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SAFETY INVESTIGATION REPORT

Serious incident to the AIRBUS A320 registered **9H-EMU** and operated by Airhub Airlines on Monday 23 May 2022 on approach to Paris - Charles de Gaulle airport

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July 2024

BEA2022-0219

Safety investigations

The BEA is the French Civil Aviation Safety Investigation Authority. Its investigations are conducted with the sole objective of improving aviation safety and are not intended to apportion blame or liabilities.

BEA investigations are independent, separate and conducted without prejudice to any judicial or administrative action that may be taken to determine blame or liability.

SPECIAL FOREWORD TO ENGLISH EDITION

This is a courtesy translation by the BEA of the Final Report on the Safety Investigation.

As accurate as the translation may be, the original text in French is the work of reference.

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Synopsis

Time	Around 11:40[1]
Operator	Airhub Airlines (Maltese operator)[2]
Type of flight	Scheduled passenger commercial air transport
Persons on board	Captain (PF), co-pilot (PM), 4 cabin crew, 172 passengers
Consequences and damage	None

Transmission of incorrect altimeter setting (QNH) by air traffic service, near-collision with ground during satellite approach procedure with barometric vertical guidance

The crew of the Airbus A320 registered 9H-EMU were carrying out scheduled flight NSZ4311 between Stockholm Arlanda airport (Sweden) and Paris-Charles de Gaulle airport (France). Work was being carried out on the ILS for runway 27R at CDG, so the crew carried out a satellite approach with barometric vertical guidance (RNP APCH down to LNAV/VNAV minima).

During the approach, in a rain shower which severely impaired visibility, the crew were given an incorrect altimeter setting (QNH) by the air traffic service with a difference of 10 hPa (1011 hPa instead of 1001).

An error in the altimeter setting will mean that the aeroplane's actual altitude does not correspond to the altitude displayed. For approaches with barometric vertical guidance, the vertical profile and the associated vertical guidance are thus affected. Using a QNH value 10 hPa higher than the actual value resulted in the approach being flown on a vertical profile that was parallel to but around 280 ft (85 m) below the published vertical profile.

The design of the IFR procedures is based on normal operations and thus does not take into account an incorrect altimeter setting. The crews' operating procedures and those of the air traffic controllers did not prevent the use of an incorrect altimeter setting. Furthermore, neither the aeroplane's instruments nor the air traffic controller's tools were designed to detect this type of error.

At low height, a ground proximity warning (MSAW) was triggered in the control tower. Several seconds later, the air traffic controller informed the crew of the situation using an incorrect and inappropriate phraseology. The crew did not hear this announcement and continued their descent.

After reaching the indicated altitude corresponding to the chosen minima, the crew carried out a go-around because they had not acquired the visual references needed to continue the landing. During the manoeuvre, the minimum recorded and corrected radio-altimeter height was 6 ft, i.e. about 2 m, when the aeroplane was about 0.9 NM from the runway threshold, outside the limits

[1] Except where otherwise indicated, the times in this report are in Coordinated Universal Time (UTC). Two hours should be added to obtain the legal time applicable in Metropolitan France on the day of the event.

[2] The aeroplane was operated under a wet lease agreement (or Aircraft Crew Maintenance and Insurance (ACMI) leasing agreement) between Norwegian Air Sweden (lessee) and Airhub Airlines (lessor).

of Paris-Charles de Gaulle airport. As per design, there was no on-board ground proximity alert (TAWS) during the event. In their statements, the crew indicated that they had not been aware of this proximity with the ground.

The second approach was also carried out with the same incorrect QNH. This time, the crew acquired visual contact with the ground, at a height of more than 600 ft. The PF corrected the flight path and landed without further incident.

The BEA has issued twelve safety recommendations, six safety recommendations were issued when the preliminary report was published on 11 July 2022, and six additional safety recommendations accompany the publication of this report. These latter recommendations concern:

- the overall reassessment of the Controlled Flight Into Terrain (CFIT) risk and the associated mitigation measures in relation to the threat of an incorrect altimeter setting for baro-VNAV approach operations;
- maintaining the safety level of approach operations in Europe in 2030, in connection with the Commission Implementing Regulation (EU) 2018/1048 of 18 July 2018 laying down airspace usage requirements and operating procedures concerning performance-based navigation known as the “IR-PBN” regulation;
- ground systems for detecting an incorrect altimeter setting;
- onboard Terrain Awareness Warning Systems (TAWS);
- air traffic controller training in response to a MSAW alert;
- the DSNA safety management system.

Contents

Glossary

Abbreviation	English version
AAL	Above Aerodrome Level
ABAS	Aircraft-Based Augmentation System
ACARS	Aircraft Communication Addressing and Reporting System
ACCREP	Accredited Representative
ACO	Auto-callouts
ADI	Aerodrome Control Instrument
ADIRU	Air Data Inertial Reference Unit
ADS-B	Automatic Dependent Surveillance – Broadcast
AIP	Aeronautical Information Publication
ALTSM	Altimeter setting monitor
AMC	Acceptable Means of Compliance
AP	Auto-Pilot
APCH	Approach
APM	Approach Path Monitor
APS	Approach Control Surveillance
APV	Approach Procedure with Vertical guidance
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
ATPL	Airlines Transport Pilot Licence
BAAI	Bureau of Air Accident Investigation of Malta
Baro-VNAV	Barometric Vertical Navigation
BEA	French Civil Aviation Safety Investigation Authority
BKN	Broken
BOREAL	Operational lighting with status and alarm feedback
BPS	Barometric Pressure Setting
CAM-BTA	Corrected Altitude Monitor Below Transition Altitude
Cb	Cumulonimbus
CBT	Computer Based Training
CDFA	Continuous Descent Final Approach
CDG	Charles de Gaulle
CFIT	Controlled Flight Into Terrain
CLS	Local safety committee
CPL	Commercial Pilot Licence
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
CVS	Combined Vision System
DA/H	Decision Altitude/Height
DAP	Downlink Aircraft Parameters

Abbreviation	English version
DAR	Direct Access Recorder
D-ATIS	Data link-Automatic Terminal Information Service
DECOR	Données environnement contrôle pour Orly et Roissy
DGAC	French Civil Aviation Authority
DME	Distance Measuring Equipment
DSAC	Civil Aviation Safety Directorate
DSNA	Air Navigation Services Directorate
DSNA/DO	Operations Directorate
DSNA/DSEC	Safety Directorate
DSNA/DTI	Technical and Innovation Department
EASA	European Union Aviation Safety Agency
EC	European Commission
ECAC	European Civil Aviation Conference
EFB	Electronic Flight Bag
EFIS	Electronic Flight Instruments System
EFVS	Enhanced Flight Vision System
EGNOS	European Geostationary Navigation Overlay Service
EGPWS	Enhanced Ground Proximity Warning System
EHS	Enhanced Surveillance Mode S
EIS	Electronic Instruments System
ENAC	French National Civil Aviation School
EPAS	European Plan for Aviation Safety
ETSO	European Technical Standards Order
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FCOM	Flight Crew Operating Manual
FCU	Flight Control Unit
FD	Flight Director
FDM	Flight Data Monitoring
FDP	Final Descent Point
FDR	Flight Data Recorder
FL	Flight Level
FLS	FMS Landing System
FLTA	Forward Looking Terrain Avoidance
FMA	Flight Modes Annunciator
FMGS	Flight Management and Guidance System
FMS	Flight Management System
FNE	Event Notification Sheet
FPA	Flight Path Angle
FSAU	Abnormal and Emergency Situation Training
FSTD	Flight Simulation Training Device

