at the time when the crew was assessing the anomalies that had just appeared and were about to start the ENGINE SEVERE DAMAGE procedure. Despite this, the crew managed to communicate with ATC between the execution of actions 2 and 3 of the procedure, 50 seconds after the event. This communication was both fast and complete in terms of content because it transmitted the emergency declaration using the word MAYDAY, the type of emergency (engine failure) and their immediate needs (stand by). The next communication from the aircraft was made immediately after performing action number 3 of the ENGINE SEVERE DAMAGE procedure, during which they reported that the engine was secured and requested radar vectors.

Navigation:

The trajectory followed (maintaining the runway heading up to 5 NM from SSY and then turning towards NVS) confirms that the crew followed the established procedure for an engine failure before SSY after take-off from runway 36L. The change in the planned route (ZMR5L) was promptly notified to ATC, specifically before starting the turn towards NVS. This action is considered to be of critical importance because ATC does not know which route an aircraft with an emergency is advised to follow, and in this case, the crew of flight ACA837 informed them of its intention to turn to NVS rather than continue north, as expected.

<u>Difficulty gaining altitude:</u>

One of the characteristics of the ACA837 flight was that the events took place at a low altitude (1,000 ft above the ground), below the minimum surveillance height for a period of 9 minutes. The aircraft's inability to climb can be explained by a combination of three factors: operating on a single engine, having the landing gear down and carrying full take-off weight. The aircraft performance calculations show that it was able to maintain flight above the acceleration altitude and increase speed. Therefore, although the flight altitude was below the radar minima, the aircraft performed as expected.

With regard to the performance of the landing gear, the recorder showed that:

- The crew did not attempt to retract the landing gear until 3 minutes into the flight, with the aircraft at 1,000 ft AGL and heading towards NVS, despite the fact that in their statement, they indicated they first attempted to do it at 400 ft.
- It wasn't until 9 min after the event, with the aircraft at 1,000 ft AGL, which the crew managed to retract the landing gear using the alternative procedure.

In the interview, the commander described how they suspected the landing gear might be affected by a possible high-temperature problem due to the smell of burning rubber they had noticed during take-off. This suspicion led him to postpone the retraction of the landing gear, intending to cool it down and avoid potential subsequent problems in the landing gear compartment, which would have added to the engine failure.

The aircraft's situation was transmitted in all communications to ATC, demonstrating the development of the problems they were facing: initially, they reported an engine failure, then operating on a single engine and, finally, in addition to only having one engine, they reported they could not raise the landing gear and were unable to climb. In all communications, the aircraft communicated its needs to ATC: initially vectors and later vectors to go to a lower area, hold and, in the words of the crew, manage the multiple emergencies they had.

They finally managed to retract the landing gear 9 minutes into the flight by applying the GEAR LEVER WILL NOT MOVE UP procedure. The LOCK OVRD SWITCH allowed them to bypass the landing gear blockage caused by damage to the tilt sensor, so it makes sense that the landing gear could be retracted using this procedure. After retracting it, the landing gear up and locked indications in the cockpit were normal, and the landing gear didn't have any other consequences for the flight. The landing gear was subsequently raised or lowered on three separate occasions (during the inspection carried out by the EF-18A and during the final approach) with no further movement or indication issues.

The possibility of ascending after retracting the landing gear was immediately notified to ATC, and from that moment on, the aircraft managed to climb above 1,000 ft AGL, move away from the urban centre of Madrid, and follow ATC instructions. From the crew's point of view, this dramatically improved the situation, and this was noticeable in the tone of their communications with ATC.

Tyre failure, assessment of the situation and the remainder of the flight:

The crew were initially unable to confirm the tyre failure. There is no sensor to provide that information in the cockpit, so at first, they could only intuit a problem with the landing gear from the smell of burnt rubber, the black marks on the engine, the momentary yaw and the information that the service director gave them. Only after the failed attempt to raise the landing gear did the crew first comment on the problem (4 min after the event), and after 8 min, they confirmed again that at least one tyre had exploded.

ATC was aware of the debris on the runway 6 min after the event, but they still didn't know if it had come from this aircraft or a previous one and, therefore, did not transmit the information to the aircraft. It took 1 h 43 min for the maintenance personnel to confirm the runway debris belonged to the ACA837 and for this information to be transferred to the aircraft.

