CIAIAC

COMISIÓN DE INVESTIGACIÓN DE ACCIDENTES E INCIDENTES DE AVIACIÓN CIVIL

Report IN-037/2016

Incident involving a Gulfstream G200 aircraft, registration EC-KBC, at the Barcelona-El Prat Airport (LEBL, Spain) on 26 September 2016.

GOBIERNO DE ESPAÑA

MINISTERIO DE FOMENTO

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Foreword

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

In accordance with the provisions in Article 5.4.1 of Annex 13 of the International Civil Aviation Convention; and with articles 5.5 of Regulation (UE) nº 996/2010, of the European Parliament and the Council, of 20 October 2010; Article 15 of Law 21/2003 on Air Safety and articles 1., 4. and 21.2 of Regulation 389/1998, this investigation is exclusively of a technical nature, and its objective is the prevention of future civil aviation accidents and incidents by issuing, if necessary, safety recommendations to prevent from their reoccurrence. The investigation is not pointed to establish blame or liability whatsoever, and it's not prejudging the possible decision taken by the judicial authorities. Therefore, and according to above norms and regulations, the investigation was carried out using procedures not necessarily subject to the guarantees and rights usually used for the evidences in a judicial process.

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

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

Contents

Abbreviations

AAIB	Air Accidents Investigation Branch
ACC	Air Control Center
AD	Airworthiness Directive
ADI	Aerodrome Control Instrument
AEMET	Spanish Meteorological Agency - Agencia Estatal de Meteorología
AENA	Airport operator
AESA	Spanish Aviation Safety and Security Agency - Agencia Estatal de Seguridad Aérea
AFM	Aircraft Flight Manual
AGL	Above Ground Level
AIP	Aeronautical Information Publication
AMM	Aircraft Maintenance Manual
A/P	Auto Pilot
APU	Auxiliary Power Unit
APU	Auxiliary Power Unit
ARR	Arrivals
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATPL (A)	Airline Transport Pilot Licence
ATS	Air Traffic Services
CAAI	Civil Aviation Authority of Israel
CAS	Crew Advisory System
CECOPS	Airport Operations Control Centre
CPL(A)	Commercial Pilot Licence
CT	Control Tower
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
EFIS	Electronic Flight Instrument System
EICAS	Engine Indications and Crew Alerting System
ENAIRE	Air Navigation Services Provider
EUROCAE	European Organization for Civil Aviation Equipment
EW	Empty Weight
FDR	Flight Data Recorder
FFS	Fire Fighting Service

FL	Flight Level
FMS	Flight Management System
FOD	Foreign Objects Debris
Ft	Foot
g	Center of gravity
GMC N	Ground Movement Control - North
GMS	Ground Movement Surveillance
GND	Ground
GPWS	Ground Proximity Warning System
GS	Ground Speed
H	Hour(s)
IAS	Indicated Airspeed
ICAO	International Civil Aviation Organization
IFR	Instrumental Flight Rules
ILS	Instrument Landing System
IR	Instrumental Rating
Kg	Kilogram (s)
KIAS	Knots Indicated Airspeed
Km	Kilometer (s)
Kt	Knots (s)
lb	Pound (s)
LCL	Local controller
LDA	Landing Distance Available
LEBL	ICAO code Barcelona-El Prat airport
LECB	ICAO code Barcelona control center
LEMD	ICAO code Adolfo Suárez Madrid-Barajas airport
LH	Left Hand
LW	Landing Weight
m	Meter (s)
min	Minute (s)
mm	Milimeter (s)
METAR	Meteorological Aerodrome Report
MTOW	Maximum Take Off Weight
N/A	Not affected
NLG	Nose Landing Gear
NM	Nautical miles

NMOC	Eurocontrol Network Manager Operations Centre
NOTAM	Notice to Airmen
NPA	Non Precition Approach
NTSB	National Transportation Safety Board- USA
NWS	Nose Wheel Steering
OIS	Operational Information Supplement
P/N	Part Number
PF	Pilot Flying
PFD	Primary Flight Display
PM	Pilot Monitoring
PNF	Pilot Not Flying
psi	pounds-force per square inch
QFU	Magnetic bearing of the runway in use
QNH	Atmospheric Pressure (Q) at Nautical Height
QRH	Quick Reference Book
RAD	Aerodrome Radar Control
RH	Right Hand
s	Second (s)
S/N	Serial Number
SAR	Search and Rescue
SB	Service Bulletin
SACTA	Air Traffic Control Automated System - *Sistema Automatizado de Control del Tránsito Aéreo*
SID	Standard Instrumental Departure
SOP	Standard Operating Procedures
SYSRED	Integrated Center for Air Navigation Network Services and Monitoring
TOAM	Marshaller - *Técnicos de Operaciones en el Área de Movimiento*
TRM	Team Resources Management
TWR	Control Tower
T/R	Thrust Reverser
UTC	Universal Time Coordinated
WOW	Weight On Wheels

Synopsis

Owner and Operator:	Executive Airlines
Aircraft:	Gulfstream G200, EC-KBC
Date and time of incident:	Monday, 26 September 2016 at 19:53 UTC[1]
Site of incident:	Barcelona-El Prat Airport (LEBL, Spain)
Persons onboard:	2 flight crew and 2 passengers, none injured.
Type of flight:	Commercial air transport- Non-scheduled- Domestic – Passenger
Rules of flight:	IFR
Date of approval:	20 March 2018

Summary of incident:

The aircraft was flying from the Adolfo Suárez Madrid-Barajas Airport (LEMD) to the Barcelona-El Prat Airport (LEBL). Onboard were two flight crew and two passengers. The aircraft had taken off at 19:01 UTC. The first officer was the pilot flying. Upon reaching Barcelona, the crew made the approach and landed on runway 25R normally, but as the brakes were applied during the landing run, the aircraft started to veer left. The captain took control of the aircraft. When he was unable to make the aircraft turn right, he decided to let the aircraft depart the runway without correcting its course. The aircraft came to a stop on a patch of sand between exits R3 and R4. There was no apparent damage to the aircraft, except for the nose gear. The occupants were not injured.

The likely cause of the incident was the lack of ability to maintain the runway centerline during the landing run after applying the brakes due to differential braking, which caused the aircraft to depart the side of the runway. During the investigation, several control inputs carried out by the crew to offset this deviation were identified, but there was no effective response on the aircraft's heading correction as a consequence of them.

1 All times in this report are in UTC unless specified otherwise. To obtain local time, add two hours to UTC time.

This Commission is of the opinion that the differential braking was not significant enough to cause the sudden deviation. Control of the airplane was not recovered despite the crew control inputs to correct its track The investigation was unable to determine the cause of the deviation, or why the aircraft systems were ineffective in correcting it.

1. FACTUAL INFORMATION

1.1. History of the flight

The aircraft was flying from the Adolfo Suárez Madrid-Barajas Airport (LEMD) to the Barcelona-El Prat Airport (LEBL). Onboard were two flight crew and two passengers. The aircraft had taken off at 19:01 UTC. The first officer was the pilot flying. According to the crew's statement, it was the first flight of the day and both crewmembers reported they were not fatigued. The ATIS information available to them indicated that the weather as "good" [2], with no significant adverse phenomena along their route. The aircraft did not have any hold items and the airport was known to the crew, especially the captain, who had been based there for the previous 15 years.

The flight had been normal until the moment of the approach. When established on the ILS localizer for runway 25R, the crew requested to reduce their speed, since they estimated the preceding aircraft was within 5 NM and they had experienced slight wake turbulence. Once cleared by control, they reduced the aircraft's speed to 150 kt. In the crew's opinion, they made a stabilized approach and the contact with the runway was smooth and controlled. The reversers were armed and it was as they were about to decelerate with the brakes, with the airplane under control, that the airplane yawed sharply to the left. At that point, the captain took control of the aircraft, asking the first officer to transfer control. However, he was unable to return to the runway centerline, and the aircraft departed the left side of the runway, stopping in an unpaved area between exits R3 and R4 (see Appendix 1).

Neither the crew nor the passengers were injured. The aircraft also appeared to have sustained no damage. An inspection of the runway and the area where the incident (runway excursion) occurred revealed no damage to the airport installations, with the exception of three plastic cabling box covers located at the edge of the sandy patch. Emergency teams and airport services proceeded to tow the aircraft to parking, with all actions pertaining to the incident being completed by around 02:30 on 27 September.

2 Not flight limiting.

Photograph 1: Aircraft after the incident

1.2. Injuries to persons

Injuries	Crew	Passengers	Total in the aircraft	Others
Fatal				
Serious				
Minor				Not applicable
None	2	2		Not applicable
TOTAL	2	2	4	

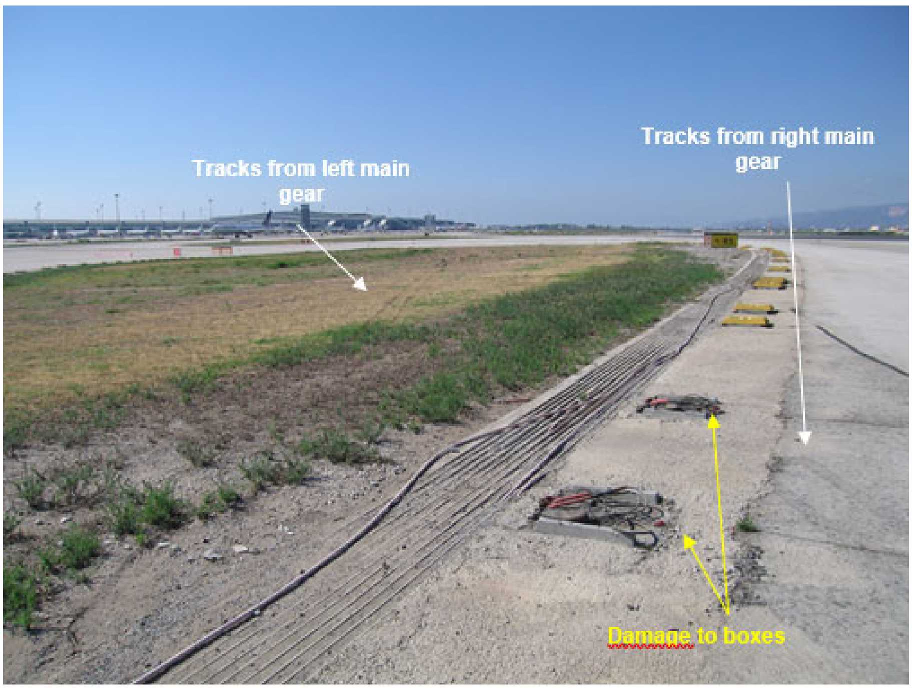
1.3. Damage to aircraft

The aircraft had no apparent damage except to the nose gear. This damage consisted of notches on the tire, a dented rim and a broken bracket for one of the weight-on-wheel (WOW) sensors (see Photograph 2).

Photograph 2: Damage to the nose wheel and to the nose wheel bracket.

1.4. Other damage

The covers on three electrical wiring boxes, located between the runway in use (25R) and the island between exits R3 and R4, were damaged (see Photograph 3).



Photograph 3: Damage to electrical boxes and tracks of the aircraft seen in the direction of motion of the aircraft.

Photograph 4: Damage to electrical boxes and tracks of the aircraft seen head-on.

1.5. Personnel information

1.5.1 Information on the aircraft crew

The captain, a 42-year old Spanish national, had an ATPL(A) license issued by the AESA with G200 and IR(A) ratings that were valid and in force until 31 January 2017. He had a class-1 medical certificate that was valid until 28 April 2017. According to information provided by the company, the captain had 4672:50 flight hours, of which 2365:55 had been on the type. On the day of the incident, the captain was the pilot in command but he was not the pilot flying, he was the PNF[3] /PM[4]. His last flight prior to the incident had been on 13 September.

The first officer, a 39-year old Spanish national, had a CPL(A) license issued by the AESA with G200 and IR(A) ratings that were valid and in force until 31 December 2016. He had a class-1 medical certificate that was valid until 13 May 2017. According to information provided by the company, the captain had 975:10 flight hours, of which 178 had been on the type. On the day of the incident, the first officer was the pilot flying (PF). The incident flight was the first officer's first flight in September following a period of vacation.

3 PNF- Pilot Not Flying

4 PM- Pilot Monitoring

1.5.2 Information on aerodrome control personnel

The local controller for the runway in use, 25R, was a 37-year old Spanish national. He had had an air traffic controller license since 2008 and had the ratings and unit endorsements (ADI[5]/TWR[6]/GMS[7]/RAD[8]) required to perform air traffic controller duties at the corresponding unit (LEBL). His ratings and endorsements were valid until 13 October 2016. He had a class-3 medical certificate that was valid until 5 January 2018. On the day of the incident, he had been working the afternoon shift[9]. The day before he had also worked the afternoon shift.

The supervisory controller was a 54-year old Spanish national. He had had an air traffic controller license since 1999 and had the ratings and unit endorsements (ADI/TWR/GMS/RAD) required to perform air traffic controller duties at the corresponding unit (LEBL). His ratings and endorsements were valid until 2 February 2017. He had a class-3 medical certificate that was valid until 2 June 2017. On the day of the incident, he had been scheduled to work the night shift[10], but had relieved the watch early. The previous day he had worked the afternoon shift.

1.6. Aircraft information

1.6.1 General information

The Gulfstream Aerospace G200 aircraft, registration EC-KBC and serial number (S/N) 145, was manufactured in 2006. This aircraft is equipped with two Pratt & Whitney PW-306A engines, S/N CC0298 (LH) and CC0299 (RH). According to information in the AESA's registration database, it has a maximum takeoff weight (MTOW) of 16080 kg and an empty weight (EW) of 10886 kg. Its landing weight (LW) on the day of the incident was about 11974 kg (26400 lb), according to an entry in the aircraft logbook, which was part of the flight information provided during the investigation.

5 Aerodrome Control Instrument

6 Control Tower

7 Ground Movement Surveillance

8 Aerodrome Radar Control

9 14:30 to 22:00

10 22:00 to 07:30

Photograph 5: Photo of the aircraft

The aircraft had a Registration Certificate, Certificate of Airworthiness, Airworthiness Review Certificate and a Noise Level Certificate, all of them valid and in force. The last maintenance activity, involving the APU[11], had been performed on 19 September 2016 with 2167:57 hours on the aircraft. The landing gear had been lubricated, both nose wheels were replaced due to change of tires (WO 088-16KBC), on 26 June 2016.

According to the entries in the aircraft's logbook, it had a total of 2170:04 h at the start of the flight. The takeoff had been at 19:01, and the landing at 19:53. The runway excursion that occurred during this flight was also logged. The aircraft's last flight prior to the incident flight had been on 23 September.

1.6.2 Information on the Landing Gear System.

The landing gear is of the tricycle type with two wheels on each gear strut. Each unit retracts into its own well and is fully covered by doors that are mechanically connected to the landing gear.