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Abbreviation	English version
FWC	Flight Warning Computer
GBAS	Ground-Based Augmentation System
GLS	GBAS Landing System
GM	Guidance Material
GMS	Ground Movement Surveillance
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HBN	Cloud base height
HF	Human Factors
IAF	Initial Approach Fix
IAS	Indicated Air Speed
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICNA	French air traffic controller
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IMS	Integrated Management System
INI controller	Initial approach controller
IRBA	French Army Biomedical Research Institute
ISIS	Integrated Standby Instrument System
ITES	Significant Events Handling Body
ITM controller	Intermediate approach controller
LC	Line Check
LNAV	Lateral Navigation
LOC	Localizer
LOSA	Line Operations Safety Audit
LPC	Licence Proficiency Check
LPV	Localizer Performance with Vertical guidance
LVP	Low Visibility Procedure
MAPt	Missed Approach Point
MDA/H	Minimum Descent Altitude/Height
MEL	Minimum Equipment List
METAR	Meteorological Aerodrome Report
MLS	Microwave Landing System
MMR	Multi Mode Receiver
MOPS	Minimum Operational Performance Standard
MSAW	Minimum Safe Altitude Warning
NALS	No Approach Lighting System
ND	Navigation Display
NDB	Non-Directional Beacons

Abbreviation	English version
NES	Notification of a Significant Event
NOTAM	NOtice To AirMen
NOZ	Normal Operating Zone
NPA	Non-Precision Approach
NPA	Notice of Proposed Amendment
NTSB	National Transportation Safety Board
NTZ	Non-Transgression Zone
OCC	Operator Conversion Course
OCH	Obstacle Clearance Height
OJTI	On the Job Training Instructor
OM	Operating Manual
OPC	Operator Proficiency Check
PA	Precision Approach
PANS-ATM	Procedures for Air Navigation Services - Air Traffic Management
PANS-OPS	Procedures for Air Navigation Services - Aircraft Operations
PAPI	Precision Approach Path Indicator
PBN	Performance Based Navigation
PC	Controller fully qualified
PDA	Premature Descent Alert
PdD	Descent Path
PF	Pilot Flying
PFD	Primary Flight Display
PIC	Pilot In Command
PM	Pilot Monitoring
RA	Radio Altimeter
RAD	Aerodrome Radar Control
RNAV	Area Navigation
RNP	Required Navigation Performance
RTCA	Radio Technical Commission for Aeronautics
RVR	Runway Visual Range
RVSM	Reduced Vertical Separation Minima
SBAS	Satellite-Based Augmentation System
SCT	Scattered
SD	System Display
SDF	Sted Down Fix
SHRA	Shower Rain
SIA	French Aeronautical Information Service
SIL	Service Information Letter
SLS	SBAS Landing System
SOP	Standard Operating Procedure
SPP	Standard Practices and Procedures

Abbreviation	English version
STC	Supplemental Type Certificate
STCA	Short Term Conflict Alert
STD	Standard
TAWS	Terrain Awareness and Warning System
TCF	Terrain Clearance Floor
TDZ	Touch Down Zone
TEM	Threat and Error Management
TLB	Technical Log Book
TMA	Terminal Manoeuvring Area
TOGA	Take-Off Go-Around
TR	Type Rating
TWR	Tower
UCS	Unit Competence Scheme
UTC	Universal Time Coordinated
UTP	Unit Training Plan
VD	Vertical Display
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation
VOR	VHF Omnidirectional Range
VSD	Vertical Situation Display

Organisation of the investigation

The serious incident occurred on 23 May 2022 at around 13:40 local time. An occurrence notification form was completed the same day by the tower controller. The following day, the Paris-Charles de Gaulle control unit notified the French authorities, including the BEA, of a significant occurrence, namely the near-collision with the ground.

Based on the initial factual information gathered, the BEA opened a safety investigation into this incident. In accordance with Annex 13 to the Convention on International Civil Aviation and Regulation (EU) No 996/2010 concerning the investigation and prevention of accidents and incidents in civil aviation, the BEA informed on 25 May 2022, the following stakeholders of the opening of the safety investigation:

- the Maltese investigation authority, the Bureau of Air Accident Investigation (BAAI), as State of Registry and State of the Operator of the aeroplane;
- Airbus, the aeroplane manufacturer;
- the French air navigation service provider (DSNA) of the French Civil Aviation Authority (DGAC);
- the French civil aviation safety directorate (DSAC) of the DGAC;
- the European Union Aviation Safety Agency (EASA);
- the International Civil Aviation Organization (ICAO).

The BAAI appointed an accredited representative accompanied by technical advisers from the air operator, Airhub Airlines.

From 24 May to 31 May, the investigation team consolidated the initial information which had been obtained with additional information from flight data and statements from the crew and air traffic controllers.

The event was reclassified as a "serious incident" on 31 May 2022 due to the proven proximity with the ground (near-collision), with no external visual references, and no situational awareness on the part of both pilots and controllers.

A preliminary report was published on 11 July 2022 by the BEA:

- given the seriousness of the occurrence;
- to urgently recommend that those on the front line in this serious incident implement immediate safety measures;
- to raise collective awareness of the CFIT risk caused by an incorrect altimeter setting;
- to encourage the various institutional stakeholders to initiate the appropriate studies and define associated safety actions.

Six safety recommendations were issued to the air navigation services at Paris-Charles de Gaulle airport and to the air operator, Airhub Airlines.

Four working groups were then set up to identify and gather the information required for the investigation in the following areas: flight operations, air traffic management (ATM), on-board and ground systems, and performance-based navigation (PBN).

The following entities were also approached during the investigation:

- the United States investigation authority, the National Transportation Safety Board (NTSB), which appointed an accredited representative accompanied by technical advisers from the TAWS manufacturer, Honeywell, from Boeing and from the American civil aviation authority, which is also in charge of air navigation, the Federal Aviation Administration (FAA);
- the European Commission (EC);
- Eurocontrol;
- Météo France (French met office);
- the International Air Transport Association (IATA);
- the French Armed Forces Biomedical Research Institute (IRBA);
- the equipment manufacturer Aviation Communication & Surveillance Systems (ACSS).

The draft final report was submitted for consultation to the accredited representatives and their advisers, in accordance with article 6.3 of ICAO Annex 13. It was also sent to the European Commission, EASA, DSAC, DSNA, ICAO, Eurocontrol, Airbus and Météo France.

1 FACTUAL INFORMATION

1.1 History of the flight

Note: the following information is based on radio-communication recordings, radar data, DAR data, as well as the crew's and controllers' statements. The CVR data was not preserved.