Despite not having confirmation until much later, the crew correctly assessed the initial indications and postponed an immediate landing despite it being one of the recommendations in the SEVERE DAMAGE procedure. The tyre failure is not considered an emergency but is considered an 'abnormal' and, therefore, deemed less critical than engine damage. The guidelines for wheel damage in the aircraft manual even allow for the possibility of continuing to the destination and carrying out a normal approach, flare and taxi without the need for towing. One of the few restrictions that do exist is to avoid landing with excessive weight, a consideration that was taken into account and prioritised by the crew when evaluating the situation.

This evaluation was reflected in their request to ATC to hold, first to finish managing the ongoing emergencies, and then to burn the necessary fuel. This calm and collected way of making decisions was also reflected in the two hours of CVR that enabled to analyse the communications in the cockpit. Both pilots were able to hold a relaxed, two-way conversation. On several occasions, they could be heard reviewing both the performed and pending procedures, they clearly and concisely established the expectations for the remainder of the flight and landing, commented on the possible risks during landing, and created an environment in which they could clarify or comment on any doubts or concerns. Investigation did not find any issues with the communication or assertiveness of either of the pilots. The checklists were completed in full, and the handover of controls from one pilot to another was correctly verbalised. The aircraft was correctly configured for the new situation, and all the new factors were taken into account (such as not using the autobrake).

Their flight preparation during the final and most critical phase (given that the EF-18A had confirmed the damage was limited to one main gear tyre) was just as thorough as in the previous phases. The briefing contemplated a possible missed approach manoeuvre, and they communicated this to ATC to ensure the initial ascent zone would be free should it be necessary. This proves that the crew were not focused on landing at all costs, despite the circumstances.

Finally, the communications show that the crew tried to taxi on their own once on the ground to avoid having to evacuate the aircraft. The decision to do this meant the passengers, who had been in flight for more than 4 hours without an entertainment system, had to stay on the aircraft for almost another hour while its brakes were cooled on the runway. The alternative would have been to speed up the disembarkation process by evacuating with one side of the aircraft being unusable due to the overheated brakes, so the decision to postpone the disembarkation of the passengers is considered correct.

<u>Coordination with the passenger cabin:</u>

The service director’s description of the flight indicated that the commander’s management in relation to the flight deck was thorough and adequate. The last two hours of the CVR confirmed that this was the case. With regard to the cabin crew, the captain provided complete and detailed information on the nature of the emergency via the service director, explaining the reality of the situation at hand, their intentions regarding the rest of the flight, the estimated remaining flight time and that, initially at least, no special actions or preparations were required for the landing. The service director was informed of the potential risks involved in the landing and the action they would take in each situation. As a result, the cabin crew was correctly informed.

The statements also unanimously confirmed that the cabin crew transmitted everything they observed on take-off (rubber marks, smell, etc.) to the flight crew, and this information helped the pilots establish the likely scenario of a problem with one of the landing gear wheels. Furthermore, the service director transmitted the information at a time when he perceived the workload in the flight deck would have eased. Therefore, the interaction between the pilots and the cabin crew was both thorough and correct.

With regard to the passengers, the announcements made by the commander confirm that they were also correctly informed. Before any event (such as the coordinated flight with the EF-18A, initiating the approach, or the presence of emergency vehicles and lights), the captain told the passengers what was going to happen so as not to alarm them and reassure them about the situations that would occur. The information was specific, regularly updated, and had the appropriate scope, which, together with the “composed” way the crew managed the flight, helped keep the passengers calm. In addition, the announcements were made in English and translated into French and Spanish, which meant that all the passengers felt adequately informed.

2.4. Management of the emergency by ATC

The most critical moments of the flight were the first 12 minutes in which the aircraft's crew made the distress call, found they were unable to climb, were unsure to what extent they could manoeuvre, were flying on a single engine and, as yet, did not know what their intentions should be. Two units managed this period: the departure controller at TWR Barajas and the Madrid ACC DWN-WNN sector controller.