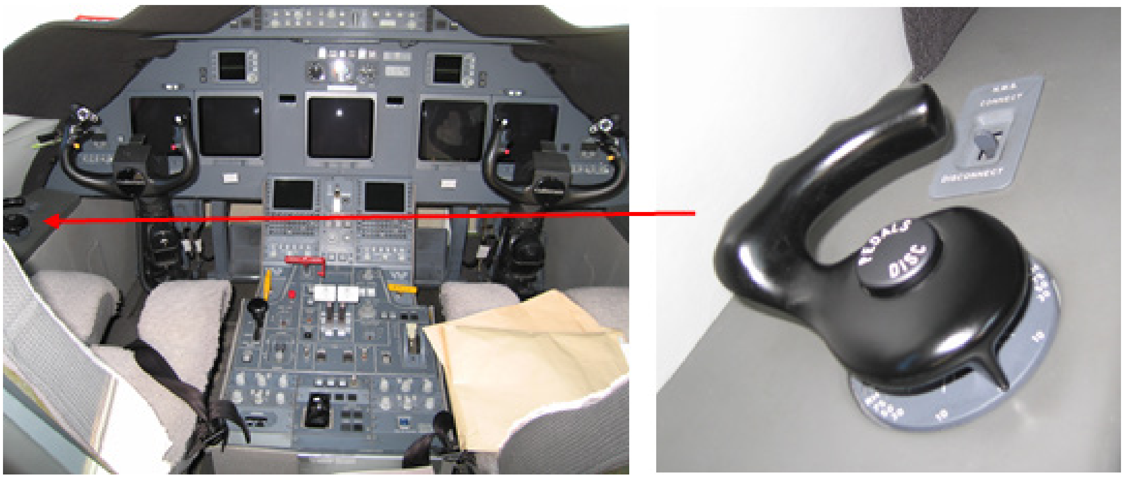
The outboard door on the main landing gear is rigidly attached at the strut. The inboard door operates by a mechanical linkage to the strut and is held in the up position by two uplock cylinders. This uplock is released by hydraulic pressure when the landing gear lever is placed in the down position, or by nitrogen pressure in an emergency. The main landing gear is held in the retracted position while airborne by hydraulic pressure in the actuator and by the inboard door mechanical uplock if the pressure drops. As the gear is extended, an internal lock in the actuator automatically locks it in the fully extended position.

11 APU- Auxiliary Power Unit

The nose landing gear retracts forward and locks up by a spring-loaded mechanical lock. It is unlocked by hydraulic pressure.

Photograph 6: Gear retracted with the aircraft on hydraulic jacks.

The nose wheel is moved by the NWS (Nose Wheel Steering) system, with an active steering angle of **±60°** and a towing angle of **±100.** The pilot controls the steering system by rudder pedals, over an angle of **±3°,** or by a handwheel, located on the pilot console, over an angle of **±60°.** The NWS ON-OFF switch is used to activate the NWS system, or to turn it off and keep the NLG in a free-swivel mode, which provides shimmy damping.



Photograph 7: Handwheel located to the left of the captain's seat and NWS switch.

The NWS modes of operation are:

Active steering - normal mode on the ground

Actively centered mode - the system actively maintains the nose wheel in a centered position during approach and take-off when both NLG weight-on-wheel (WOW) switches are in the air-position

Bypass mode - The bypass mode is the normal mode after NLG retraction. The two actuators are hydraulically interconnected by the bypass valve if the NWS switch is OFF, or as a result of a hydraulic pressure failure.

Any single failure in the NWS system is detected by the monitoring channel, which switches the system to the bypass mode (fail-passive). In this case, aircraft directional control is achieved via differential braking and/or rudder control.

1.6.3 Information on the Hydraulic System.

Two separate and independent left and right hydraulic supply systems are provided in the aircraft to supply the motive power to the primary flight controls, secondary flight controls, thrust reverser, brakes and landing gear control and nose wheel steering systems. The connections between the two hydraulic supply systems and the aircraft systems are shown in the hydraulic power system distribution schematic diagram (See Figure 1).

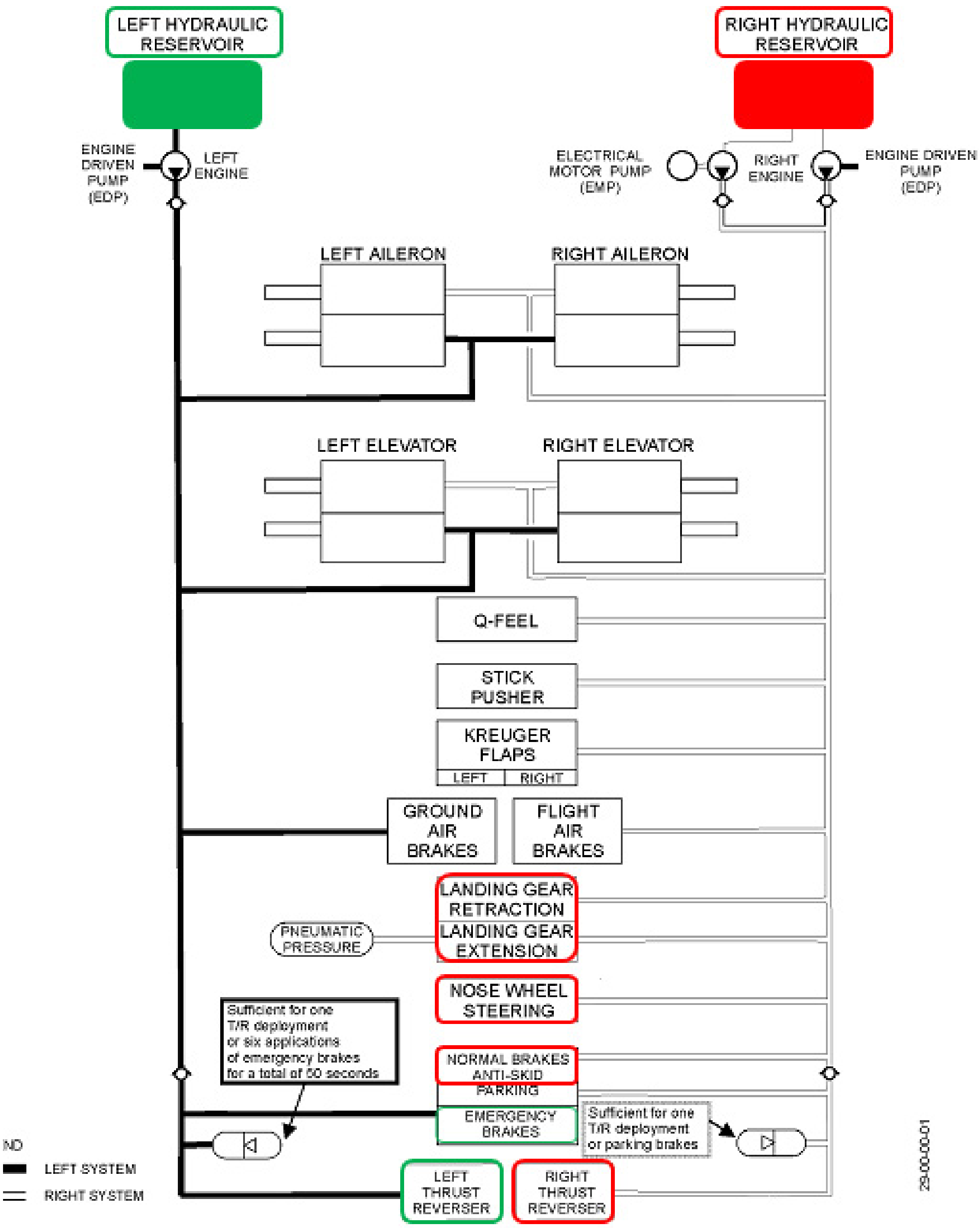


Figure 1: Schematic diagram of the hydraulic system.

The right system provides hydraulic pressure to the right thrust reverser, normal brakes and Nose Wheel Steering. The left system provides hydraulic pressure to the left thrust reverser and emergency brakes.

1.6.4 Information on Wheel Brake System.

The normal and emergency hydraulic wheel brake systems are controlled by conventional, dual, "tip-toe" brake pedals which actuate multi-disk self-adjusting brake units on each of the four main landing gear wheels. Normal operation of the brakes on each MLG strut is controlled by an anti-skid valve. The "anti-rotation" function stops the rotation of the main wheels after takeoff during landing gear retraction before the main landing gear enters the wheel wells.

The manufacturer reported that the maximum design brake pressure is 1600 +50/-100 psi.

During the investigation, the CIAIAC had access to a Gulfstream information bulletin from 2009 (see Appendix 2) that made reference to reports of uncommanded momentary braking on landing roll out. According to the Gulfstream Service Bulletin, hydraulic back pressure during thrust reverser actuator deployment may result in momentary braking with no crew input to the brake pedals. This resulted in a service bulletin (SB-200-32-227 [12]) being issued in February 2012 that recommended the installation of a check valve in the hydraulic system. The incident aircraft did not have this service bulletin implemented.

1.6.5 Information on the Thrust Reverser System.

Each engine employs an identical, independent thrust reverser system. It consists of two target doors that are moved 10° from the vertical by a bar linkage system and hydraulic actuators that, when deployed after landing, redirect the exhaust gases forward. When stowed they form the rearward extension of the nacelle. The thrust reverser hydraulic system is supplied with hydraulic fluid at 3000 psi of pressure from the aircraft hydraulic system.

The T/R Ready light, located at the top of the pedestal power quadrant, indicates that the nose WOW is in the ground mode with the thrust reversers armed.

1.6.6 Information on the Air/Ground brakes

The airbrake system consists of four panels at the top rear of each wing. The two

12 SB-200-32-227 Landing Gear - (ATA 32) - parking valve -installation of check valve on parking valve return port.

inboard panels on each wing are the flight airbrakes. These panels can be used either as airbrakes in flight or they automatically become part of the ground airbrakes when that system is on the ground. They are electrically controlled and hydraulically operated.

Once the aircraft touches down on landing (ground mode), both throttle levers are below max cruise and the GROUND A/B switch is on, the flight and ground airbrakes extend and remain extended even if the airplane bounces on the runway.

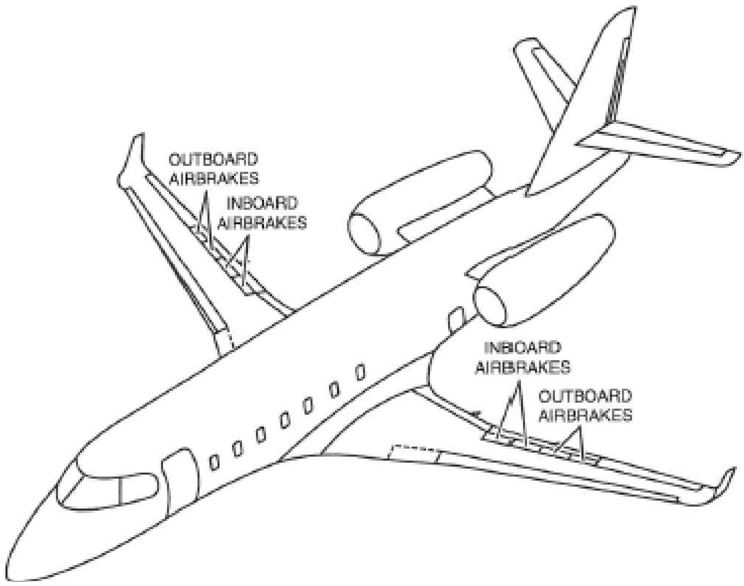


Figure 2: Location of the airbrakes.

1.6.7 Information on the Rudder System

The rudder has a manual, single-loop control. The pilot and copilot pedals are interconnected. The rudder bias actuator is connected in parallel to the control system. It is actuated by the differential bleed pressure acting on the faces of the rudder bias actuator piston during an asymmetric thrust condition, when high pedal forces are required to maintain directional control. During an engine failure, the system deflects the rudder in the direction of the working engine.

A yaw damper servo is mechanically connected to the rudder system. Directional (rudder) trim is accomplished by moving a trim tab on the rudder. This tab is operated by two mechanically interconnected electrical actuators, each protected by a separate circuit breaker.

The total rudder travel range is 20° ±15′ in each direction, with a default offset of -1.7° (rudder neutral).

1.7. Meteorological information

Based on information provided by the AEMET, specifically on lightning and radar images, there was no convective activity at the Barcelona-El Prat Airport between 19:00 and 20:30 UTC. According to airport logs, though there were some towering cumulus clouds forming at around 15:00, which persisted until 16:00, there was little cloud cover. The temperature at the times indicated was 23° C. There was a light wind (late in the afternoon) from the southwest, exceeding 10 kt at times. After 19:00, the wind, which by then was primarily from the north, began to die down, dropping below 5 kt on average. The 20:00 METAR was as follows:

LEBL 262000Z 32003KT 220V350 9999 FEW025 22/18 Q1021 NOSIG=

This indicates that the wind at 20:00 was at 3 kt from 320° (northwest), varying in direction between 220° and 350°, visibility was good, in excess of 10 km, with few clouds at 2500 ft. The temperature was 22° C, dew point 18° C, QNH 1021 and no significant phenomena were expected.

This information matched that logged by crew in the operational flight plan and obtained from the arrival ATIS.

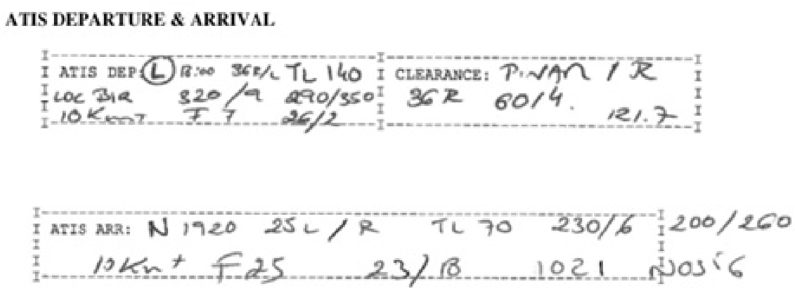


Figure 3: Information in the Operational Flight Plan.

Based on the wind readings at the various thresholds, the maximum wind speeds recorded between 20:00 and 20:30 were as follows: 4 kt at the 07L threshold, 7 kt at the 25R threshold, 5 kt at the 02 threshold, 4 kt at the 20 threshold and 8 kt at the 07R and 25L thresholds.

1.8. Aids to navigation

The aids to navigation had no effect on the incident.

According to information on the radar track provided by the control services provider (ENAIRE), the aircraft is seen making the approach and landing lined up with the runway before subsequently deviating to the left and eventually coming to a stop at an island located off the left shoulder.

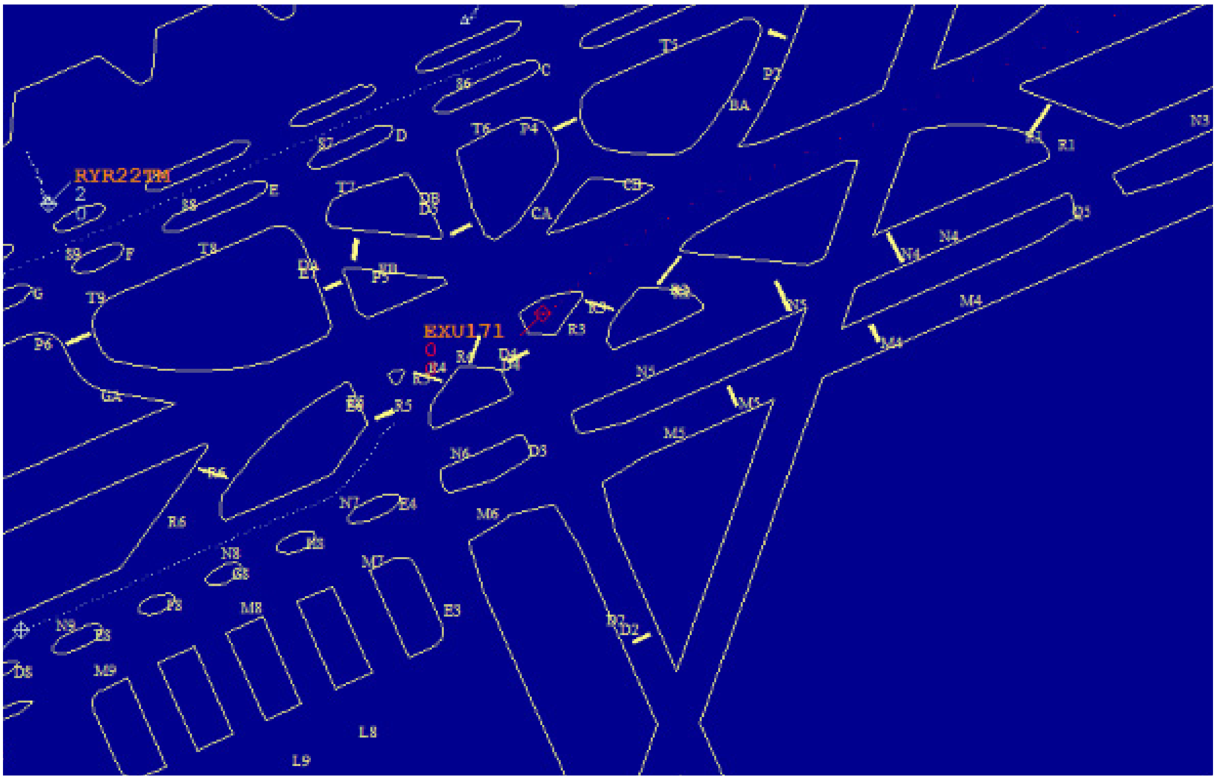


Figure 4: Final position of the aircraft after runway excursion.