The crew of the Airbus A320, performing flight NSZ4311 (call sign Red Nose 4311), took off on 23 May at around 09:30 from Stockholm Arlanda airport (Sweden) bound for Paris-Charles de Gaulle airport (CDG). The captain was the PF, the co-pilot was the PM.

Before the descent, the flight crew prepared for a satellite approach procedure with barometric vertical guidance, in this case a RNP APCH operation down to LNAV/VNAV minima, to runway 27R at CDG because the ILS was out of service. The meteorological information indicated in the ATIS Q (Automatic Terminal Information Service) used by the flight crew to prepare the approach was the following:

> *Transition level 70, wind 280/10 kt, visibility 10 km, broken clouds at 1,500 ft, temperature 19°C, dew point 14°C, QNH 1001 hPa.*

The crew indicated in their statements that they remained in clouds, without visual references, for all of the approach. They experienced moderate turbulence and flew through heavy rain, which led them to use the windshield wipers at high speed.

1.1.1 Transmission of incorrect altimeter setting (QNH) to crew by the intermediate approach (ITM) controller

At 11:32:24, when the aeroplane was on approach to CDG, the intermediate controller cleared the crew to descend to 6,000 ft and gave them an incorrect QNH value of 1011 hPa instead of 1001 hPa in force at the time[3]: "*Red Nose 4 3 1 1 descend ... descend … 6,000 feet 1 0 1 1.*" The PM read back the QNH provided: "*6,000 feet 1 0 1 1 ... 1 ... 0 1 1 … Red Nose 4 3 1 1.*"

At 11:34:28, she cleared the crew to descend to 5,000 ft, repeating the incorrect QNH, and clearing them for the RNP approach. "*Red Nose 4 3 1 1 descend 5,000 feet 1 0 1 1 cleared full R N P 2 7 right.*" The PM read back the information and the incorrect QNH: "*Descend 5,000 feet Q N H 1 0 1 1 cleared full R N P approach 2 7 right Red Nose 4 3 1 1.*"

At 11:35:37, the ITM controller cleared an easyJet crew to descend to 5,000 ft and gave them the same incorrect QNH: "*Easy 7 5 Mike Alpha direct Papa Golf 6 5 0 … and descend 5,000 ft 1 0 1 1 cleared RNP approach 2 7 right.*" The easyJet crew did not correctly read back the message as they read back the valid QNH of 1001 hPa: "*Direct to Papa Golf 6 5 0 descend 5,000 ft QNH 1 0 0 1 Easy 7 5 Victor Alpha.*" This was not picked up by the controller.

[3] The meteorological conditions indicated in the ATIS S in force were: wind 280°/9 kt, visibility 10 km, scattered clouds at 1,600 ft, broken clouds at 2,800 ft, few CB 5,000 ft, temperature 18°C, dew point 15°C, QNH 1001 hPa.

At 11:36:04, the ITM controller cleared in French, an Air France crew to descend to 5,000 ft with the correct QNH 1001 hPa. "*Air France trente-cinq Alpha Juliette bonjour descendez cinq mille pieds mille un et guidage R N P vingt-sept droite*." The Air France crew correctly read back the message along with the QNH 1001. The correct QNH was then transmitted in English, two other times while NSZ4311 was still on the frequency.

At 11:36:55, the crew of flight NSZ4311 reached the Final Approach Fix (FAF) at an indicated altitude of 4,889 ft QNH 1011 (4,623 ft QNH 1001) at around 14.3 NM from the runway threshold. The Indicated AirSpeed (IAS) was 185 kt and the aeroplane was in configuration CONF 2. The FINAL APP mode was engaged.

Around one minute later, the ITM controller instructed the flight crew to contact the north tower (N TWR) air traffic controller.

NOTE: due to the incorrect altimeter setting, the altitude value displayed on the aeroplane instruments was around 280 ft higher than the actual altitude of the aeroplane. The crew thus carried out the approach on a vertical profile around 280 ft below the published and expected vertical profile without being aware of this.

1.1.2 Near-collision with ground

At 11:38:09, the crew contacted the N TWR controller who replied: "*Bonjour Red Nose 4 3 1 1 you are number 1 wind 2 6 0 degrees 12 knots runway 2 7 right cleared to land.*" The crew correctly read back the clearance.

At 11:38:44, at a height of 2,500 ft, and as per design, the Radio-Altimeter (RA) values were displayed on the Primary Flight Displays (PFD).

At 11:40:49, at an indicated altitude of 1,395 ft QNH 1011 (1,123 ft QNH 1001, 837 ft RA), corresponding to the stabilization altitude for the crew (1,000 ft above aerodrome), and at 3.1 NM from the runway threshold, the aeroplane was configured for landing (CONF FULL) with an IAS of 139 kt corresponding to the target approach speed without the engine thrust controls being set to IDLE, and with a vertical speed of -738 ft/min.

NOTE: aside from the fact that the aeroplane's flight path was not on the correct vertical profile, the approach could be considered as stabilized.

At 11:41:32, the ground Minimum Safe Altitude Warning (MSAW) was triggered (see Figure 1, Point 1) in the air traffic control systems. The aeroplane was at an indicated altitude of 919 ft QNH 1011 (645 ft QNH 1001, 239 ft RA), at 1.5 NM from the runway threshold.

At 11:41:41, at 1.2 NM from the runway threshold, and with a vertical speed of -717 ft/min, the aeroplane flew through the indicated altitude of 811 ft QNH 1011 (537 ft QNH 1001, 122 ft RA), which corresponded approximately to the Decision Altitude (DA)[4] for the crew (Point 2). The crew indicated in their statements that they initiated a go-around at the minima as they had not acquired external visual references.

[4] The operator's policy with respect to LNAV/VNAV approaches was to add 50 ft to the published minima. Therefore, according to the NavBlue chart used by the crew, their DA was 802 ft (752 ft + 50 ft).

At the same time, i.e. roughly nine seconds after the MSAW was triggered, the N TWR controller warned the crew: "*Red Nose 4 3 1 1 I just had a ground proximity alert are you okay do you see the runway?*" (Point 2). The crew indicated in their statements that they did not hear this radio-communication.

At 11:41:47, when the controller had finished his message and the aeroplane was at an indicated altitude of 735 ft QNH 1011 (461 ft QNH 1001, 52 ft RA) and at 1 NM from the runway threshold, the auto-pilot (AP) was disengaged and the captain made a nose-up input on the mini-stick almost to full deflection (Point 3).

Three seconds later, at 11:41:50, at an indicated altitude of 679 ft QNH 1011 (405 ft QNH 1001), the minimum recorded and corrected radio-altimeter height was 6 ft when the aeroplane was about 0.9 NM from the runway threshold. The aeroplane's pitch attitude at this point was 11° nose-up. At the same time, the captain moved the thrust levers forward into the TOGA detent (Point 4).

No Terrain Awareness and Warning System (TAWS) alert was recorded during the approach.

The two pilots indicated in their statements that they only heard the radio-altimeter auto-callouts at 2,500 ft and 1,000 ft.