2.4.1 Management of the emergency by TWR Barajas

The following aspects of the management carried out by TWR are assessed positively:

- With regard to the distress call made by flight ACA837, it is note that the controller respected the crew's “stand by” request in the initial call and did not interrupt the aircraft. Crews use this term when they need to prioritise other actions before communication, a situation it was possible to verify through the FDR, which confirms the crew were analysing all the warnings that were appearing and applying the emergency procedure. ATC did not attempt to contact the aircraft again until the crew initiated another communication with them.
- Also, the information was immediately transmitted to the next controller (sector DWN-WNN) by the TWR controller. This could be verified on two occasions: firstly, the communication of the engine failure at 50 seconds, and secondly, when the Runway and Apron Service confirmed that the runway was full of debris, at 8 minutes.
- The decision to transfer the aircraft, despite it being in an emergency, is also deemed to have been correct. Although, from a control point of view, an attempt is generally made not to transfer traffic in emergency situations, in this particular case, keeping it on the tower frequency would have been counterproductive because the tower did not have enough information to ensure separation from the terrain and any other traffic in the area. The DWN-WNN sector controller was the most suitable position for this type of management.
- Runway 36L was closed after the emergency notification, and all the traffic waiting to take-off was diverted to 36R.
- The management of taxiing traffic in the vicinity of the runways ensured the area around the runways the ACA837 might use for landing were kept free of traffic, eliminating risks, including those associated with a potential runway excursion on landing.
- Communications with the airport's emergency services deployed during the landing were both thorough and correct and ensured all actors were kept informed about the intentions and requirements of the aircraft with an emergency.

However, two aspects could have been improved: the failure to request a runway inspection after take-off and the communication of the emergency to the airport.

TWR did not request an inspection of runway 36L after the ACA837 reported the emergency. At that time, the controller was unaware that the origin of the event had been a tyre explosion. According to the information he had at the time, the aircraft had an “engine failure”, which, by itself, did not constitute a clear or obvious reason to suspect the presence of objects on the runway. The emergency is covered by ENAIRE's Emergency Response Plan but deals with a different flight phase, only considering the possible debris that may remain on the runway after landing with an engine failure. In both the engine failure emergency and the landing gear emergency, runway inspections are only prescribed after landing. The distinctive feature of this emergency is that it was reported very shortly after take-off.

In this context, it is issued a recommendation to ENAIRE, suggesting that, in the case of emergencies reported near take-off and/or while still on the tower frequency (as was the case in this event), the need to conduct a runway inspection should be assessed to rule out the presence of debris.

It was the Runway and Apron Service that acted proactively by offering to carry out a runway inspection 6 minutes into the event when they became aware that the runway was being reserved for the possible emergency landing of flight ACA837. Even though the controller anticipated the aircraft’s potential need to land on runway 36L and reserved it, landing on it could have generated additional problems because it was full of tyre debris. Thanks to the Runway and Apron Service taking the initiative to inspect it before flight ACA837 arrived, it was determined unsuitable for use.

TWR activated the alert immediately and almost simultaneously to receiving the notification. However, the terminology used to transmit the information from TWR to the airport was inadequate because it used an ambiguous term that did not facilitate its decision-making. Using specific terminology is essential, as it determines the alert level and informs decisions on which services need to be mobilised. The terminology used in the ACA837 event was “emergency”, an ambiguous term that does not facilitate decisions on what type of actions should be initiated. This was reflected in the fact that, for 30 minutes, the alert status remained at the local level until the service executive confirmed that a MAYDAY had been declared and raised it to general half an hour later. Fortunately, in the ACA837 event, the generalised choice of terminology did not have any consequences because the aircraft eventually landed without incident several hours later.

However, to reinforce the usage of the correct terminology while transmitting information in emergencies, a safety recommendation is issued to ENAIRE.

2.4.2 Emergency management by the DWN-WNN sector

Flight over the urban centre of Madrid

The controller of the DWN-WNN sector, who was highly experienced in both the activity and at the unit, had a difficult task to perform in managing this event, making it difficult to assess. The most relevant aspect of the event in this sector was the flight over the capital, Madrid, at 1,000 ft above the ground. While, in this event, the low-altitude flight over the city passed without incident, it did generate a risk that, in other circumstances, could have had consequences for people and populations.

The instruction to turn south (160º), issued by the DWN-WNN sector at 15:02:45, was the one that directed the aircraft over the urban nucleus. When it issued this instruction, the controller had the following information:

- that the aircraft was at 3,000 ft in a 4,500 ft zone bordering a 6,500 ft zone, that it could not climb, that it had an engine failure, that its tyre had exploded,
- that it was north of Madrid, above Tres Cantos heading southwest towards NVS, and
- he had just requested vectors to proceed to a lower area.