1.9. Communications

The investigation team had access to the communications held between the crew and the air traffic stations involved (approach and tower). The communications between the crew and the approach controller and local tower controller for the runway in use, 25R, were analyzed. The aircraft's callsign was SACIR171 (ICAO code[13] EXU171). The crew did not report any anomalies, with the exception of the request to reduce speed due to the wake turbulence of the preceding aircraft. At 19:52:33, the tower controller cleared the aircraft to land, giving information on the runway in use (25R) with wind from 310° at 3 kt. The crew acknowledged the clearance. At 19:54:00, the captain of the aircraft contacted the control tower to report they had experienced a runway excursion. The communications that followed were intended to provide assistance to the incident aircraft and to manage subsequent traffic.

13 ICAO code for the company

1.10. Aerodrome information

The Barcelona-El Prat Airport (LEBL) is located 10 km southwest of the city of Barcelona, at an elevation of 14 ft. It has two parallel runways in a 25R/07L and 25L/07R orientation, and one cross runway in a 02/20 orientation, which is not used for landings. All of the runways are paved. The runway in use on the day of the incident was 25R (see Appendix 1). This runway is 3352 m long (which is the same as its LDA[14]) and 60 m wide. The runway strip is 3472 m long and 300 m wide. The threshold for this runway is at an elevation of 10 ft.

According to the Minimum runway occupancy time/Arrivals section of the AIP[15], "In order to maximize runway use, lower runway occupancy time and reduce go-arounds, it is important for pilots in command vacate the runway quickly while observing normal aircraft safety and operations. Unless ATC indicates otherwise, the following rapid exit taxiways shall be used to vacate the corresponding runway: Runway 25R: P3, P5, P6, R3, R5, R6." In the case of the incident aircraft, it was going to vacate the runway to the right to facilitate taxiing to the parking stand at the executive aviation terminal (see Appendix 1).

According to information in the AIP, the distance from rapid exit taxiway R3 (where the runway excursion took place) to the 25R threshold is 1409 m.

The airport had video footage of the landing, captured by the airport's security cameras. It showed a centered landing until the aircraft suddenly swerved to its left. There were no other appreciable unusual movements until the aircraft came to a stop.

1.11. Flight recorders

1.11.1 General information

The aircraft was equipped with Honeywell digital flight data recorder (DFDR), P/N 980-4710-003 and S/N 0298, and a Universal Avionics cockpit voice recorder (CVR), P/N 1503.02.12 and S/N 1204, which complied with the standards specified in document ED-112 (Minimum operational Performance Specification for Crash Protected Airborne Recorder Systems) of the European Organization for Civil Aviation Equipment (EUROCAE[16]).

14 LDA-Landing Distance Available

15 AIP- Aeronautical Information Publication

16 EUROCAE standardizes electrical and electronic devices for aircraft and ground systems for air navigation and localization, and it develops associated standards and documents, which use the ED abbreviation. The members of EUROCAE are international aviation authorities, airplane manufacturers, aviation safety service providers, airport operators and other aviation entities.

Both recorders were removed from the airplane on 3 October 2016 and downloaded on 6 October 2016.

DFDR

CVR

Photograph 8: Aircraft's DFDR and CVR

The CVR audio files were downloaded on 6 October 2016 at the laboratory of the UK's Aircraft Accident Investigation Board (AAIB), which was the closest facility with the necessary resources.

Four high-quality, 30-minute audio files were downloaded from the CVR, associated with the four different tracks containing the conversations recorded by the Captain's microphone (track 1), the conversations recorded by the first officer's microphone (track 2), communications with the passenger cabin (track 3) and the ambient cockpit sounds (track 4).

Also downloaded were two more, 2-hour long standard-quality tracks that contained a mix of the aforementioned tracks and a recording of the signal from the ambient microphone in the cockpit.

1.11.2 Información del DFDR

The investigation focused on the elements related to the aircraft's directional control while on the ground: the **Nose Wheel Steering** system, problems with the rudder and the possibility of **asymmetric reversers** and/or **asymmetric braking** of the main landing gear.

The following information taken from the DFDR was the most relevant to the investigation:

TAKEOFF, CLIMB AND CRUISE PHASES

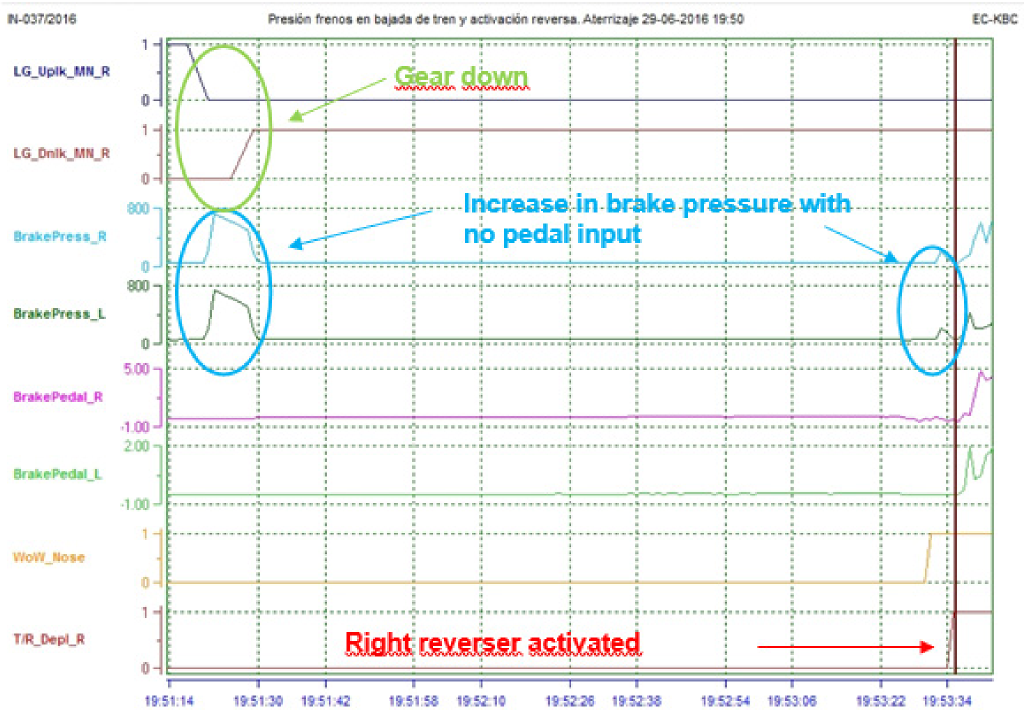
The crew commenced the start-up procedure at the Madrid-Barajas airport at 18:35:49, and began to taxi approximately five minutes later (18:41:12). While taxiing, the crew conducted the required test of the reversers. Also during the taxi phase the crew conducted several alternate deployments of one reverser so as to reduce speed. The recorder shows that every time the right reverser was deployed, there was an increase in the same-side brake pressure of about 150 psi. It was also noted that the pressure increase commanded did not exceed 200-250 psi, even with the brake pedal depressed.

The aircraft took off from runway 36R at the Madrid-Barajas Airport at 19:01:27 on magnetic heading of 005°. During the taxi phase, when applying the reversers independently, there were symmetrical low brake pressure peaks only when the right reverser was deployed. At 19:02:03, the gear was retracted, during which a brake pressure spike was recorded that reached 256 psi in the left system and 249 psi in the right. At 19:02:32, at 3390 ft, autopilot 2 was engaged. The aircraft climbed without interruptions, reaching its cruise level of FL300 at 19:13:27. The indicated airspeed maintained during the cruise phase was 293 kt.

DESCENT AND ILS APPROACH PHASES

The top of descent was at 19:26:56, and at 19:39:38, at an altitude of 10000 ft, the crew reduced the indicated airspeed to 250 kt. At 19:45:56, they began to configure the aircraft for approach by lowering the slats (25°) and reducing the indicated airspeed to 200 kt. At that point they were at an altitude of 3101 ft on a magnetic heading of 115°. At 19:46:34, the flaps were lowered to 12°. The speed remained at 200 kt. At 19:47:15, the aircraft intercepted the runway 25R localizer 15.8 miles out, at an altitude of 2537 ft and a speed of 190 kt. They maintained a crab angle of -5° (QFU 245°).

At 19:48:22, the crew selected 20° flaps and at 19:51:22, the landing gear was lowered. At that point, they were descending on the glide slope at an indicated airspeed of 150 kt and an altitude of 1443 ft, 4.4 miles out. During the gear extension process, maximum brake pressure values of 731 and 721 psi were recorded in the left and right systems respectively (see Graph 1).



Graph 1: Increase in brake pressure during gear extension and right reverser deployment

From 19:48:51 until 19:48:56, at a steady altitude of 2300 ft and IAS of 175 kt, a variation in the normal acceleration was recorded, reaching a maximum value of 0.69 g. The crew reduced the IAS to 150 kt. The airplane was fully configured for landing (flaps 40°) at 19:51:43, at an altitude of 1190 ft. At 19:51:59, they descended through 1000 ft, disengaging the autopilot 7 seconds later. The wind recorded between 1000 ft and the ground was from the west at 6 kt. The aircraft followed the 25R ILS localizer and glide slope, maintaining an IAS of 143 kt.

FINAL APPROACH AND LANDING PHASES (see Appendix 3)

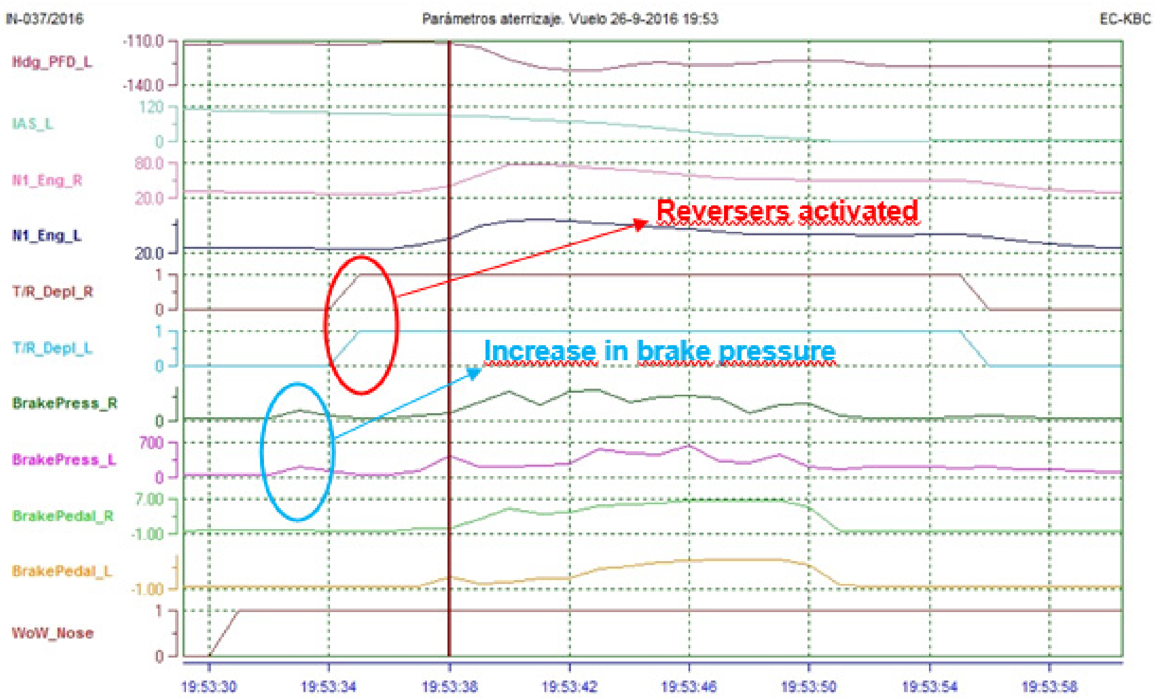
At 19:53:15, the crew began the flare maneuver at 70 ft AGL[17] and 138 kt, reducing power and reaching a pitch angle of +6.7°. The wings remained parallel, with maximum recorded right/left roll angles of 3.5° and 2.8°, respectively. At 19:53:26, the aircraft's left main landing gear leg contacted the ground for 1 second at an IAS of 120 kt. The airplane's attitude was 5.1° pitch and 0.4° left roll on a magnetic heading of 247°. A vertical acceleration of 1.3 g was recorded. The wind recorded at that moment was from 294° at 5 kt. The airbrakes – ground were deployed due to momentary contact of the left landing gear on the ground (one second) causing temporary activation of the weight-on-wheels (WOW) sensor.

17 AGL- Above Ground Level

At 19:53:30, the DFDR recorded the activation of the two WOW sensors on both main gear legs with an IAS of 111 kt, a 3° pitch angle and a 1° left roll angle. The contact was smooth, with no significant accelerations recorded, on a heading of 246º. Two seconds later, the nose strut WOW sensor was activated at an IAS of 108 kt, and the aircraft began to decelerate. One second later, the DFDR recorded a rudder position of 4.254º[18] left, in response to a pedal input to the left.

At 19:53:34, there was a symmetric increase in the brake pressure to 218 and 211 psi without there being any brake inputs from the crew, and two seconds later, the reversers deployed simultaneously at full power while at an IAS of 99 kt on a magnetic bearing of 247° (see Graph 2).

Over the next two seconds, the rudder was deflected to the left by 5.339° and



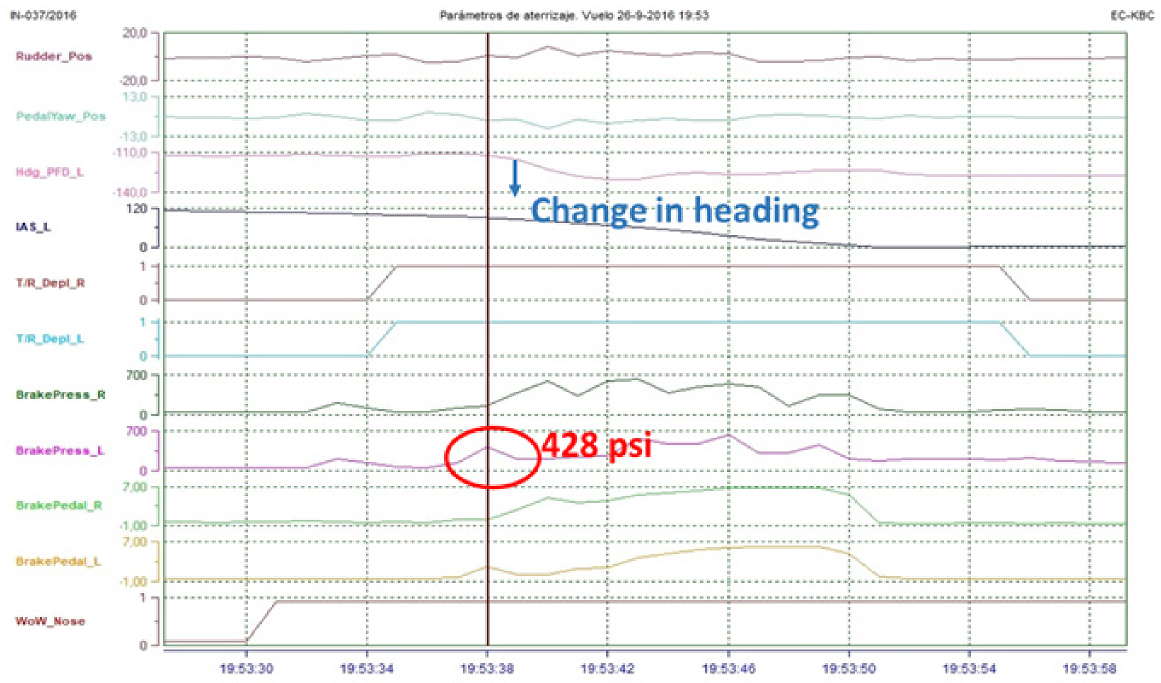
Graph 2: Increase in brake pressure and subsequent activation of reversers

4.105º. The aircraft remained on heading 249º.