At 11:42:02, the flight crew reported to the controller that they were going around (Point 5). The latter replied: "*Roger … Red Nose 4 3 1 1 turn right on heading 3 6 0 and climb altitude 5 000 feet 1 0 0 1.*" The crew read back using the previous incorrect QNH, which the N-TWR controller did not pick up: "*3 6 0 and climb 5 000 feet on 1 0 1 1 Red Nose 4 3 1 1*" (Point 6).

During these exchanges, the controllers on duty in the tower could still not see the aeroplane. After a few seconds, they saw it coming out of the clouds, at low height, with a pitch up attitude.

At 11:42:05, the AP was re-engaged at an indicated altitude of 1,203 ft QNH 1011 (930 ft QNH 1001, 593 ft RA) and at 0.3 NM from the runway threshold.

At the same time, and while the N TWR controller was transmitting the message to the flight crew, the S TWR assistant in the south tower[5] advised the N TWR assistant that they had not switched on the approach lights of runway 27R.

At 11:42:27, the N TWR controller switched on the approach lights. Following the MSAW and the omission of switching on the approach lights, the N TWR controller was replaced by his N TWR assistant and a new N TWR assistant took over.

[5] At the time of the incident and in accordance with CDG procedures, each set of parallel runways (north and south) was managed by a pair of controllers: a TWR controller and a TWR assistant. The pair of controllers responsible for the north runways was situated in the north tower, the pair in charge of the south runways was situated in the south tower.

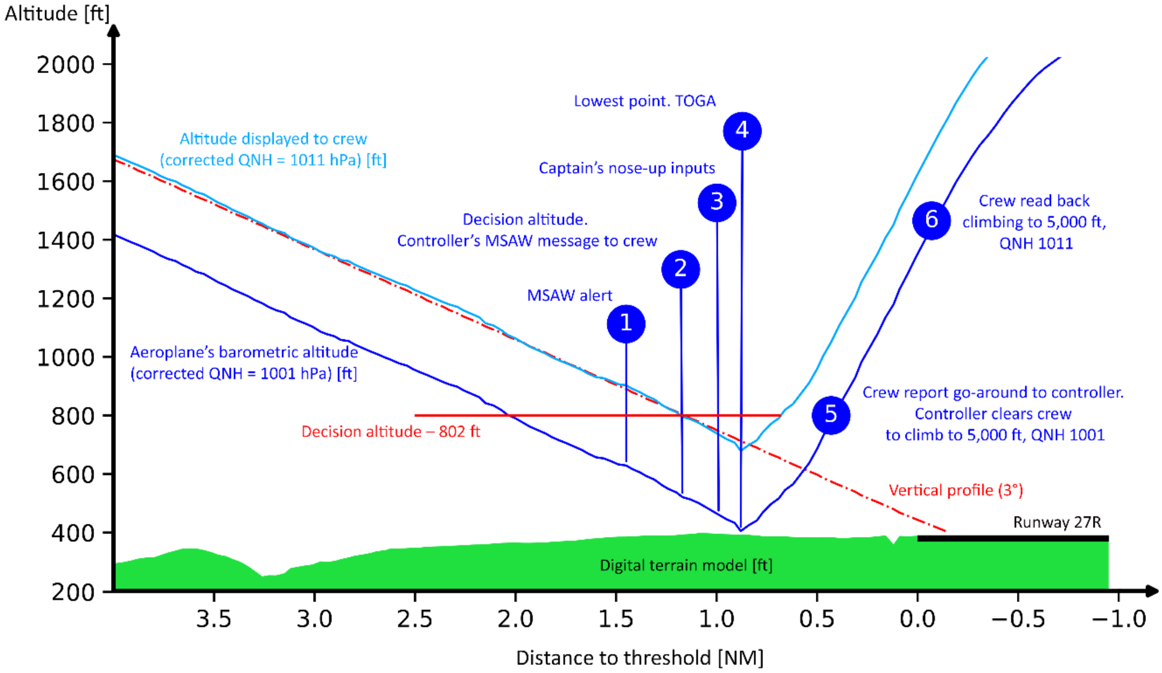

Figure 1: vertical profile of first approach, flight path calculated using recorded flight parameters (source: BEA)

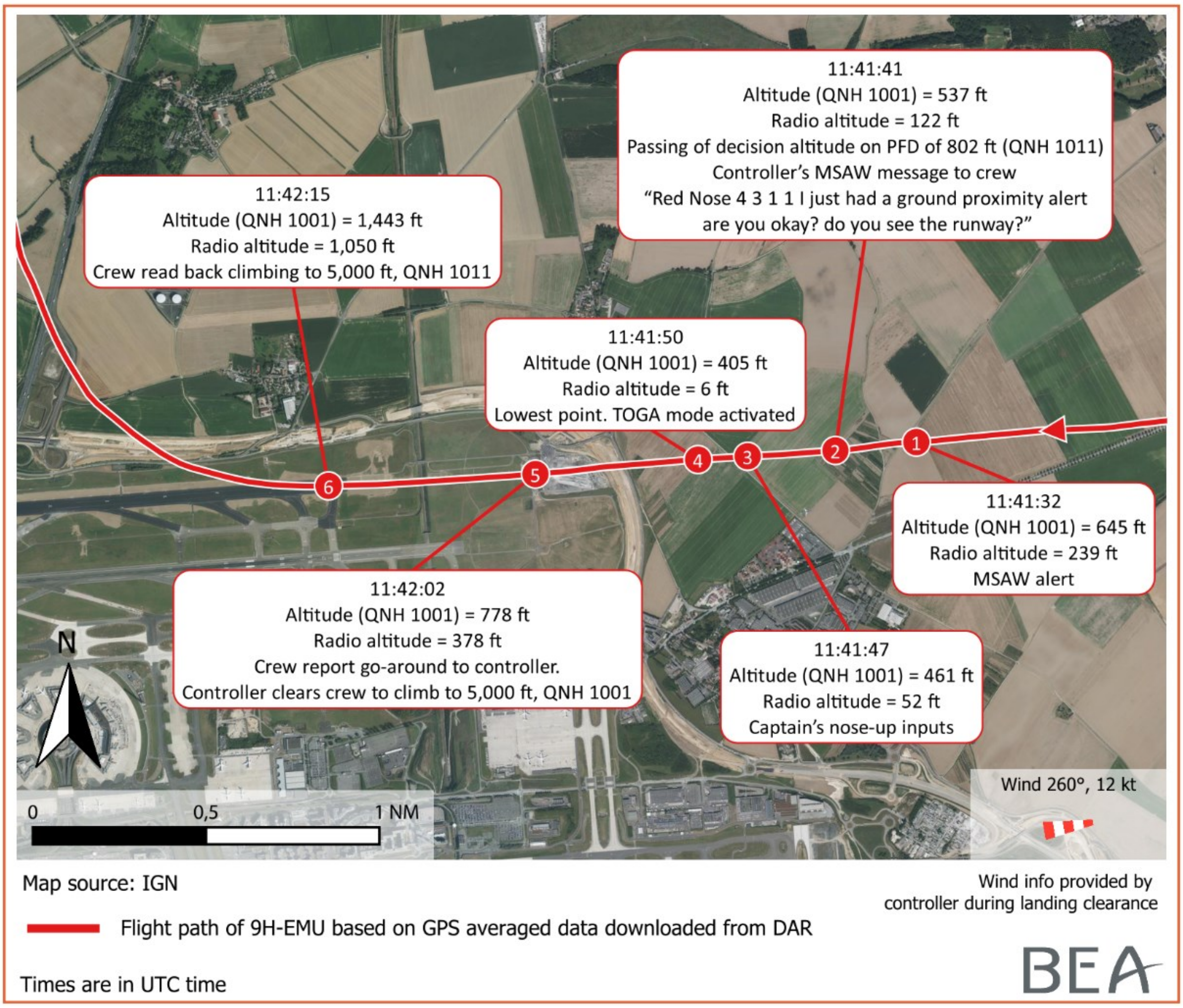

Figure 2: horizontal profile of first approach (source: BEA)

1.1.3 Second approach

At 11:44:42 and after giving them several radar headings, the N TWR controller instructed the crew to contact the Arrival (ITM controller) for the second approach. The aeroplane was on the downwind leg for runway 27R. Around 15 s later, the ITM controller indicated to the flight crew to expect RNP 27R.