Added to these factors were the orographic conditions of the terrain surrounding Madrid Airport. On the one hand, with the aircraft unable to exceed 3,000 ft, the areas to the west and north of its position presented an ascending orographic profile (minimums from 5,500 ft to 11,000 ft). Flying to the east would have also entailed flying over Madrid and the minimums were 5,500 ft. Considering the aircraft's performance limitations, the only option was to head south, which was the area with the lowest altitudes (4,500 ft and 4,000 ft). Therefore, the instruction to head 160º south, in addition to directing them to the lowest possible area, allowed them to comply with the previous request from the crew to proceed to a lower area.

The elevation of the terrain and the minimum altitude, as well as bringing the aircraft closer to the LEMD approach route (runways 32R and 32L) to facilitate its entry to the airport, appear to have been the preponderant criteria at the time of issuing this instruction. The decision to direct the aircraft to the southern zone is deemed to have been a good one for the reasons stated above. However, the assessment did not take into account that this meant flying over Madrid, with all the risks that this could have implied given the fact that they didn’t know what type of failure had occurred or how it was going to evolve (non-contained failures, secondary failures, separation of parts, emergency landing, etc.). It was a complicated scenario with few viable alternatives: to have separated the aircraft from the urban nucleus it would have had to be directed further west, keeping it in the 4,500 ft zone, moving it away from the approach to Madrid, and coming into conflict with the airspace around Cuatro Vientos Aerodrome. In addition, it should be noted that the controller cannot see the geographical location of population centres on the radar display due to the amount of extra information that this would entail. In conclusion, it was a difficult situation to assess with a complicated scenario due to the multiple restrictions and factors involved.

Subsequently, the DWN-WNN sector issued a new instruction to turn towards a 140º heading, which was incorrectly acknowledged as 120º by the crew. Despite the fact that the controller did not correct the acknowledgement and that the aircraft was converging towards the locator on runway 32L, this error had no consequences for the following reasons:

- At all times, the aircraft maintained a lateral separation of more than 2 miles from said locator.
- The controllers coordinated to ensure no traffic was allowed to make an instrument approach to either locator, so at the time, there were no other aircraft within 25 miles.
- As the aircraft was ascending through 4,700 ft, they would have had vertical separation from the “hypothetical” aircraft that could have been established at the 32L locator.

- Being aware of their proximity to the locator, the controller acted proactively by asking if they could turn right on a 200º heading.

Collaboration and coordination with the aircraft and between units

With regard to the overall management of this sector, which was the most critical one in the entire emergency, it should be noted that it coordinated correctly with other units that could be affected, such as Cuatro Vientos. Separation instructions were issued in relation to various traffics that may have come into conflict with the incident aircraft, and priority was given to the needs and requests transmitted by the aircraft: initially, all approaching traffic was stopped to allow the direct entry of the ACA837, and when the crew indicated they would need to hold, the aircraft was kept separate from other traffic, but within close range to facilitate quick access if necessary.

The decisions to keep it initially at TOBEK and later at PDT RDL responded to the time estimates provided by the aircraft, and all the sectors involved provided all the help they could and everything requested. Continuous coordination between LECM and LEMD was maintained, updating the information and time estimates received. Examples of the control service's collaborative effort and willingness to help include the suggestion to use a military aircraft to inspect the landing gear and sending the photos it took to the crew via social networks.

Instructions for referencing the holding point

The instruction to go to a second holding point by referencing a distance on a radial from a reference point with outbound timings in a holding pattern, led to several communications to confirm the instructions. While the instruction complies with regulations, it would have been counterproductive to use this type of reference at other times in the emergency. In the case of the ACA837, by the time the crew received the reference, they were calmer and more collected than in the initial stages of the emergency, which meant it had no negative impact other than the time invested in clarifying the instruction.

Information about the tyre

The DWW-WNN sector was made aware of the situation by the aircraft in its second communication with it at 15:02:28. In this communication, the crew notified the controller that they had experienced a "tyre explosion". This information was not transmitted by the sector to the airport, despite the proximity to take-off. A recommendation has been issued to ENAIRE, suggesting that it should assess the usefulness of including a tyre explosion casuistry in its Emergency Response Plans and ensure that when this type of information comes to light during any flight phase, it is immediately transmitted to the airport of origin due to the potential for runway contamination.

2.5. Management of the emergency by the airport

The most important conclusions concerning the airport's handling of the emergency have been indirectly addressed in section 2.4.1 Emergency management by TWR, which outlines the potential consequences of the non-specific transmission of the information to the airport and the proactive contribution from the Runway and Apron Service after the aircraft took off.