At 19:53:39, the left brake pressure increased to **428 psi,** versus a pressure of 162

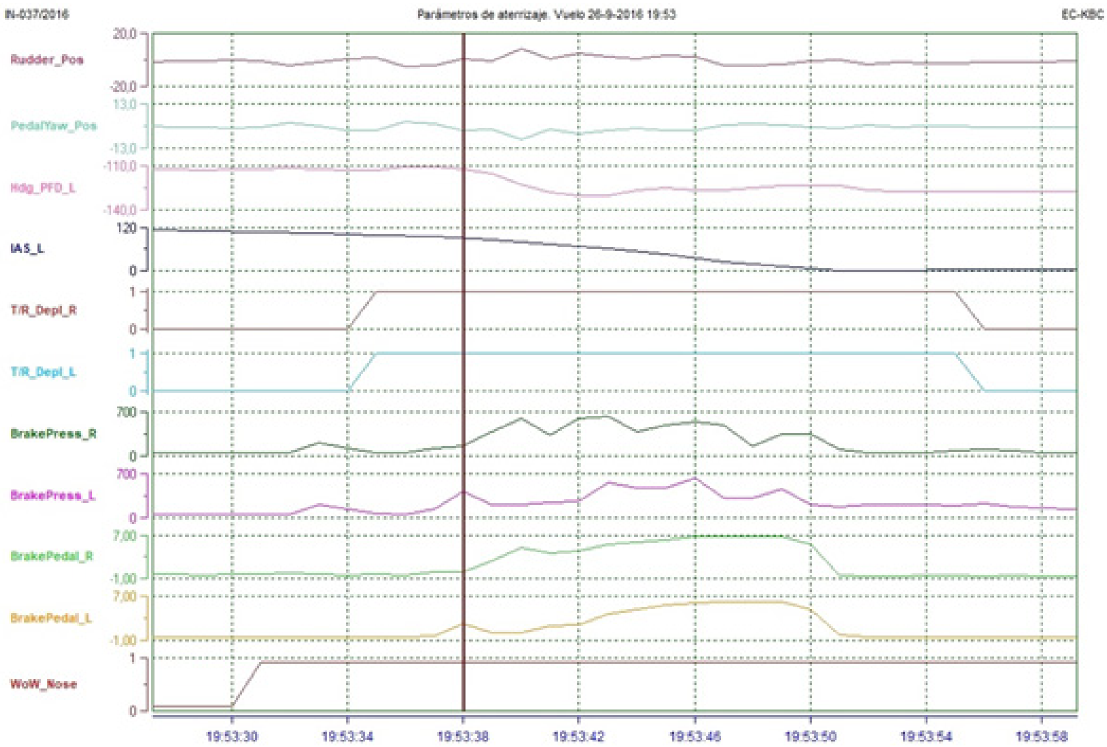
18 These details so precise are indicated in order to be identified with the Excel board (representative of DFDR data) as per Appendix 3

psi in the right. The brake pedal inputs recorded a deflection of 1.914° for the left pedal and 0.188° for the right. The aircraft's IAS was 91 kt. This event coincided with the start of the change in the aircraft's heading from **248° to 230°.**



Graph 3: Left brake pressure at 428 psi and start of heading change

One second later, the right brake pedal was deflected by 2.263°, which translated into a brake pressure of 385 psi for the right brake, versus a brake pedal deflection of 0.309° and 210 psi for the left. The recorded IAS was 87 kt. In the next second, two events were recorded, one an input to the right rudder pedal which translated into the rudder deflecting 8.616° to the right, and the other a higher differential pressure applied to the right brake of 603 psi, versus the 215 psi in the left system, with deflections in the brake pedal of 4,765° and 0,495° respectively . The recorded IAS was 68 kt. The differential braking to the right persisted for an additional two seconds, along with the input to the right rudder pedal. From then on, symmetric braking readings were recorded, though the input to the right rudder pedal was maintained until the aircraft departed the runway.



Graph 4: Brake and rudder inputs

After the symmetric brake inputs were received, the aircraft deviated slightly to the right to heading 234°, and from 19:53:47, the headings changed from 237° to 233°, with the aircraft stopping on this latter heading five seconds later. This time (19:53:47) was identified as the runway departure, which occurred when the aircraft's GS was 38.5 kt.

The reversers remained at full power until 19:53:56,h four seconds after the aircraft came to a stop.

1.11.3 Information from the CVR

The investigators listened to the CVR recordings, the most relevant parts of which are summarized below.

After intercepting the localizer, they had to reduce speed when they were affected by the wake turbulence of the preceding aircraft, even though it was four miles ahead of them, as per ATC. The crew then contacted the tower controller at the Barcelona Airport, who informed them they were third in the sequence, to continue the approach to 25R and that the wind was from 320° at 3 kt.

The crew configured the aircraft in sequence and selected full flaps (40º) for the landing, doing the "Before Landing" checklist (see Section 1.18.1 Landing information in documents) as they neared 1000 ft AGL. The captain recalled the main items on the list one by one before the ground proximity warning system (GPWS) reported they were reaching 1000 ft (One thousand): THREE GREEN, HYDRAULIC PRESSURE, REVERSE, ENGINE SYNCHRO, MASTER SWITCH, ANTISKID, PARKING BRAKE, FULL FLAPS".

During final approach, the crew maintained 141 kt until minimums, where they adjusted the speed to 131 kt. During this time, the crew were cleared to land by the control tower ("*SACYR171, AUTORIZADO A ATERRIZAR 25R VIENTO 310 3 KT*" [SACYR171, CLEARED TO LAND 25R, WIND 310 3 KT].

A few seconds before touching down, a chime was heard associated with a caution. This sound was issued once more when the aircraft contacted the runway, before the reversers and brakes were applied ("EFIS[19] COMPRTR FAIL[20]").

The captain monitored the landing continuously: "PERFECT, KEEP THE NOSE UP, LET IT FALL SLOWLY, THERE IT IS, THERE... REVERSER[21] AND BRAKES..." Three seconds later, interjections were heard from the crew as they attempted to control the aircraft. The captain took control of the aircraft (saying "MINE!"), and the first officer relinquished the controls.

After stopping, the captain inquired as to the condition of the first officer and the passengers, and the CVR recorded the disconnection of various systems.

The crew also promptly reported the runway excursion to the tower. ATC reacted immediately, ordering aircraft in the sequence behind them to go around. ATC also asked if they needed anything and reported that the emergency services had been dispatched and were en route to their location.

The captain confirmed there were no injuries and requested permission to disconnect all aircraft equipment, thus terminating communications and the CVR recording.

1.12. Wreckage and impact information

The aircraft departed the runway to the left some 1400 m away from the threshold,

19 EFIS- Electronic Flight Instrument System

20 EFIS comparator failure

21 According to DFDR data, the reversers had already been activated one second earlier, three seconds earlier if the deployment process is included.

at the island located between rapid exit taxiways R3 and R4 (see Figure 5 and Photograph 10 below).

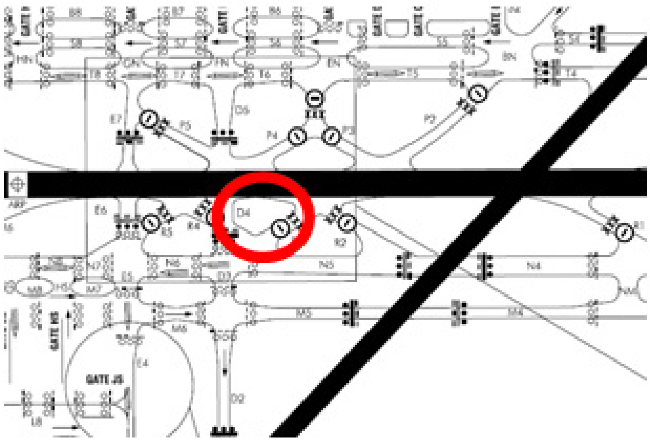


Figure 5: Location of aircraft's final position after runway excursion.

Photograph 9: Aircraft's final position shortly after the incident, with the brake marks on the runway.

Based on information gathered from measuring the tracks on the runway, the aircraft traveled approximately 233 m from the start of the excursion, and 47 m on the island where it eventually stopped.

Photograph 10: View from the aircraft's final position of the tire marks left on the island.

Photograph 11: View of the tire marks left on the runway in the direction of motion of the aircraft.

The aircraft was inspected after it was removed from the incident site (see Photograph 5). Due to the circumstances of the incident, special attention was paid to the systems used to steer the aircraft: the main landing gear and brakes, the nose wheel and handwheel, the rudder and the reversers. No signs or damage were found beyond those indicated in **Section 1.3 Damage to aircraft.**

The breakers for the flight recorders (FDR and CVR) had been pulled from their position by the crew to preserve the information contained in them, thus making it available for use during the investigation.

The flight recorders were removed and taken to the Commission's laboratory so their data could be downloaded for subsequent analysis.

Photograph 12: Condition of the flight recorder breakers.

1.13. Medical and pathological information

N/A

1.14. Fire

There was no fire

1.15. Survival aspects

The crew stated that after the runway excursion, they began the evacuation procedure. However, when the captain exited the aircraft and saw there was no danger, he decided not to evacuate the passengers after verifying they were in good condition.

1.16. Tests and research

1.16.1 Results of the tests conducted by the operator after the incident

The manufacturer informed the company of the maintenance work that had to be carried out after the incident in order to return the aircraft to service.

The brakes were inspected with the use of the traceability and maintenance records associated with each of them. There were no references in the AMM[22] of allowable maximum service life differences for the four brakes installed, nor had reports been received from the crew that the brakes were more effective on one side than the other. The measurements were taken during the work to replace the brakes. The wheel was removed to gain access, the old brake was replaced and its measurements were taken by using the two procedures for inspecting brake wear: measuring the length of the pins (which have to protrude from the brake housing) and measuring the depth (remaining thickness of the carbon pads) as the alternate method (see table below). The result was that the brakes were within the limits, though a difference was observed between the brakes on the right and left wheels, with those on the right wheel being closer to the end of their service life.

Main gear tires	Depth measurement
LH OUTBOARD	29.4 mm
LH INBOARD	31.2 mm
RH INBOARD	32.5 mm
RH OUTBOARD	39.8 mm
*If the measurement is **43.84 mm** or higher, replace the brake.*	

As concerns this inspection, there was a service bulletin from 27 October 2011 (SB200-32-389[23]) that prompted the issuing of a CAAI[24] airworthiness directive (AD[25] 32-11-10-13) on 27 October 2011, resulting from the degraded brake performance that two operators had experienced after landing. In both cases the pins showed remaining life, but the brakes were worn beyond the minimum specified. The operator implemented both on 17 November 2011.

The relevant checks were made in an effort to rule out a possible return of hydraulic fluid to the brakes after deploying the reversers. The only difference with the incident flight was that these checks were made after the new brakes were installed.

22 AMM Aircraft Maintenance Manual

23 Landing Gear (ATA32) Brake Assembly- Brake Wear Indicator Pin- Detailed Inspection Modification

24 CAAI- Civil Aviation Authority of Israel

25 AD- Airworthiness Directive

The results were satisfactory, and no instrument[26] readings were taken during the tests that showed a return of hydraulic fluid that would slow or stop the rotation of the landing gear wheels.

The tests of the gear and its components that were requested by the manufacturer were all conducted satisfactorily. After reviewing the documentation, the manufacturer issued a Letter of No Technical Objection for returning the aircraft to service, in which it specified that the FDR information indicated that the loads supported by the landing gear during the runway excursion had not been exceeded and were within the aircraft's design loads.

1.16.2 Information obtained from the aircraft manufacturer, Gulfstream.

The aircraft manufacturer sent its own analysis of the facts, based on the information taken from the FDR. Its findings were as follows:

- The aircraft exited the runway at about a 15° angle from the runway centerline.
- Initially there was asymmetric braking to the left.
- There was minimal use of rudder steering and the rudder pedal.
- The aircraft traveled 612.2 ft (186.6 m) for 4.2 s before entering the sandy area.
- There were no CAS messages[27].
- **Braking action[28]** – there was an absence of firm braking to stop the undesired turn.
  - At t=2 s the right and left brakes were applied (211 psi) and released.
  - At t=4 s both reversers were deployed.
  - At t=7 s the left brake pressure was 428 psi versus 162 psi in the right.
  - At t=7 to 8 s the aircraft started to deviate left.

26 Manometers were used directly in brake hydraulic lines to detect peaks of pressure (AMM 32-40-20 Fig 501)

27 CAS- Crew Advisory System

28 t=0 is the moment when the nose leg wheel touched the ground, activating the associated sensor (NLG WOW).

    - At t=8 s the brake pressure was 210 psi in the left and 385 psi in the right.
    - At t=9 s the brake pressure was 215 psi in the left and 603 psi in the right.
    - At t=10 s the brake pressure was 237 psi in the left and 333 psi in the right.
    - The aircraft deviated 16.3° to the left due to the asymmetric braking.
    - At t=11 s the brake pressure was 263 psi in the left and 603 psi in the right.
    - At t=12 s the brake pressure was 567 psi in the left and 635 psi in the right.
    - At t=13 s the brake pressure was 478 psi in the left and 388 psi in the right

- **Rudder activity**[29] – no firm inputs were made to the rudder pedals to stop the undesired turn.
    - At t=1 s a left 2.554° rudder was commanded.
    - At t=2 s a left 0.231° rudder was commanded.
    - At t=3 s a right 2.938° rudder was commanded.
    - At t=4 s a right 3.404° rudder was commanded.
    - At t=5 s a left 3.639° rudder was commanded.
    - At t=6 s a left 3.315° rudder was commanded.
    - At t=7 s a right 2.85° rudder was commanded.
    - At t=8 s a right 0.951° rudder was commanded.

29 t=0 is the moment when the nose leg wheel touched the ground, activating the associated sensor (NLG WOW).

- At t=9 s a right 10.316° rudder was commanded.
- At t=10 s a right 2.243° rudder was commanded.
- At t=11 s a right 6.518° rudder was commanded.
- At t=12 s a right 3.946° rudder was commanded.
- At t=13 s a right 2.373° rudder was commanded.
- At t=14 s a right 5.042° rudder was commanded.
- At t=15 s a right 3.968° rudder was commanded.
- At t=16 s a left 2.12° rudder was commanded.

The manufacturer was asked about the pressure spike during the gear retraction and after deploying the reversers (referring to the service bulletin issued by said manufacturer, SB-200-32-227, which alluded to the possibility of an uncommanded return of hydraulic fluid to the brakes when the reversers were deployed), and its effect in this particular incident. The manufacturer replied that a review of the DFDR data revealed a slight pressure rise in the brakes when deploying the reversers, caused by the hydraulic fluid returning to the tank. This return pressure was only slightly higher than the "clamp up" pressure[30] (185 to 200 psi). This pressure may or may not have been felt by the pilot, as it fell rapidly. The manufacturer thought that this pressure was more noticeable during the taxi phase than in the landing phase due to the aircraft's energy. At any rate, the manufacturer reiterated that any returning hydraulic fluid would not entail a reciprocal deflection of the pedals. As for the pressure spikes detected during the retraction and extension of the landing gear, the manufacturer stated that it was part of the aircraft's design so as to stop the rotation of the wheels during this process.