At 11:49:09, after managing a conflict between flight NSZ4311 and another aeroplane which had triggered a Short Term Conflict Alert (STCA) and required the use of the associated emergency phraseology, the ITM controller cleared the crew to carry out a second RNP approach for runway 27R.

At 11:53:40, the N TWR controller cleared the crew to land. The crew read this back and asked if the approach lights were on, which the controller confirmed was the case.

NOTE: the aeroplane was still flying with an incorrect altimeter setting. Neither the crew nor the air traffic controllers were aware of this incorrect QNH which once again put the aeroplane on a vertical profile which was around 280 ft below the published vertical profile.

Although below the published nominal vertical profile, the approach carried out in FINAL APP mode was once again "stabilized" for the crew. The aeroplane was configured for landing with an approach speed of 140 kt and the AP engaged.

At 11:55:43, there was a new MSAW alert (see Figure 3, Point 7). The aeroplane was, this time, at an indicated altitude of 1,403 ft QNH 1011 (1,131 ft QNH 1001, 842 ft RA), at 3.1 NM from the runway threshold.

Four seconds later, the N TWR controller (who was in the N TWR assistant position for the first approach) warned the crew of the MSAW alert: "*Red Nose 4 3 1 1 I've just got a ... a terrain alert are you okay?*" (Point 8).

The crew indicated in their statements that they did not understand the reason for this message. The PM replied: "*... Red Nose 4 3 1 1 we are well established on path and we have visual now*."

At 11:56:00, at an indicated altitude of 1,227 ft QNH 1011 (954 ft QNH 1001, 602 ft RA) and at 2.6 NM from the runway threshold, the PF made a nose-up input on his ministick (Point 9). Simultaneously, the AP disconnected. The Flight Directors (FD) were switched off eight seconds later.

The crew indicated in their statements that this time they had acquired the visual references well above the minima.

The PF corrected the flight path and landed without further incident at 11:57:14.

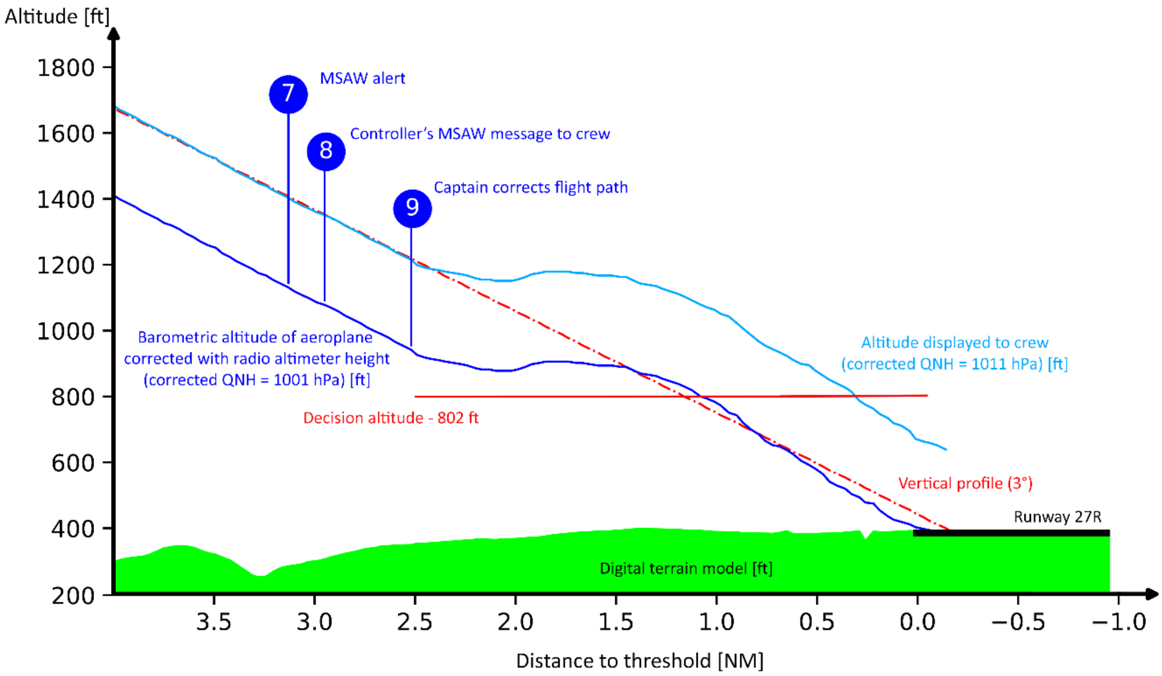

Figure 3: vertical profile of second approach, flight path calculated using recorded flight parameters (source: BEA)

1.2 Injuries to persons

Not applicable.

1.3 Damage to aircraft

Not applicable.

1.4 Other damage

Not applicable.

1.5 Personnel information

1.5.1 Flight Crew

Licence, rating, training and checks

	Captain	Co-pilot
Age, nationality	Aged 37, Lithuanian	Aged 42, Spanish
Type of licence and date of issue	ATPL(A) 23 November 2015	CPL(A) 13 October 2008
First Type Rating (TR) on A320 obtained on	23 November 2015	2018
A320 TR valid until	31 December 2022	28 February 2023
Class 1 medical fitness certificate valid until	23 March 2023	10 December 2022
English language skill level and date of validity	ICAO Level 5 24 February 2024	ICAO Level 6 Valid
Last two Operator Proficiency Checks (OPC)	4 April 2022 27 October 2021	14 March 2022 26 August 2021
Licence Proficiency Check (LPC) which can be combined with the OPC	27 October 2021	27 February 2022
Last Line Check (LC)	5 December 2021	1 September 2021
Last ground training	13 March 2022	6 June 2022

Declared experience

	Captain	Co-pilot
Total experience/as pilot in command (Flight Hours (FH))	5,878 / 2,529	2,221 / 481
Total on A320/as pilot in command (FH)	5,878 / 2,529	947 / 0
Previous three months (FH)	143 h 58 min	95 h 38 min
Previous 30 days (FH)	62 h 39 min	48 h 04 min
Previous 7 days (FH)	19 h 06 min	19 h 06 min
Previous 72 hours (FH)	16 h 23 min	16 h 23 min
Previous 24 hours (FH)	04 h 20 min	04 h 20 min

Roster

The day of the serious incident corresponded to the last day of a three-day programmed sequence of flights for the captain and the co-pilot. Prior to this, the co-pilot had been off duty since 5 May 2022 and the captain since 3 May 2022.