The information transmitted by TWR to the airport was managed correctly, activating the appropriate alert phases and levels according to the information available. The resources mobilised were appropriate for each phase. The transmission of information between the emergency services was also adequate, and by the time the aircraft landed, everything was in place.

The airport's own internal analysis concluded with a series of suggested improvements, fundamentally relating to managing access to the control rooms and their maintenance as per the action plan. Therefore, we have concluded that no safety recommendations are required.

3. CONCLUSIONS

3.1. Findings

General:

- The aircraft was airborne for 4 hours 11 minutes, with a total flight time of 5 hours 19 minutes.
- The aircraft's take-off weight was 168,452 kg, of which fuel accounted for 51,752 kg.
- The aircraft's landing weight was 142,923 kg, of which fuel accounted for 26,223 kg.
- The aircraft did not have a fuel dumping system.

Specifically related to the event:

- The event occurred two seconds before the lift off.
- The event was caused by a sharp object measuring 1.5 mm wide and 70 mm long.
- The object was on runway 36L.
- The object punctured tyre number 5 on the left main gear, causing it to explode immediately.
- The explosion produced secondary engine and landing gear failures, as well as minor damage to the fuselage.
- The left engine ingested fragments of the tyre tread, resulting in increased vibrations and increased N1.
- The crew shut down the engine.
- The landing gear sustained damage to its tilt sensor, which prevented it from retracting.
- The landing gear was retracted by the alternative gear retraction procedure.

Specifically related to the management of the emergency:

- The crew identified and managed the emergency immediately.
- ATC was immediately notified of the emergency.
- After the event, the aircraft reached 3,000 ft of altitude (1,000 AGL).
- The aircraft remained at an altitude of 3,000 ft, below the minimum ATC surveillance altitude, for 10 min.
- The aircraft managed to exceed the minimum radar altitude 10 min after the event.
- 15 min after the event, the aircraft entered holding patterns at 5,000 and 8,000 ft of altitude.
- The aircraft remained in the holding patterns to consume the necessary amount of fuel for it to land with a weight within limits.
- A military aircraft (EF-18A) was mobilised to determine the extent and scope of the damage.
- The approach and landing were stable and carried out with the aircraft correctly configured.
- The aircraft stopped on the runway after a 4 h 11 min flight.
- The brakes became hot during the landing and were cooled by fans.
- The passengers disembarked the aircraft via the normal procedure.
- ATC gave priority to the requests and requirements communicated by the crew.

3.2. Causes/Contributing factors

The investigation has determined that the incident involving the C-GHOZ aircraft was caused by the presence of a sharp foreign object (FOD) on runway 36L at Madrid-Adolfo Suárez Airport, which punctured tyre number 5 on its left main landing gear and resulted in the explosion of the tyre and other secondary failures.

4. OPERATIONAL SAFETY RECOMMENDATIONS

The ACA837 event has shown that even small objects on the runway can lead to the complete collapse of a tyre. In this regard, runway inspections are the main method of detecting the presence of these objects. At Madrid-Adolfo Suárez airport, the scheduled inspections are carried out visually by an operator in a car that travels up to 60 km/h. Taking into account the fact that implementing other means of continuous detection would be much more expensive, the following recommendation is issued:

> RECX38/21. It is recommended that AENA, as the provider of the Runway and Apron Service, should study the possibility of improving the procedure for the detection of foreign object debris on the runway.

In regard to the management of the emergency by the TWR unit, we identified two aspects for improvement, relating to the terminology used when informing the airport about the emergency and not taking the initiative to inspect the runway, which are the subject of the following recommendations:

> REC39/21. It is recommended that ENAIRE, as the provider of the air navigation services for the Madrid-Adolfo Suárez Airport TWR, should incorporate this accident into its ongoing training plans to reinforce the importance of using the correct terminology when conveying alert situations to the airport in order to ensure the appropriate action plans are activated.

> REC40/21. It is recommended that ENAIRE, as the provider of the air navigation services for the Madrid-Adolfo Suárez Airport TWR, should assess the possibility of including the requirement to carry out a runway inspection whenever an emergency is declared shortly after take-off in the Emergency Response Plan.

> REC41/21. It is recommended that ENAIRE, as an air navigation service provider, should assess the possibility of incorporating the specific casuistry of a tyre explosion in the Emergency Response Plan, including the instruction that, whenever a tyre explosion is reported, regardless of the flight phase, a runway inspection must be carried out at the airport of origin.