The manufacturer was subsequently asked about the effect that the broken nose wheel bracket could have had on the aircraft's steering control if the bracket had broken during the landing run instead of when the aircraft was being towed (as was initially thought). The manufacturer stated that this bracket supplied the third WOW sensor, which affected the reverser system, and that in such a case, the reversers would have retracted automatically. The reversers were in operation throughout, and thus the possibility that this bracket broke during the landing run was ruled out.

30 The clamp-up pressure is defined as the pressure at which the brakes start to generate resistance.

The manufacturer was asked about the point in the AFM[31] (see 1.18.1 Landing information in documents) which instructed not to exceed reverse idle thrust when below 60 KIAS. The manufacturer stated that there were no operational consequences to using the reversers at full thrust below 60 kt, and that the limitation was only in place to limit FOD ingestion, which could cause engine damage.

As for the question regarding the effectiveness of the rudder in steering the aircraft, the manufacturer replied that said effectiveness was lost below 80 kt and that the aircraft had to be steered by turning the nose wheel or by using differential braking.

1.16.3 Tests conducted on the aircraft after the incident

The flight crew reported there had been another event during a landing in Madrid in which they had noticed a slight tendency to drift to the right side when the reversers were actuated.

On 27 May 2017, the investigation team traveled to the operator's facilities to conduct tests on an aircraft, along with the flight crew. The purpose was to assess the effect that the operation of the reversers had on the braking action while taxiing. The airplane was taxied on the apron while activating the reversers simultaneously and alternatively at idle thrust. While there did seem to be a slight drop in the acceleration, it did not translate into a deflection of the brake pedals.

The DFDR data were once again downloaded to identify the effect reported during the landing and compare it with the data from the incident in question. The data analyzed revealed a temporary heading deviation of 4° to the right when the reversers were used, with a lateral acceleration of 0.131 g when the aircraft was decelerating at a speed of 100 KIAS. The crew controlled that deviation using the rudder.

During that deviation, the brake pressure was asymmetric, with a higher pressure in the left side. The maximum value reached during the seven seconds that the heading deviation lasted, until the crew restored the initial heading, was 229 psi in the left system. This pressure had been 179 psi at the time of the initial deviation. No firm conclusions were drawn from these tests.

31 AFM Aircraft Flight Manual

1.17. Organizational and management information

1.17.1 Information on the air traffic services provider, ENAIRE

Over the course of the day, the airport uses two different configurations due to noise pollution concerns. These are the daytime configuration (from 7 am to 11 pm) and the nighttime configuration (from 11 pm to 7 am).

The most common preferred daytime configuration (west) is known as WRL. In this configuration, landings take place on runway 25R and takeoffs on 25L. The most common preferred nighttime configuration (north) is called ENR, in which aircraft land on runway 02 and take off from 07R.

All of the possible configurations are shown in the table below.

CONFIGURATION	LANDINGS	TAKEOFFS	REMARKS
WRL	25 R	25 L	Preferred daytime configuration (more common)
ELR	07 L	07 R	Preferred daytime configuration
ENR	02	07 R	Preferred nighttime configuration (more common)
WLL	25 L	25 L	Preferred nighttime configuration
ELL	07 L	07 L	Only in duly justified cases
ELS	07 L	20	Rarely used
ENL	02	07 L	Only in duly justified cases
ENN	02	02	Rarely used
ERR	07 R	07 R	Rarely used
WLS	25 L	20	Rarely used
WRS	25 R	20	Used when runway 25L is closed
WRR	25 R	25 R	Only in duly justified cases

The air traffic service provider wrote a report with its own analysis of the incident. From the information compiled (voice recordings, control tower log, flight plans and flight progress strips, operating procedures, controller and pilot reports, etc.), it concluded that the applicable procedures[32] had been carried out.

On the day of the incident, the airport was in a preferred daytime configuration (WRL). The local arrivals controller (LCL ARR) directly observed the runway excursion and immediately sounded the alarm. He ordered the two aircraft in the sequence behind EXU171 to go around (the rest were diverted by the Final ACC sector) and coordinated the entry of the firefighting service (FFS) into the runway with the north ground controller (GMC N).

The runway excursion took place at 19:54, and the FFS arrived at the incident aircraft's location at 19:58.

The Barcelona tower (LEBL) supervisor coordinated and exchanged information as required with:

- The Barcelona Area Control Center (LECB) supervisor.
- The airport's duty manager.
- The SYSRED[33].

The configuration was changed to a single-runway WLL and operations were resumed. The first landing in this configuration took place at 20:04. The relevant check was made of runway 07L/25R. After verifying that RWY02 was unaffected and the area affected by the incident and the assistance and recovery work was cordoned off, the configuration was changed to ENR (higher capacity) at 20:27 UTC while waiting for the incident aircraft to be removed.

As part of ENAIRE's recommendations, the management of the incident was discussed at training sessions on emergency response and TRM[34] as an example of best practices.

1.17.2 Information on the airport manager, AENA

The airport manager (AENA) gave investigators a video that showed the aircraft approach and land, and how at one point, the aircraft suddenly swerved to the left and continued straight to the area where it eventually came to a complete stop.

32 Runway blocked procedure – Emergency and special situation guide – SYSRED accident reporting procedure – Runway configuration change procedure.

33 Integrated Center for Air Navigation Network Services and Monitoring, charged with processing the information generated by incidents that occur in the ENAIRE network in real time, 24 hours a day.

34 TRM- Team Resource Management

AENA wrote a report with its own analysis of the incident in terms of the condition of the airport facilities and the response to the local alert, as per its protocol.

This report reviewed the horizontal markings, in case they could have contributed to the incident. They were found to be in good condition and in accordance with the horizontal markings map.

The runway friction measurement for 4 September 2016 indicated that friction was GOOD, with a friction coefficient of 0.71.

Following the analysis and a check of the runway check logs, no FOD was found on the pavement that could have caused damage to the aircraft's wheel. The level of friction on the runway and the dry condition of the surface did not contribute to the event.

As corrective measures, the unpaved area was paved after the incident to conform to the values specified for the 07L/25R runway strip, and the damaged box covers were repaired.

1.18. Additional information

1.18.1 Statement from the control room supervisor

The aircraft with callsign EXU171 and registration EC-KBC was cleared to land on runway 25R at 19:54. It landed normally and after traveling some distance on the runway, it departed the runway to the left at the intersection with taxiway D4. He was located in the control tower next to the local arrivals controller, and both saw a cloud of dust kick up where it departed the runway. They immediately proceeded to confirm that it had departed the runway and from his position he pressed the emergency alert button. Two aircraft that were established on the runway 25R localizer were instructed to go around at 19:55.

The FFS, which called in response to the alert activation, was informed of the incident and the position. They were cleared to proceed to the site of the incident and runway 25R was taken out of service.

All engine start-ups and taxis were stopped at the airport and the Area Control Center (ACC) supervisor was informed so approaching aircraft could be re-routed away from runway 25R. The tower supervisor reported that arrangements would soon be made to change to the WLL[35] configuration, and that he would report

35 Non-preferred nighttime configuration (west). Runway 25L is used for landings and takeoffs.

back when ready to operate in that configuration. All of the parties involved (CECOPS, SYSRED, tower chief, NMOC[36], SAR[37]) were informed.

All of the installations needed to operate in the WLL configuration (fixes, lights, ILS, SACTA, etc.) were placed in service and arrangements were made with every tower controller to start single-runway operations on 25L. The ACC supervisor was also informed. The first landing in this configuration took place at 20:04. Operations commenced in the WLL configuration and avoiding crossing runway 25R via taxiways D and E. After confirming that both runway 02 and taxiway E, where it crosses runway 25R, were clear and operational, the configuration was changed to ENR[38] at 20:27.

1.18.2 Statement from the crew

According to the crew's statement, on the day of the incident they were flying from Madrid to Barcelona. The aircraft's previous flight had been on the Saturday or Friday before[39]. They reported 1 ½ h before the flight for the pre-flight arrangements and to check the dispatch information, NOTAM, weather, etc. There was nothing unusual and the weather was good. They proceeded to the aircraft some 40 minutes before the flight to prepare it. They used the APU. The PF (first officer) was preparing the FMS[40] while the PNF (captain) did the cabin checks. While taxiing out, they had the standard roles, with the captain (PF) steering with the handwheel[41] (see Photograph 7) and the first officer (PNF) communicating and helping with the taxi instructions. Once lined up on the runway, they transferred control. The nose wheel steering (NWS) system provides an angle of ±3° with the pedals and ±60° with the handwheel. While taxiing only the captain actuates the pedals. There was nothing out of the ordinary during the taxi out.

They departed at 19:01, flying standard instrument departure (SID) PINAR 1R and climbed to cruise level FL300. The flight took place in nighttime conditions with some light turbulence, which they reported to the passengers so they could fasten their seatbelts (while climbing to cruise level).

At the localizer they ran into wake turbulence 5 miles out. They were flying at 180 KIAS and asked control to reduce to 150 kt due to wake. Approach control informed

36 NMOC Network Manager Operations Centre at Eurocontrol

37 SAR Search and Rescue

38 ENR- Most commonly used preferred nighttime configuration (north). In this configuration, aircraft land on run way 02 and take off from 07R.

39 According to flight logs, it had been on Friday, 23 September.

40 FMS- Flight Management System

41 Located on the left side only.

they were 4 NM away from the preceding aircraft.

In normal operations, the autopilot is typically engaged at 500 ft and climbing and disengaged at 80 ft on ILS and at 300 ft on non-precision approaches (NPA). In this case it was disengaged at 1000 ft. The Before Landing checklist says, for the A/P YAW DAMPER, that if it is disconnected before the gear was down, then the A/P would disengage but not the YAW DAMPER. In that case, the pedals would lock up, which did not happen in the incident. The YAW DAMPER light is a small white YD indication on the PFD informing that it is disengaged. There was no YD FAIL warning. The auto-throttle goes to idle automatically at 50 ft. The RUDDER BIAS is a system that compensates for a thrust asymmetry or an engine failure by using the rudder. It is checked on the ground. It compensates automatically and then the pilot, upon identifying the pedal that is compensating, applies full pedal. RUDDER BIAS OFF is a caution on the EICAS. If it is ON it does not say anything.

In the crew's opinion, the actions and support of the airport personnel were proper. The FFS arrived quickly. The firefighters did not enter the airplane. Also sent were ambulances, the Civil Guard, TOAM and the Duty Manager. They removed the airplane by pulling on its tow bar (which they had with them).

The crew thought the landing had been good. There was some crosswind (about 3 knots) and they were in a full flaps configuration. They landed in the center of the runway, no further forward than usual, and deployed the reversers. The captain recalled telling the first officer "Very nice landing", since the landing had been smooth. Their Vref was 131 kt, and they landed at about 125 kt. They landed and dropped the nose gently. As soon as they touched the brakes, the airplane veered.

The fuel was balanced. They left with 7000 kg and landed with 5000 kg. The ground spoilers (ground airbrakes) were deployed. As for the anti-skid system[42], they confirmed that the anti-skid light was off before landing. There is an indicating light on the captain's side with a button to disconnect the system.

The crew believed they went off the runway at a low speed, since the captain thought he could control it. Although the first officer was the PF, the captain took control of the aircraft when he saw they were running off. He said "Mine" and tried to correct with his right foot. The aircraft fish-tailed, and he decided not to fight it. They did not emergency brake. Once off the runway, they started the evacuation procedure but after assessing the situation, decided not to complete it. They pulled the circuit breakers for the CVR some 5 to 10 minutes after the incident.

42 System that keeps the wheels from locking while braking during the landing run

1.18.3 Prior G200 runway excursions

In 2013 there was an incident[43] at the Chautauqua County Airport in Jamestown (New York) in which a Gulfstream G200 aircraft departed the runway during the landing run after making an ILS approach in good weather conditions and visibility. In this case it was an instructional flight. During the final approach, at 100 ft AGL, the PNF warned the PF that they were approaching 15 kt above the reference speed and not to go faster because the runway was short. The aircraft landed within the touchdown zone, 1000 ft away from the runway threshold, and although the pilot attempted to stop the aircraft by braking and deploying the reversers, the aircraft overran the runway, coming to a stop some 40 ft from the end of the paved portion of the runway. In this case it was concluded that the main cause of the incident was the crew's inability to effectively use the aircraft's braking systems (brakes and reversers) to decelerate the airplane, resulting in a runway excursion. A contributing factor was the pilots' failure to execute a go-around upon realizing that the aircraft's airspeed was excessive during the final approach phase.

1.18.4 Rudder Blanking effect (lack of rudder effectiveness)

The rudder blanking effect is defined as a loss of or reduction in the effectiveness of the rudder (loss of aerodynamic directional control) resulting from a disturbance of the airflow around the rudder. This effect is different from rudder stalling since the loss of effectiveness in the latter is the result of operating this aerodynamic surface at a high angle of attack.

This phenomenon was analyzed as a consequence of an accident[44] that occurred in 2015 in which an MD88 aircraft departed the runway at the La Guardia Airport (New York). The conditions were similar to those present in the incident considered herein, with good visibility and after doing an ILS approach. Following its investigation, the NTSB[45] determined that there had been an excessive application of reverser thrust, which caused the rudder blanking effect during the landing run, which directly affected the directional control of the aircraft. Although the captain reacted by stowing the thrust reversers and applying hard right rudder, steering the nose wheel to the right and manually braking to the right, he was unable to keep the aircraft from departing the left side of the runway, since by the time the directional control was recovered, it was too late to be effective.

The rudder blanking effect is of particular concern in aircraft with engines installed at the rear and with T-shaped tails, in which the activation of the thrust reversers deflects the air forward of the engines to generate the braking thrust. The engine

43 http://www.asias.faa.gov/pls/apex/f?p=100:17:0::NO::AP_BRIEF_RPT_VAR:ERA13IA294

44 https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR1602.pdf

45 NTSB- National Transportation Safety Board- Official transportation accident investigation body in the USA.

exhaust, when deflected in this manner, disturbs the air flow that reaches the rudder.

The manufacturers of aircraft that are prone to this effect recommend limiting reverse thrust when the reversers are deployed, especially in contaminated runways in which nose wheel steering control is going to be less effective.

1.18.5 Landing information in documents

According to the Quick Reference Handbook (QRH), the reference speed for landing (Vref) with a weight of 26400 lb (11974.8 kg) is 131 KIAS.

Gulfstream G200 *Quick Reference Handbook*

Landing Reference Speeds (V_{REF})

The following table is provided in the event that an immediate return for landing becomes necessary. The following conditions apply:

- All speeds shown are KIAS
- For wet or dry runways
- Anti-ice OFF
- Surface DE-ICE OFF. If surface de-ice or engine anti-ice is ON, increase V_{REF} speed by 10% and landing distance by 20%.

Landing Weight	**35,450**	**35,000**	**34,000**	**33,000**
V_{REF}	**154**	**153**	**151**	**148**
Landing Weight	**32,000**	**31,000**	**30,000 (2)**	**29,000**
V_{REF}	**146**	**143**	**140**	**138**
Landing Weight	**28,000 (1)**	27,000	26,000	25,000
V_{REF}	**135**	133	130	128
Landing Weight	24,000	23,000	22,000	21,000
V_{REF}	125	123	120	118

(1) Maximum Landing Weight: Airplanes Not Having Mod 7166

(2) Maximum Landing Weight: Airplanes Having Mod 7166

NOTE: If surface de-ice and/or engine anti-ice is on, AOA compensation will be activated. For Collins FMS performance calculations only, select "DE-ICE ON" in the FMS conditions which provides the corrected V-Speed values and increase in landing distance required for operating during icing conditions.

END

Figure 6: Reference speeds in the QRH.

As concerns the use of reversers, the AMS specifies the following: "Do not exceed idle reverse thrust below 60 kts". The Operational Information Supplement also makes reference to this, although in relation to operations on icy runways or with strong crosswinds, for which it states that the use of reverse thrust destabilizes the aircraft because the proximity of the rudder to the exhaust gases can reduce rudder effectiveness. Reverse thrust should not be used at the expense of directional control.