Date	Legs (IATA codes)	Start of flight service time	Flight time
Before 20 May	Rest	N/A	N/A
21 May	ARN CTA	04:30	3 h 40 min
	CTA ARN		3 h 39 min
22 May	ARN BUD	04:20	2 h 07 min
	BUD ARN		2 h 13 min
23 May	ARN HEL	03:50	0 h 52 min
	HEL ARN		1 h 00 min
	ARN CDG		2 h 52 min
	CDG ARN		*Flight post incident*
TOTAL	**N/A**	**N/A**	**16 h 23 min**

No deviations were identified from the flight time and rest period rules applicable to commercial air transport operators based on the provisions of commission regulation (EU) No 965/2012 (known as "AIR OPS") and its amendment laying down technical requirements and administrative procedures related to air operations.

The sleep deficit possibly accumulated by the succession of three early starts in the days preceding the incident, and to a lesser extent, the sequence of three flights on the day of the incident, may have contributed to a possible state of light or moderate fatigue in the crew, without them being aware of it.

1.5.1.1 Captain

Professional experience

The captain carried out his initial training in 2011. He was then recruited by an air operator in 2013 as co-pilot on the A320. He was appointed captain in 2018. He joined Airhub Airlines in October 2021 as captain. He was not one of the operator's employees and had a freelance contract.

Statement

The captain had decided to be the PF for the flight to CDG, a destination he was used to flying to. He had not felt tired on this flight. The forecast weather conditions indicated storms on arrival. He therefore decided to take extra fuel on-board. The flight was uneventful. Communication with the co-pilot was good, he had already flown with him and he considered that the Crew Resource Management (CRM) was satisfactory.

In cruise, just before starting the descent, both he and the co-pilot had consulted the ATIS information in turn and had noted the information on a piece of paper. They then compared their data and calculated the landing performances using the Electronic Flight Bag (EFB).

BEA

They started the approach briefing and reviewed the Flight Management and Guidance System (FMGS) inputs in preparation for a landing on runway 26L or 27R. The threats identified were the bad weather and the heavy traffic at CDG. He specified that the operating manual had an additional check-list to be carried out during the briefing for RNP approaches, including checking GPS accuracy at level 100, altitude/distance cross-checks at the various final approach points and increasing minima by 50 ft. He considered that this additional RNP briefing had been carried out satisfactorily as they were used to doing it. They then started the descent.

At the first altitude clearance to 6,000 ft, the air traffic controller gave them the QNH. He remembered that the co-pilot read back the QNH and that the controller did not correct him. He thought that if the controller had heard an incorrect read-back, he would have reacted. The captain therefore thought that the QNH provided was correct and entered it in the FCU. He then checked with the co-pilot that the altimeters were consistent. He thought that he was only given the QNH value once before the go-around. He also indicated that he tended to trust the controller when the latter provided a QNH, particularly as their information was more recent than that of the crew's who had the ATIS QNH.

He remembered a certain confusion in the frequency changes with the ATC. They were then cleared to descend to 5,000 ft and to continue to the Initial Approach Fix (IAF). This was followed by a clearance for the RNP approach. The weather conditions were bad, the weather radar was ON and he could see storm cells on the radar. Nevertheless, the approach proceeded normally.

During the final approach, the co-pilot (PM) cross-checked that the altitudes-distance were consistent every nautical mile and each time, they were on the slope. The FMGS displayed the PROGRESS page. The approach was stabilised. They were continuously in the clouds without visual references.

He indicated that on this aeroplane, there are no RA auto-callouts "HUNDRED ABOVE" and "MINIMA" and that it is thus the PM who makes the calls. He remembered having heard auto-callouts at 2,500 ft and 1,000 ft but not the other calls. In particular, he could not remember having heard the "50", "40", "30" and "20" auto-callouts. He indicated that without external visual references and at the minima, if he had heard this sequence, he would have immediately carried out a go-around. Neither could he remember a message from the controller about a terrain proximity alert. He indicated that they both used the Airbus standard audio headsets.
They did not have sight of the ground during the approach. The rain was heavy and the windshield wipers were at maximum speed. At the minima and still not having sight of the ground, he called out "*Go Around flaps.*" The co-pilot informed air traffic control of the go-around. During the go-around, another pilot indicated over the frequency that the approach lights were extinguished. The controller replied that it was an error on their part.

During the go-around, they were given heading 360° and cleared to climb to 5,000 ft. From what he could remember, the QNH was not mentioned at this time and the controller did not ask them why they had carried out a go-around.

They then contacted the approach controller. He made a passenger announcement advising that they had carried out a go-around due to the bad weather. He temporarily transferred the controls to the co-pilot, updated the FMGS and carried out a quick briefing. They were then cleared for the IAF still at 5,000 ft. The second approach proceeded as for the first one, with the co-pilot cross-checking the altitude-distances every nautical mile. The approach was once again stabilised.

Just before the minima, he saw the approach lights, the runway and the Precision Approach Path Indicator (PAPI). From what he could remember, he saw "*a white, pink and two red lights. Maybe three red lights, but not four*." He disengaged the AP and the FDs. It was still raining and the windshield wipers were still at high speed. He corrected for the gusts and turbulence.

At practically the same time, the controller warned them of a terrain proximity alert and asked them if all was well. The co-pilot replied that they could see the runway and that they were going to land normally.

The controller made no further mention of anything else, nor did he indicate that anything had gone wrong. They thought that there might have been a technical problem in the tower. They then contacted the ground and taxied to the parking area. For him, the operations were normal. They then prepared the aeroplane for a return flight to Stockholm. The flight to Stockholm proceeded without incident.

Two days after the landing at CDG, the chief pilot called to inform him that the French authorities had opened an investigation due to the low altitude alert reported by the control services. At the time, he did not understand why, as for him it was an uneventful flight apart from the go-around at the minima which was a normal operation.

1.5.1.2 Co-pilot

Professional experience

The co-pilot started flying on light aeroplanes in 2008. He was an instructor on the Cessna C172. He worked as a calibration engineer from 2010 to 2018; during this time he also assessed RNP approach operations.

He started his career as an airline transport pilot in 2018 and flew briefly on the Boeing 737. He then obtained an A320 rating and was employed by a European operator until 2019. He did not fly for several months because of the COVID-19 pandemic and then joined GetJet Airlines in July 2021 and followed a supplementary module to allow him to fly with Airhub Airlines in September 2021. The two air operators had nearly the same procedures. He was not one of the operator's employees and had a freelance contract.

Statement

They prepared the flight bound for CDG. The weather conditions had been updated, storms and rain at destination were reported, windshear was not forecast. There was no particular NOTAM apart from the ILS not being available. They then checked performance and the minima in order to carry out a RNP approach. They anticipated landing on runway 27R. By mutual agreement, they had taken on extra fuel because of the weather conditions. They were ready at 08:55 but were given a slot at 09:25 because of the storms. They were running late but did not feel under any pressure. The flight was uneventful. He had not felt tired on this flight. It was the first time that he had flown to CDG with this operator. He had been there several times when working for another operator.