Gulfstream
OPERATIONAL INFORMATION SUPPLEMENT

GAC-OIS-08 ADVISORY DATA ONLY

VISUAL APPROACH AND LANDING	
Pilot Flying (PF)	**Pilot Monitoring (PM)**
Thrust reverse can be actuated immediately after main gear touchdown for G100/G150 and upon nose gear WOW for G200, but use of reverse thrust beyond reverse IDLE should be limited to after nose gear contact. CAUTION: During heavy crosswinds and/or operation on icy runways, use of reverse thrust is de-stabilizing due to the reverse thrust exhaust proximity to the rudder which can reduce the rudder's effectiveness. Use of reverse thrust should not be used at the expense of directional control.	
Upon main gear touchdown:	
	• Confirm ground airbrake deployment. If ground airbrake do not automatically deploy, callout: **"No Ground Airbrakes"** • Confirm thrust reverser deployment. If one or both thrust reversers do not deploy, callout: **"No Thrust Reversers"**
Decelerating through 70 Knots:	
• Reduce reverse thrust so as to be at Reverse IDLE by 70 knots. • Reverse IDLE can be used all the way down to safe taxi speed. • PF transitions from rudder pedal steering to tiller steering when at a safe taxi speed.	**"70 Knots"**

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Figure 7: Information on the effect of reverse thrust on the rudder.

The company's Standard Operating Procedures (SOP) specify the following:

STABILIZED ILS APPROACH: An ILS approach is regarded as stabilized whenever the following are met at 1000 ft AGL:

- *Within ½ dot of the glideslope and localizer.*
- *Speed (IAS) between Vref and Vref+15 kt.*
- *Airplane configured for landing (slats/flaps 40, gear down).*
- *Vertical speed (VS) below 1000 ft/min.*

NOTE: The BEFORE LANDING CHECKLIST is not read out loud, except for the gear down (three green), reversers armed and ground airbrakes armed checks, and flaps changes, which require a reply.

BEFORE LANDING		
LANDING GEAR (3 GREEN)	DOWN	BOTH
HYDRAULIC PRESSURE	GREEN	BOTH
THRUST REVERSERS	ARM	BOTH
GROUND AIRBRAKES	ON	BOTH
ENGINE SYNCHRO	OFF	PNF
CABIN AC MASTER SWITCH	OFF	PNF
ANTISKID	ON	PNF
PARk / EMERG BRAKE LEVER	OFF	PNF
LANDING FLAPS	SELECTED	PNF
AUTOPILOT / YAW DAMPER	OFF	PNF
AUTO THROTTLE	DISENG'D	PNF

Figure 8: Excerpt from the Before Landing checklist.

LANDING RESTRICTIONS:

- *Maximum demonstrated crosswind for landing = 28 kt.*
- *Maximum demonstrated tailwind for landing = 10 kt (Remember that this is limiting).*
- *The fuel imbalance limitation on landing is 600 lg.*
- *Minimum approach speed to 200 ft AGL = Vref + 10 kt.*
- *Maintain Vref from 200 ft AGL until crossing over threshold at 50 ft. The use of the auto-throttle is recommended until contact is made. Verify that the SPEED message is flashing at 100' and that the system automatically retards the levers to the RETARD/IDLE position at 50', before disengaging them and the DISENGAGED message is shown on the corresponding panels. If these messages are not displayed, IMMEDIATELY disengage them and operate the throttles manually.*

Due to the flight characteristics of the G200, a positive landing should be made and the nose wheel lowered as quickly as possible, unlike in other aircraft in which it is better to "grease" the landing.

1.18.6 Actions taken after the investigation

The investigation team was in close contact with the aircraft manufacturer, the engine manufacturer, the operator and the full crew of the aircraft[46]. They were all informed of the progress of the investigation and of the results of the analysis carried out by this Commission.

As a result of this cooperation, the operator reported that even though the tests conducted on the landing gear (see 1.16.1 Results of the tests conducted by the operator after the incident) did not indicate backflow of hydraulic fluid, it was decided to apply SB-200-32-227 to the incident aircraft.

As a result of the questions posed to the crewmembers involving the operation of the aircraft, a discrepancy was identified in the Before Descent checklist (see 1.18.4 Landing information in documents), which required placing the auto-throttle in the "DISENGAGE" position, and should actually state "AS REQUIRED". The crew relayed this discrepancy to the Operations Department so that it can take the appropriate action.

1.19. Useful or effective investigation techniques

N/A

46 The crew of this aircraft consists of three pilots, two captains and one first officer.

2. ANALYSIS

The aircraft was flying from the Adolfo Suárez Madrid-Barajas Airport (LEMD) to the Barcelona-El Prat Airport (LEBA). Onboard were two flight crew and two passengers. The aircraft had taken off at 19:01 UTC on its first and only flight of the day. The first officer was the pilot flying. According to the ATIS information they had available, the weather was good with no adverse phenomena of note anywhere along their route. The aircraft had no deferred items and the crew were familiar with the airport.

Before the landing, the flight had been uneventful. The approach had been stabilized and the landing took place on runway 25R at 19:53 with the aircraft under control (the contact was soft, with no notable accelerations recorded) and lined up with the runway (heading 246º). The reversers were then armed and as the brakes were applied, the aircraft yawed sharply, changing its heading to the left. The captain took control of the aircraft, but it continued to veer left, eventually departing the runway near the R3 and R4 exits, some 1400 m away from the runway 25R threshold. Neither the crew nor the passengers were injured. The aircraft also had no visible damage. The tower controller contacted the crew of the aircraft and activated the local alert. The crew confirmed they had departed the runway, but that everyone onboard was well. Emergency personnel reported to the site of the incident. Two aircraft following the incident aircraft in the sequence had to go around when the runway was rendered inoperative, and arrangements were made with the remaining parties involved (ACC, airport, FFS) to change the airport's configuration.

2.1. Analysis of the management of the local alert

On the day of the incident, the airport was in a preferred daytime configuration (WRL). Once the runway was occupied by the aircraft and after the local alert was activated, the relevant transition (to the WLL configuration) was made, before subsequently continuing to the preferred nighttime configuration (ENR) upon confirming that runway 02 had not been affected. The ATC personnel all had valid licenses and ratings.

As part of the recommendations made by the ATS provider (ENAIRE) following its internal investigation, the handling of the incident was presented in training sessions on emergency actions and TRM as an example of best practices.

The airport manager (AENA) also issued a report with its own analysis of the incident, in which it noted that the horizontal markings on the runway were in good condition and in agreement with the indications on the corresponding chart. The coefficient of friction and the dry conditions of the runway did not contribute to the event. During the inspection of the runway following the incident, no FOD was found on the pavement that could have contributed to the sudden change in the aircraft's direction.

Based on all of the information collected and subsequently analyzed, this Commission is of the opinion that the actions of the control, airport and emergency personnel were correct in terms of dealing with the incident aircraft and of coordinating the actions needed to allow the airport to remain operational.

2.2. Analysis of the aircraft's performance

The aircraft had the necessary documentation, which was valid and in force, and a total of 2170:04 h at the start of the flight. Its last maintenance check had been on 19 September 2016, when it had 2167:57 h. The previous flight had been on 13 September 2016.

The manufacturer analyzed the incident based on the DFDR data, and sent its findings to this Commission, which are summarized below:

- The aircraft departed the runway at an angle with the centerline of approximately 15° left.
- Initially there was asymmetric braking toward the left.
- There was minimum use of the rudder and the rudder pedal.
- There were no messages alerting of system faults in the CAS.
- The crew did not brake firmly to stop the undesired turn.
- The crew did not apply sufficient or consistent rudder pedal commands to correct the aircraft heading back to the runway centerline.

In light of the circumstances of the incident, the investigation conducted by this Commission focused on every component and system that is used to control the aircraft's direction on the ground, that is: the **reversers,** the main gear **brakes,** the **rudder** and the nose wheel **steering.** The analysis and conclusions of this Commission are presented below.

2.2.1 Operation of the reversers.

The reverse thrust system redirects the exhaust flow, providing additional dynamic braking during the landing run. Each engine uses an identical and independent reverse thrust system that is deployed hydraulically. The right system provides hydraulics to the right reverser, brakes and nose wheel steering. The left system supplies hydraulic fluid to the left reverser and has no effect on the brakes.

The reversers were at full thrust for the entire landing run and runway excursion. This rules out the possibility that the bracket in the nose leg, which was found damaged after the incident, could have broken during the landing run, since it housed the third WOW sensor[47], which affects only the reverser system, meaning they would have stowed automatically. It was concluded that this bracket must have been damaged while towing the aircraft.

The AFM specifies not to exceed reverse idle thrust below 60 kt. The Operational Information Supplement (OIS) also includes this caution, indicating that the aircraft could be destabilized due to the proximity of the rudder to the gas exhaust, which could reduce the rudder's effectiveness. This caution, however, is specific to operations on icy runways or with strong crosswinds. The manufacturer later reported that there were no operational consequences to using the reversers at full thrust below 60 kt, and that the limitation had only been established to limit the ingestion of FOD, which could damage the engines. Due to the rudder blanking effect on this type of aircraft with a T-shaped tail and rear-mounted engines, however, manufacturers do recommend limiting thrust when deploying the reversers, especially on contaminated runways, in which the directional control of the nose wheel is less effective. Therefore, the way in which the reversers were operated, at full thrust, could have affected the air flow around the rudder, though it would only have done so for four seconds, which is the time that elapsed between the activation of the reversers until the aircraft's speed dropped below 80 kt, at which point the rudder lost all effectiveness on the directional control of the aircraft.

2.2.2 Operation of the landing gear braking system

The hydraulic brake systems for the wheels are controlled by way of the captain's and first officer's brake pedals, which are mechanically linked and act on the multi-disc brake assemblies on each of the four main landing gear wheels. The reference speed used was as specified in the SOPs (131±10 kt). The aircraft landed at 111 kt and the anti-skid system did not engage, meaning that the aircraft's speed during the landing did not exceed the limits established by the manufacturer, nor were there faults in the brake system that could have triggered the anti-skid system to engage.

47 WOW SW3

Investigators had access to information concerning a potential hydraulic fluid backflow into the brake system from the reversers when they were deployed, which could have caused a small symmetrical increase in brake pressure without any inputs from the crew to the brake pedals. As a result of this phenomenon, a service bulletin was issued in February 2012 (SB-200-32-227) that recommended installing a check valve in the hydraulic system. This service bulletin had not been implemented on the incident aircraft. After the incident, the operator contacted the manufacturer and carried out several inspections of the brake system. One of them involved deploying the reversers while the aircraft was on hydraulic jacks to see if this affected the rotation of the landing gear wheels. These checks were made after the landing gear had been replaced following the accident, but the results were satisfactory, with no evidence of any fluid backflow into the brake system. Despite this, the operator reported that independently of these results, it had decided to implement the aforementioned service bulletin.

An analysis of the data taken from the DFDR showed changes in the brake pressure two seconds before the reversers were activated, independently of when this was done, during the taxi out phase of the flight or during landing roll out.. This could have been caused by hydraulic fluid being returned to the brake system following the reverser deployment. It was noted that during the taxi phase, applying the reversers independently only yielded those pressure peaks when the right reverser was deployed. This is because, due to the configuration of the hydraulic system, only the right hydraulic system affects both the right reverser and the brake system. The pressure peaks corresponded to what the manufacturer described as "clamp up" pressure (from 185 to 200 psi) and lasted one second. The pressure peaks were also identified when the reversers were tested (right reverser) while taxiing before the flight. It was also noted that every time the landing gear was lowered or raised, there was an increase in brake pressure. But this was due to the anti-rotation feature on the aircraft, present by design, which stops the wheels from rotating before the gear enters or leaves its housing, and had no effect on the incident.

At the moment of landing, the DFDR data showed that once the WOW sensors were activated in the main and nose landing gear, there was a symmetric increase in brake pressure of **218** and **211** psi, without any inputs made to the brakes by the crew. This was probably due to returning hydraulic fluid following the deployment of the reversers. This pressure increase, however, could not be related to the aircraft's deviation.

Two seconds after this symmetrical pressure increase, the reversers were simultaneously activated at full thrust, with an indicated speed of 99 kt and a magnetic heading of 247°, that is, with an adequate speed and centered on the runway (250º). One second later, the left brake pressure increased for one second to a value of **428 psi,** versus a value of **162 psi** in the right. The recorded inputs to the brake pedals indicated a deflection of 1.914° in the left pedal versus 0.188° in the right. At that point the aircraft's indicated speed was 91 kt. This increase in pressure indicates the start of the aircraft's course change, from 248° to the 230° of the aircraft's final position. This moment will be referenced in other points of this analysis.

As for the brake system, another inspection carried out after the incident involved measuring the remaining thickness of the brake pads on the brakes. As the operator noted, the AMM contained no references to the maximum allowable differences in service life for the four brakes installed, nor had reports been received from the crew that the brakes on one side were more effective than on the other. Despite this, and although the results of the inspection were within the limits specified by the manufacturer, there was a difference between the left and right wheel brakes, with those on the right wheel being closer to the end of their service life. This could have affected the braking efficiency when the crew wanted to correct the aircraft's deviation to the left.

2.2.3 Operation of the rudder

The rudder is operated using the pilot's/copilot's pedals, which are linked. The aerodynamic effectiveness of the rudder, according to the manufacturer, is lost below 80 kt. Below that speed, directional control can only be achieved by steering the nose wheel or through differential braking. No anomalies were found during the post-incident inspection of the rudder, and there was continuity in the controls throughout the rudder's range of motion. The system that is activated only in the event of asymmetric thrust (rudder bias) did not engage. According to the DFDR data, after the WOW sensor in the nose strut was activated, at an indicated speed of 108 kt, an initial left rudder pedal input of 4.254° was recorded that had no immediate effect on changing the aircraft's heading.

In the two seconds following the deployment of the reversers, the rudder was deflected 5.339° and 4.105° to the left, but this did not affect the aircraft's heading, probably due to the rudder blanking effect. Three seconds after the activation of the reversers (one second after the left brake pressure rose to 428 psi, causing the change in direction), the rudder was moved 8.616° to the right (maximum deflection reached during the landing run), probably in an effort to correct the aircraft's heading. At that point, the aircraft's indicated speed was 79 kt, below the minimum aerodynamic speed for rudder effectiveness, meaning this aerodynamic surface was no longer providing directional control. Any rudder blanking effect, if it existed, can thus be ruled out as contributing to the aircraft's runway excursion. It should be noted that two seconds after the application of asymmetric braking to the left (source of the excursion), the aircraft's indicated speed was 79 kt, meaning the rudder no longer had any effect.

2.2.4 Operation of the nose wheel steering (NWS)

The nose wheel steering directional control is provided by rudder pedal steering system. With full rudder deflection, NWS can be commanded to ±3°.. Any failure in the NWS system is detected by monitoring channel, which changes the system into bypass mode (passive fault). There were no failure warnings for this system, nor did the subsequent inspections detect any problems in the system, with the exception of the bracket containing the third WOW sensor, which did not affect the NWS system. The crew's operation of the pedals, however, did not yield any response in the aircraft that allowed for its course to be corrected. The investigation was unable to determine why this system was ineffective in helping to correct the aircraft's heading.

2.2.5 Crew and analysis of the flight.

On the day of the incident, the first officer was the pilot flying. It was his first and only flight of the day after a vacation period. The captain's last flight prior to the incident flight had been on 13 September. The crewmembers were thus not deemed to have been influenced by fatigue.

According to their statement and to the DFDR and CVR analysis, the flight was normal and conducted in keeping with the company's SOP. The captain was monitoring the flight closely and watching the first officer's actions. The weather information used for the approach reflected the conditions present, with few clouds.

The crew configured the aircraft for landing and did the Before Landing checklist as they approached 1000 ft AGL. The captain recalled the main items in the list one by one prior to reaching 1000 ft. During the final approach phase the crew maintained 141 kt. The crew were cleared by the control tower to land on the runway in use, which was 25R. The wind was from the northwest (310º) and calm (3 kt).

Before landing, the left landing gear contacted the ground momentarily (one second), causing the airbrakes to deploy. Four seconds later, the WOW sensors on both the right and left main landing gears were activated, followed by the nose landing gear WOW. Four seconds later, the reversers were activated, and three seconds after that the **pressure in the left brake increased to 428 psi,** versus **162 psi** in the right, causing the sudden change in the aircraft's direction from 248º to 230º.

The crew had planned to exit the runway via one of the rapid exit taxiways to the right and then proceed to the stand of the executive aviation terminal. This, along with the sequence of conversations contained on the CVR, rule out any voluntary actions by the crew to exit the runway early.

2.2.6 Aircraft's response to the crew's actions

Once the aircraft veered sharply away from its heading, the crew took various actions involving the aircraft's directional control systems, without any apparent response from the aircraft.

One second later, the right brake pedal was deflected 2.263º, which translated into a right brake pressure of 385 psi, versus the 210 psi in the left. No changes in the aircraft's heading were identified. The indicated speed at that point was 87 kt. In the second that followed two other actions were recorded: an input to the rudder pedal (deflecting the rudder 8.616º to the right) and an increase in the differential braking, resulting in a pressure of 603 psi in the right brake versus 215 psi in the left. This action had no effect on the aircraft. The speed recorded at that time was 68 kt, meaning that the rudder no longer had any aerodynamic effect in controlling the direction of the aircraft at that point (rudder effectiveness below 80 kt). The differential braking to the right was maintained for two additional seconds, along with a right input to the rudder pedals. From then on, the DFDR recorded symmetrical braking inputs, though the right rudder input was maintained until the aircraft departed the runway.

In general, the investigation was unable to determine how a one-second application of the left brakes could have caused such a sudden change in direction that the crew were unable to correct. While their efforts were not excessively firm (as the manufacturer stated), the captain said that when he felt the aircraft make a strange movement (fishtailed), he made the decision not to correct the aircraft's direction by force, and instead tried to bring it to a stop. The findings show that by the time the asymmetric braking occurred (428 psi left versus 162 psi right), the rudder had barely any aerodynamic steering effect. The corrective asymmetric braking was ineffective, despite reaching a value of 603 psi in the right, versus 215 psi in the left. This was probably due to the remaining useful life of the brakes, despite still being within limits. From the time that the pressure increased in the left brake (source of the change in direction) until the runway departure proper, eight seconds elapsed, which may not have been enough time to obtain an effective reaction from the aircraft.

The manufacturer concluded in the lack of effectiveness of the braking action and rudder steering to correct the deviation is attributed to insufficient and indecisive braking and rudder pedal application throughout the landing roll.

3. CONCLUSIONS

3.1. Findings

An analysis of all of the available information yields the following findings:

- The aircraft's documentation was valid, and there were approximately 2171 h on the aircraft, including the incident flight.
- The last flight had been on 13 September 2016, with no reported anomalies.
- The last maintenance check had been on 19 September 2016 with 2167:57 h on the aircraft.
- There had been no previous reports of any malfunction of the brake system on this aircraft.
- The captain had a valid license, rating and medical certificate and 2365 flight hours on the type.
- The first officer had a valid license, rating and medical certificate and 178 flight hours on the type.
- Control personnel had valid licenses and ratings and the required unit endorsements.
- The runway's friction coefficient and horizontal markings did not contribute to the event.
- No FOD was found when the runway was inspected after the incident.
- The bracket that was found broken after the incident did not contribute to the incident and did not affect the directional control of the aircraft.
- No damage was found (except to the aforementioned bracket), nor did any of the aircraft's directional control systems (reversers, brakes, rudder or nose wheel steering) malfunction.
- The reference speed used during the landing was as specified in the SOPs (131±10 kt).
- The aircraft landed at 111 kt, within the specified limits.

- The reversers were at full thrust for the duration of the landing run and runway excursion.

- The aircraft's documentation cautions not to exceed idle reverse thrust below 60 kt.

- The rudder has no effect on directional control below an IAS of 80 kt.

- Due to the momentary activation of the WOW sensor in the left landing gear, the airbrakes were deployed. The aircraft banked slightly to the left before touching down.

- The manufacturer issued a service bulletin (SB-200-32-227) in 2011 that considered the possibility of pressurizing the brake system through the return line form the reversers when they were actuated.

- This service bulletin had not been implemented in the incident aircraft.

- When the reversers were deployed, there was a symmetric increase in brake pressure of 218 and 211 psi with no crew inputs to the brakes being recorded.

- This pressure increase was not associated with the cause of the aircraft's deviation.

- There were no EICAS messages warning of brake system faults or anti-skid activation.

- Three seconds after the reversers were activated, the DFDR recorded a left brake pedal deflection of 1.914° and a corresponding left brake pressure increase (for one second) to 428 psi, versus right brake pedal deflection of 0.188° and 162 psi for the right brake pressure, coinciding with the sudden change in heading.

- The rudder blanking effect is thus ruled out as having triggered the incident.

- Two seconds later, the rudder was deflected 8.616° to the right. At that point, the aircraft had an IAS of 79 kt, meaning the rudder had no effect on directional control.

- The crew braked asymmetrically to the right 2 and 4 s after the deviation, reaching 263 psi in the left brake pressure versus 603 psi on the right, with deflections in the brake pedal of 0,495° and 4,765° respectively, with no response from the aircraft, followed by practically symmetrical braking until the runway departure.

- The tests on the remaining thickness of the carbon pads on the brakes showed they were within limits, though the pads on the right wheel were closer to the end of their service life.

- Eight seconds elapsed between the increased pressure to the left brake (start of heading change) and the time when the aircraft departed the runway.

- The wind was from the northwest (310º) and calm (3 kt). It had no effect on the incident.

- This Commission believes that the differential braking was not sufficient enough to cause the sudden deviation.

- The crew also had considerable problems controlling the aircraft despite their efforts to control its trajectory.

- During the investigation process there was not possible to determine the cause of the deviation nor the lack of effectiveness of the aircraft's systems

3.2. Causes

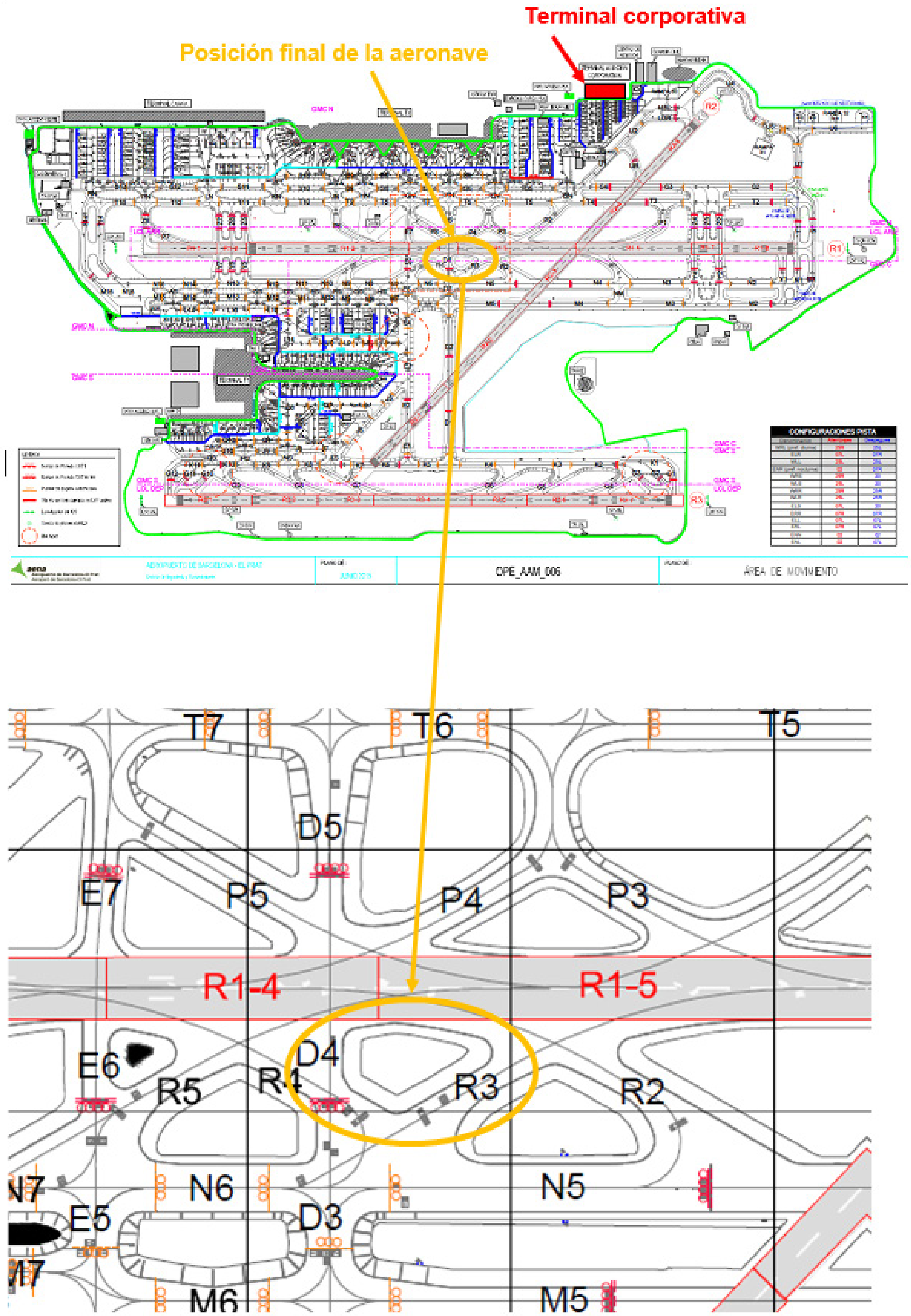
The cause of the incident was the lack of ability to maintain the runway centerline during the landing run after applying the brakes due to differential braking, which caused the aircraft to depart the side of the runway. During the investigation, several control inputs carried out by the crew to offset this deviation were identified, but there was no effective response on the aircraft's heading correction as a consequence of them.

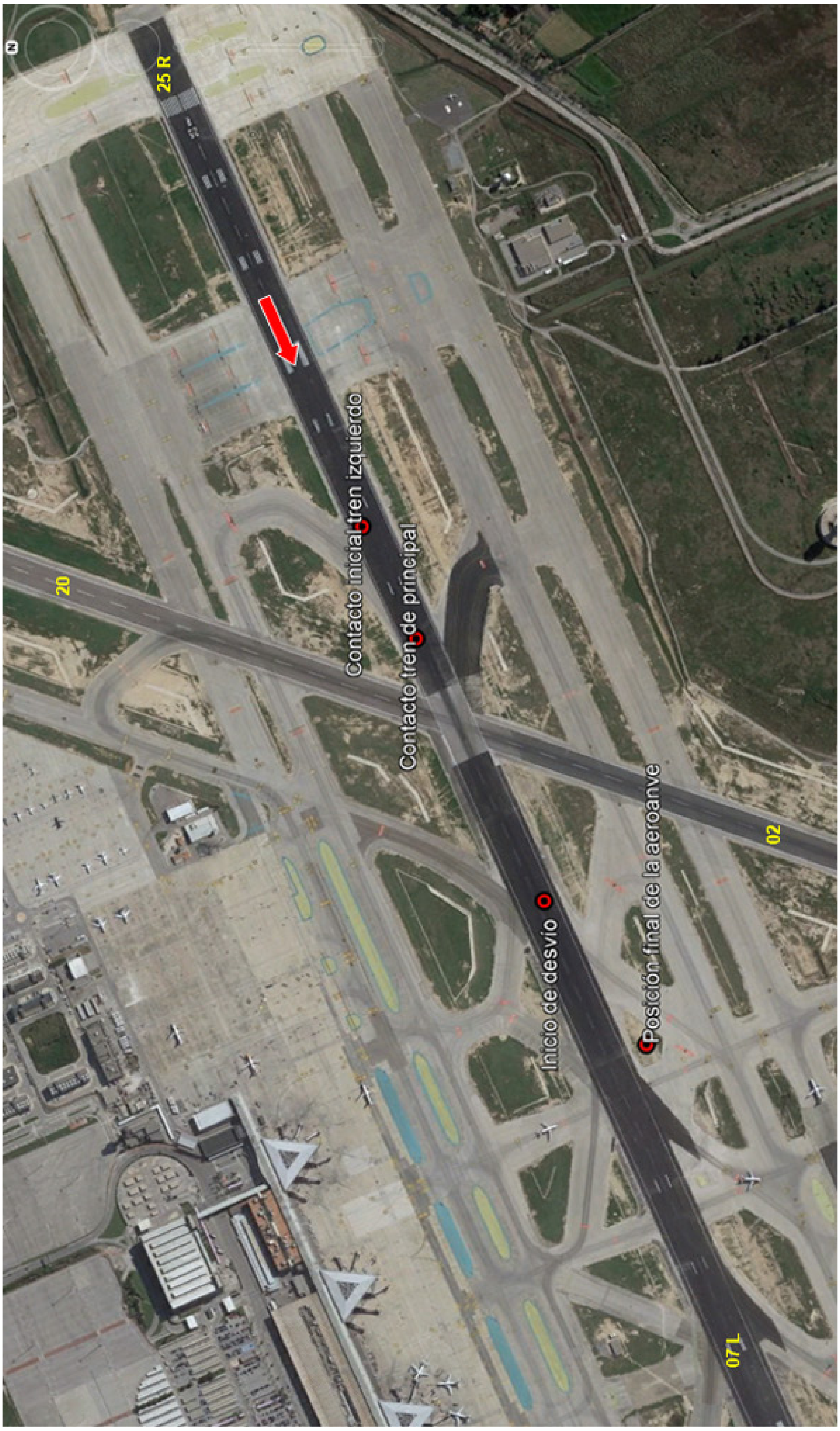
4. SAFETY RECOMMENDATIONS

After analyzing the incident, and in light of the inability to determine the specific reasons for the lack of effectiveness of the aircraft's systems, it was decided not to issue any associated safety recommendations. The operator stated that it would apply the safety bulletin (SB-200-32-227) involving the return of fluid from the reversers toward the brakes, and thus no recommendations are deemed necessary for the operator. The investigation was also unable to identify an explicit malfunction in the aircraft's system that warranted the issuing of a recommendation to the manufacturer, which has been analyzing the data in concert with the Commission to assist in clarifying the cause. As a result, it is aware of this incident and will continue to analyze improvements as necessary.