He was PM for the flight. In cruise, he consulted the FCOM and reviewed the RNP approaches. Close to Reims, he consulted the CDG ATIS but found that the audio reception was not good. He noted the information on the EFB and in his personal notebook.

He calculated the landing performance. They carried out the briefing with the additional check-list for RNP approaches that he was used to reviewing. The RNP briefing specified adding 50 ft to the minima. The threats identified were the storm activity, the busy frequency and the parallel runways in specialised operation.

After their transfer to the Reims en-route control centre, the frequency became busy with a lot of radar vectoring by the control services to avoid the storms. He added that at times, it was difficult to hear the frequency and he had to ask for the initial approach segment twice. He considered that the weather conditions were worse than forecast for that day at Paris.

They were radar vectored and cleared to an altitude below the transition level, perhaps to 6,000 ft. He could not remember exactly whether the controller gave the QNH, but he read back the clearance. He considered that if he had made a read-back error, the controller would have called him back to correct him. When a controller gives him a QNH, he likes to cross-check it with his ATIS notes. On this occasion, he indicated that he did not have time to do it, probably because of the workload associated with the weather conditions. He specified, however, that the SOP do not require this check. In retrospect and after having listened to the radio-communications of the incident at the BEA, he thought that he may have hesitated with respect to the QNH value to be used.

Shortly after being cleared for the RNP approach to runway 27R, they were transferred to the tower. At 6,000 ft, they had no external visual references and were in heavy precipitation.

During the approach, he principally looked at the FMGS, the approach charts on the EFB and the instruments. He did not look outside. He perceived that everything was grey and that there was turbulence.

As PM, he cross-checked the altitude-distance every nautical mile. Everything was consistent and there were no faults, the system was performing correctly. There was no loss of signal and the accuracy of the GPS remained between 0.3 and 1 NM in accordance with procedures. Furthermore, the Vertical DEViation indicator (V/DEV) was at zero. He indicated that both he and the captain were satisfied that the aeroplane was correctly following the vertical profile.

He indicated that he called out "*Hundred above*", 100 ft above the minima. Just before the minima, he looked outside. He expected to see ground lights or the runway but they remained without external visual references. He then called out "*Approaching minimum*" at the minima. He did not remember having received a call from the controller and specified that the workload was high on approaching the minima. He did not remember hearing the auto-callouts except for those at 2,500 and 1,000 ft.

The captain then called out "Go-around flaps" and they performed the go around. He reconfigured the aeroplane, checked the altitude and the vertical speed. He then informed the tower that they were carrying out a go-around. The controller gave them an altitude and heading clearance which differed from the standard procedure that they had prepared for during the briefing. He indicated that this was standard at CDG and that they expected to be radar vectored. He did not remember that they had been given the QNH. He was concentrated on the speed and altitude during the go-around. He checked the FMA and reconfigured the aeroplane. He specified that they had a high workload and that everything accelerated.

They carried out level flight at 5,000 ft and were then given other radar vectors. They had a quick briefing concerning the quantity of remaining fuel and the key points of the RNP approach procedure for runway 27R. After checking the minima, the pilot activated the approach phase. They went through the items of the FL 100 procedure again and the altimeters showed no difference. The co-pilot indicated that he checked that the ILS pushbuttons were actually in the OFF position during the two approaches.

At 5,000 ft on the downwind leg, they were given interception headings and then started the approach again. They had already carried out the approach check-list. Next, they repeated the same check sequence as for the first approach: verification of mode engagement on the FMA, verification of accuracy of GPS, altitude/distance cross-checks every nautical mile, verification that the V/DEV was effectively centred on zero and verification that the speed was being correctly held.

This time they exited the clouds well above the minima. They saw the runway and the environment. They thought that during the second approach someone asked if the approach lights were lit.

They continued, they had the runway in sight. Just before the flare, the controller asked them if all was well. He replied that they had visual contact and were going to land. He was surprised, he had not understood why the controller asked them this question. The controller continued by informing them that they had had a terrain alert. He still did not understand and thought it was because the captain had reduced speed or that there might have been a gust of wind or that there had been a malfunction. They were both surprised by this terrain alert call. He added that he did not know what the MSAW system was, and that the operator’s documentation did not mention it.

They landed and were transferred to the ground frequency to taxi to the terminal.

1.5.1.3 Workload of crew during approach

The final approach flown by the crew during the serious incident was carried out without any external visual references, in rather heavy rain requiring the windshield wipers to be set to the highest speed, and without the approach lights illuminated.

The final approach is a flight phase that usually generates a high mental workload, with a lot of visual and auditory information to process, and decisions to be made under high time pressure.

In particular for RNP operations, there are numerous altitude-distance cross-checks and calls taking up mental resources. This was noted by the investigation team during the playbacks of the serious incident on the flight simulator (see paragraph 1.6.4).

Here are a few examples of approaches carried out during the day with no external visual references and/or in the rain, as well as with the windshield wipers in high-speed mode, to show the reader what an approach in these conditions is like. Not all the approaches are carried out on the Airbus A320.

- https://www.youtube.com/watch?v=ySvfrRbqKc8
- https://www.youtube.com/watch?v=Sebt3x36LLE
- https://www.youtube.com/watch?v=nM13jpHrpjU
- https://www.youtube.com/shorts/pmPKxOypmNQ
- https://www.youtube.com/watch?v=LmbaaVlEv6Q

1.5.2 CDG air traffic controllers

1.5.2.1 General information

At CDG, qualified controllers, i.e. controllers who have successfully completed their training in the unit, hold the unit ZZ endorsement. They are able to take all the tower and approach positions, except for the Tower supervisor and Approach supervisor positions which require seniority and additional training.

Control tower

In the control tower, the possible positions are Pre-flight, GND, TWR, TWR assistant. There are also the Tower supervisor position in the north tower and the South tower coordinator.

TWR/TWR assistant position: the TWR controller is responsible for the manoeuvring area on the runways, the runway safety areas and the taxiways situated between the parallel runways. He issues for the runway or parallel runways under his responsibility, the take-off, landing and runway crossing clearances along with the authorisations to enter the runway and safety areas. He monitors and maintains centreline-to-centreline separations, provide crews with all the information they need for landing and taking off and draws the Tower supervisor's attention to the need to switch lighting on or off.

The TWR assistant controller assists the TWR controller so that the latter can concentrate his resources on traffic management. To do this, the TWR assistant is positioned next to the TWR controller and, in particular, coordinates and facilitates the TWR controller's work (for example by drawing the TWR controller's attention to threats such as weather changes, particular traffic, etc.). The TWR/TWR assistant pair provides the control service, the information service and the alerting service for the aircraft in their area of responsibility.

When the approach room is open and the north and south towers are open, one TWR/TWR assistant pair man the north parallel runways in the north tower and a second pair man the south parallel runways and heliport in the south tower.