APPENDIX 1:

PATH TAKEN AND TRACKS LEFT DURING THE INCI-DENT


Terminal corporativa
Posición final de la aeronave
OPE_AAM_006
ÁREA DE MOVIMIENTO
T7
T6
T5
D5
E7
P5
P4
P3
R1-4
R1-5
E6
R5
R4
D4
R3
R2
N7
N6
N5
E5
D3
M7
M6
M5



Aerial photograph of the airport with the aircraft's direction of motion and final position
Image taken from Google Earth

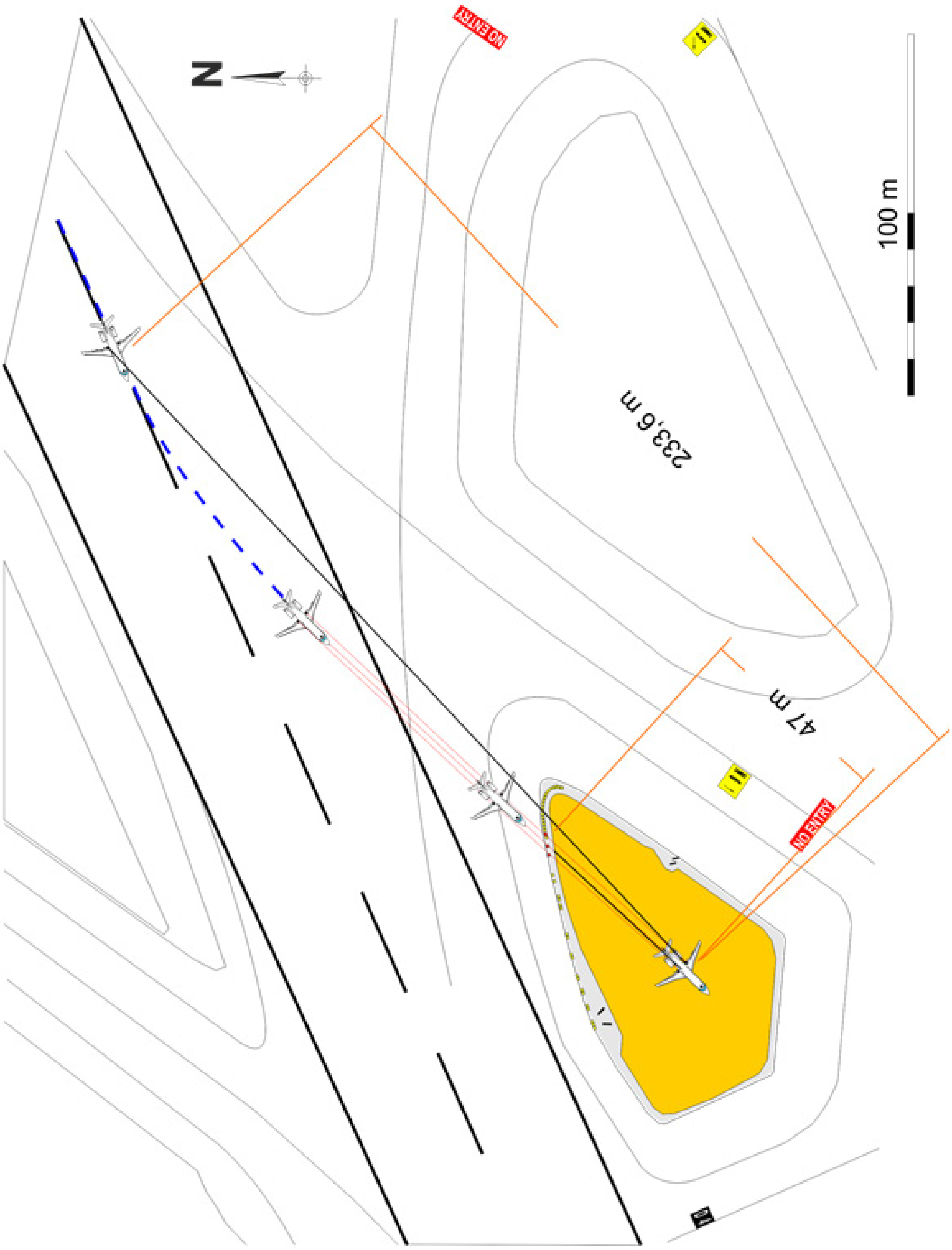


Diagram of the path taken by the aircraft and its track

APPENDIX 2:

INFORMATION ON THE HYDRAULIC PRESSURE RISE IN THE BRAKE SYSTEM

BREAKFAST MINUTES

May 8, 2009

G200® (ATA 32): Brakes Apply When Right Thrust Reverser Is Deployed

By John Deputy, G200/G250 Model Manager

A G200 operator reported that when the right thrust reverser (T/R) was deployed, brake pressure would be applied without crew input.

Gulfstream Technical Operations was contacted concerning this anomaly. They provided an Engineering Order (EO) to the operator to install a check valve in the return port of the parking brake valve. The respective check valve (P/N CV26-72) was ordered and installed, resolving the condition.

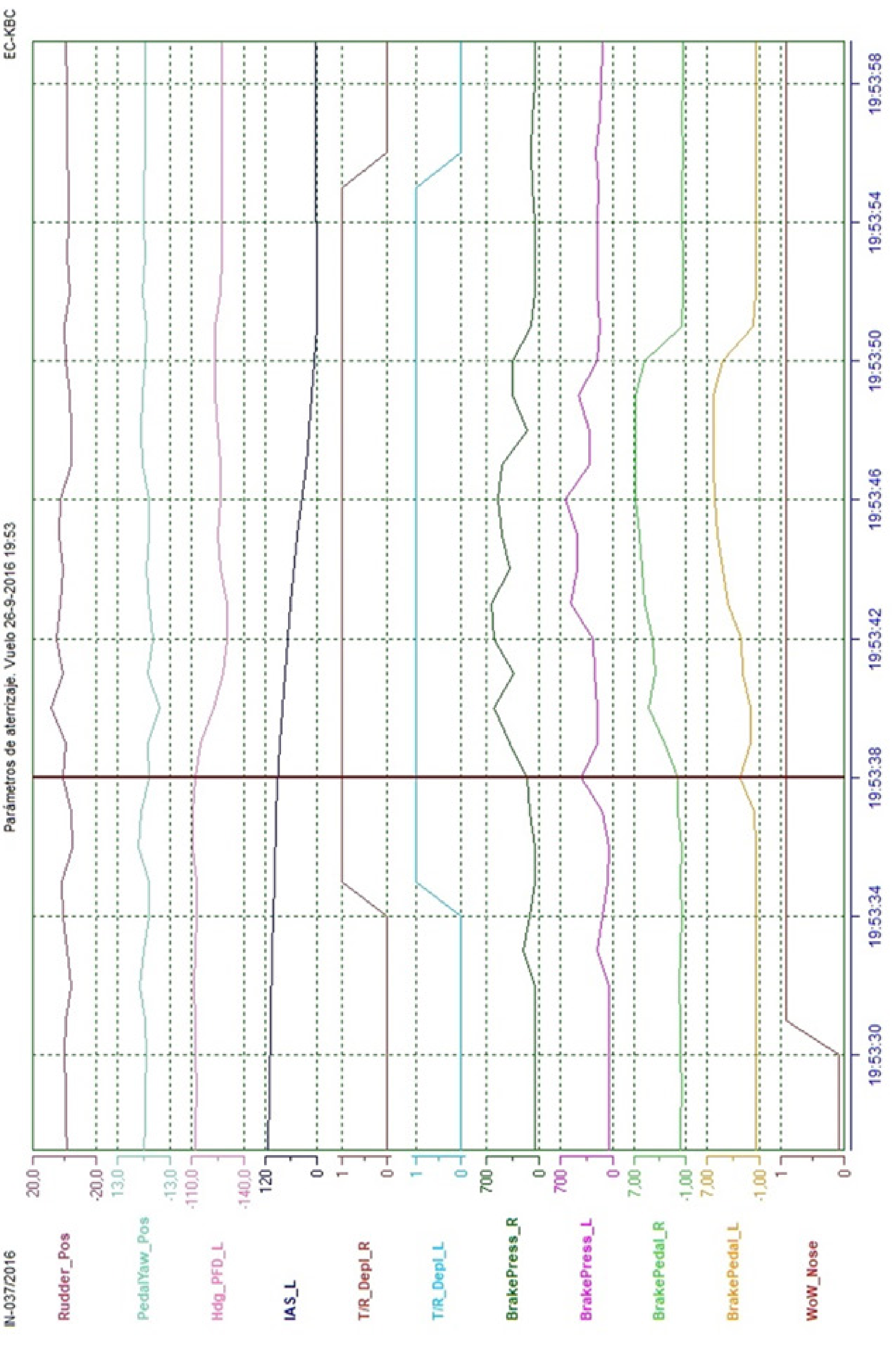
When the right T/R is deployed, a pressure rise is generated in the hydraulic return line. This is normally unnoticed by the crew unless there are contributing factors (such as air in the hydraulic system or wear in the valves) that cause this pressure rise to be experienced as a momentary pressure spike rather than a steady rise.

It should be noted that this condition is not present on all G200 aircraft. However, on those that do encounter it, the check valve can be installed in accordance with the EO attached to drawing 4AS7140030-005A01.

If assistance is needed, contact Gulfstream Customer Support – Technical Operations at 1-800-810-GULF (4853), 912-965-4178, or midcabin.techops@gulfstream.com.

APPENDIX 3:

DFDR GRAPH


EC-KBC
Parámetros de aterrizaje. Vuelo 26-9-2016 19:53
IN-037/2016
Rudder_Pos
PedalYaw_Pos
Hdg_PFD_L
IAS_L
T/R_Depl_R
T/R_Depl_L
BrakePress_R
BrakePress_L
BrakePedal_R
BrakePedal_L
WoW_Nose
19:53:30
19:53:34
19:53:38
19:53:42
19:53:46
19:53:50
19:53:54
19:53:58

WoW_Nose	WoW_Main_	WoW_Main_	Rudder_P(	PedalYaw_	Hdg_PFD_	Hdg_PFD_	T/R_Depl_L	T/R_Depl_R	Thrust_	Thrust_	BrakePed	BrakePeda	BrakePress_L	BrakePress_l	IAS_L	IAS_R
			degrees	degrees	degrees	degrees					Degrees	Degrees	PSI	PSI	knots	knots
WOW OFF	WOW OFF	WOW OFF	-1,78	-0,027	246,4	245,7	NOT ACTIVE	NOT ACTIVE	0,2	0,4	-0,477	0,049	64	58		121
WOW OFF	WOW ON	WOW OFF	-1,27	-0,49	246,4	245,7	NOT ACTIVE	NOT ACTIVE	0,2	0,4	-0,472	0,049	64	57	119,5	
WOW OFF	WOW OFF	WOW OFF	-1,704	0,04	247,1	246,1	NOT ACTIVE	NOT ACTIVE	0,2	0,4	-0,481	0,035	57	56		117,5
WOW OFF	WOW OFF	WOW OFF	-1,812	-0,101	247,5	246,4	NOT ACTIVE	NOT ACTIVE	0,2	0,4	-0,486	-0,198	57	53	116	
WOW OFF	WOW OFF	WOW OFF	-1,183	-0,503	247,5	246,4	NOT ACTIVE	NOT ACTIVE	0,2	0,4	-0,481	-0,198	58	55		113
WOW OFF	WOW ON	WOW ON	-0,77	-0,865	247,1	246,4	NOT ACTIVE	NOT ACTIVE	0,2	0,4	-0,491	-0,458	58	51	111,5	
WOW OFF	WOW ON	WOW ON	-0,109	-1,1	247,5	246,4	NOT ACTIVE	NOT ACTIVE	0,2	0,4	-0,491	-0,165	58	53		109,5
WOW ON	WOW ON	WOW ON	-0,727	-0,765	247,9	246,8	NOT ACTIVE	NOT ACTIVE	0,2	0,4	-0,491	-0,226	60	55	107	
WOW ON	WOW ON	WOW ON	-4,254	1,999	248,2	247,5	NOT ACTIVE	NOT ACTIVE	0,2	0,4	-0,486	-0,035	60	56		105,5
WOW ON	WOW ON	WOW ON	-1,931	-0,154	247,9	247,1	NOT ACTIVE	NOT ACTIVE	-3,5	-3,7	-0,491	-0,184	218	211	103,5	
WOW ON	WOW ON	WOW ON	1,139	-2,381	247,1	246,4	NOT ACTIVE	NOT ACTIVE	-3,9	-3,7	-0,491	-0,37	140	119		100,5
WOW ON	WOW ON	WOW ON	1,704	-2,287	247,1	246,4	ACTIVE	ACTIVE	-13,7	-13,7	-0,486	-0,258	63	55	99	
WOW ON	WOW ON	WOW ON	-5,339	2,77	248,9	247,9	ACTIVE	ACTIVE	-13,9	-13,7	-0,491	-0,467	61	52		96,5
WOW ON	WOW ON	WOW ON	-4,015	1,046	248,9	248,2	ACTIVE	ACTIVE	-13,9	-13,7	-0,267	0,305	147	119	94	
WOW ON	WOW ON	WOW ON	1,15	-2,388	247,9	246,8	ACTIVE	ACTIVE	-13,9	-13,7	1,914	0,188	428	162		91
WOW ON	WOW ON	WOW ON	-0,749	-1,878	245	243,6	ACTIVE	ACTIVE	-13,9	-13,7	0,309	2,263	210	385	86,5	
WOW ON	WOW ON	WOW ON	8,616	-7,505	237	235,9	ACTIVE	ACTIVE	-13,9	-13,9	0,495	4,765	215	603		79
WOW ON	WOW ON	WOW ON	0,543	-2,079	232	231	ACTIVE	ACTIVE	-13,9	-13,9	1,565	3,751	237	333	75	
WOW ON	WOW ON	WOW ON	4,818	-4,232	229,6	228,5	ACTIVE	ACTIVE	-13,9	-13,9	1,709	4,026	263	603		68
WOW ON	WOW ON	WOW ON	2,246	-2,911	229,6	228,9	ACTIVE	ACTIVE	-13,9	-13,9	3,826	5,449	567	635	62,5	
WOW ON	WOW ON	WOW ON	0,673	-1,127	233,4	233,1	ACTIVE	ACTIVE	-13,9	-12,7	4,575	5,691	478	388		55,5
WOW ON	WOW ON	WOW ON	3,342	-2,435	235,2	234,1	ACTIVE	ACTIVE	-13,9	-12,7	5,342	6,217	469	497	47,5	
WOW ON	WOW ON	WOW ON	2,268	-2,388	233,8	233,1	ACTIVE	ACTIVE	-13,9	-12,7	5,812	6,714	633	539		38,5
WOW ON	WOW ON	WOW ON	-3,82	0,644	233,4	232,7	ACTIVE	ACTIVE	-13,7	-12,3	6,086	6,817	318	486	24	
WOW ON	WOW ON	WOW ON	-4,34	1,429	234,8	234,1	ACTIVE	ACTIVE	-13,4	-12,3	6,035	6,779	309	158		16,5
WOW ON	WOW ON	WOW ON	-3,364	0,557	236,2	235,5	ACTIVE	ACTIVE	-13,2	-12,3	6,021	6,784	454	346	12	
WOW ON	WOW ON	WOW ON	-0,445	-0,939	236,6	235,9	ACTIVE	ACTIVE	-13,2	-12,3	4,64	5,268	213	353		5,5
WOW ON	WOW ON	WOW ON	0,141	-1,019	236,2	235,5	ACTIVE	ACTIVE	-13,2	-12,3	-0,002	-0,458	167	101	0	
WOW ON	WOW ON	WOW ON	-3,277	0,543	233,4	232,4	ACTIVE	ACTIVE	-13,2	-12,3	-0,491	-0,491	215	60		0
WOW ON	WOW ON	WOW ON	-1,888	-0,349	232,7	232	ACTIVE	ACTIVE	-13,2	-12,3	-0,491	-0,491	204	57	0,5	
WOW ON	WOW ON	WOW ON	-2,3	-0,201	232,7	232	ACTIVE	ACTIVE	-13,2	-12,7	-0,491	-0,486	202	56		0
WOW ON	WOW ON	WOW ON	-2,181	-0,168	232,7	232	ACTIVE	ACTIVE	-0,5	17,1	-0,486	-0,486	199	95	2,5	
WOW ON	WOW ON	WOW ON	-1,639	-0,429	232,7	232	NOT ACTIVE	NOT ACTIVE	7,4	0,7	-0,491	-0,495	226	100		2,5
WOW ON	WOW ON	WOW ON	-1,563	-0,402	232,7	232	NOT ACTIVE	NOT ACTIVE	0,4	0,4	-0,486	-0,486	169	90	3	
WOW ON	WOW ON	WOW ON	-1,552	-0,443	232,7	232	NOT ACTIVE	NOT ACTIVE	0,4	0,4	-0,495	-0,491	166	51		2,5

Leyenda
WOW tren de aterrizaje principal
WOW tren de morro
Activación y desactivación de las Reversas
Inicio del desvío
Acción sobre la aeronave para corregir el desvío

APPENDIX 4:

TRACKS OF RUNWAY EXCURSION