Tower supervisor position: the tower supervisor is responsible in real time, for the operation of the control structure and the supply of air traffic services for all of the CDG platform. The tower supervisor position is manned 24 h from the north tower or the central tower (in particular at night). The real-time management of the south tower is delegated to the south tower coordinator who warns the tower supervisor of any problem. A tower supervisor (or south tower coordinator in the south tower) can hold a control position if he can quickly resume his duties if necessary.

At the time of the serious incident: in compliance with the Operating Manual (OM), the controller holding the N TWR position[6] was also the tower supervisor. Another controller was in the N TWR assistant position, a third in the GND position and a fourth in the PRE-FLIGHT position. The physical stations of these controllers are directly situated in front of the picture windows. Set back in the tower, another controller with the appropriate training was at the tower supervisor station to ensure telephone communications, but not the supervisor duties.

The N TWR frequency was busy less than 18% of the time during the serious incident.

Approach room

In the Approach room, the possible positions are DEP (N/S), DEP COOR (N/S), INI (N/S), INI COOR (N/S), ITM (N/S/BA) and approach supervisor.

Intermediate approach (ITM) positions: the ITM controllers provide control, information and alert services for the aircraft for which they are responsible. Their area of responsibility includes the parts of the Paris TMA managed by the CDG approach in which inbound aircraft or certain outbound aircraft operate, after their transfer by another sector or unit, as well as the final approach paths[7] before their transfer to the TWR controller. They provide air traffic services and carry out radar "monitoring, assistance and vectoring" functions for CDG and Le Bourget arrivals at the end of the initial approach until their transfer to the TWR controller and for any other aircraft entering their area of responsibility. Among other things, they apply the interception rules for independent parallel approaches and ensure the separations required to maintain the runway landing and take-off rates and wake vortex separations.

The ITM sector in the approach room is made up of three control positions, corresponding respectively to the northern sector (N ITM), the southern sector (S ITM) and the sector concerning arrivals at and departures from Paris-Le Bourget airport and other peripheral aerodromes (BA ITM). The positions may be combined at the discretion of the approach supervisor, as long as each ITM handles fewer than eight aircraft.

Approach supervisor position: the approach supervisor is responsible in real time, for the operation of the approach room control structure and the supply of air traffic services for all of the CDG airspaces.

At the time of the serious incident: on returning from her lunch break, the ITM controller mentioned below was at the North ITM station where the three ITM positions were combined. The first exchange with flight NSZ4311 took place in this configuration. Due to heavier traffic, the positions were split at 11:31 and the controller kept the N and BA ITM positions.

The N + BA ITM frequency was busy less than 50% of the time during the serious incident.

[6] The term "station" refers to the physical location where the controller performs his duties and the term "position" refers to the geographical area of responsibility. e.g. “The N ITM, S ITM and BA ITM positions were combined at the N ITM station.”
[7] And their NOZ (Normal Operating Zone) and NTZ (Non-Transgression Zone).

1.5.2.2 ITM controller for the two approaches

Licence, rating, training and checks

Age, nationality	Aged 43, French
Valid ratings and endorsements[8]	ADI/(GMS, TWR, RAD), APS
Unit endorsement	LFPG/ZZ
Endorsement expiry date	14 September 2023
Other endorsements and expiry dates	Assessor valid until 14 February 2023, OJTI/STDI[9] valid until 10 December 2023
English language endorsement and expiry date	ICAO level 4 valid until 25 March 2023
Last refresher training	FSAU/APP 12 October 2020, FSAU/TWR 31 March 2022, PPS 16 November 2021
Medical fitness certificate	Valid

Experience

On completing her initial training, the controller in the N ITM position during the serious incident was assigned to an en-route control centre for six years. In 2007, she was assigned to the Paris-Charles de Gaulle control unit. She had been a qualified controller since 2009. She obtained the assessor rating in 2014. She had also had a two-year secondment between 2013 and 2015 to the Instruction subdivision.

Activity and duty periods prior to the serious incident

The ITM controller's team had been off duty the two days preceding the day of the serious incident. The controller indicated that she had arrived on site at 09:30 UTC and that she started her duty period at around 11:00.

Statement

History of the serious incident

The controller indicated that she had not been aware of any abnormal situation at the time of the serious incident. She stated that the crew had carried out their approach and that a MSAW alert had been triggered on short final. She was no longer in radio contact with the crew at the time of the alert. She added that this alert had been perceived by all the personnel in the approach room, as it appeared both on the display screens and as an aural alert throughout the room. This alert had no operational consequences in the approach room as the aeroplane was already in contact with the tower.

She recalled that the crew carried out a go-around and came back on her N+BA ITM approach frequency. The aeroplane was established on the downwind leg at 5,000 ft on a heading of 090°. She added that she had not been aware that the altimeter setting was incorrect and had given the crew the instruction, "*Continue as cleared.*" She specified that she did not give the QNH again because the crew had reported that they were stable at 5,000 ft and were supposed to have already received this information.

[8] See glossary.

[9] Instructor.

The controller indicated that she then received a Short Term Conflict Alert (STCA) because of a potential flight path conflict between NSZ4311 and another aeroplane that was in contact with the S ITM controller and that was cleared to descend to 4,000 ft for ILS 26L. She reported that she used the emergency phraseology to resolve the conflict, as did the controller in the S ITM position, which meant that they did not go below the separation standards.

She stated that the crew of NSZ4311 carried out a new approach and that a MSAW alert was triggered again. She was no longer responsible for the aeroplane and was not in radio contact with the crew. She assumed that there was a technical problem on board and that the crew were going to divert to another airport. She completed the occurrence notification form with respect to the triggering of the STCA. She considered, along with the other people in the approach room, that the only significant safety occurrence was the one involving the triggering of the STCA with the use of emergency phraseology.

She also specified that on that day, at around 13:20, there was another safety occurrence concerning a conflict between two aeroplanes and the triggering of the STCA, followed by an in-flight loss of control of an aircraft[10] [into which the BEA has opened an investigation] which attracted most of the attention of the air traffic controllers that day, with the controller being relieved and the immediate playback. In her opinion, this may have mitigated the perceived seriousness of the serious incident involving NSZ4311.

After the occurrence

The controller indicated that she was informed a week later of the "near-CFIT" classification of the serious incident involving NSZ4311. She then became aware of the actual course of the event and its seriousness. She subsequently discussed the serious incident with other controllers who were also unaware of the importance of the QNH for certain RNP approaches [*Note: Several other controllers questioned by the BEA during the investigation indicated the same lack of awareness*]. However, she indicated that one of her relatives, an Air France pilot, was surprised by this perception, because for him the QNH is a "*killer item*" during Baro-VNAV approaches.

Before the serious incident, she considered that the controller should pay particular attention to the following points during an RNP approach in contrast to an ILS approach:

- there is only one interception altitude;
- the absence of any possibility of intercepting the vertical profile from above.

With regard to the first QNH error, she indicated that it was possible that there had been a confusion between the flight call sign spelled out in English as "Red Nose 4 3 1 1" and the QNH announced as "1 0 1 1". She also specified that 1 0 1 1 is easier to say than 1 0 0 1 .

She indicated that she was in the habit of looking at the DECOR screen (see paragraph 1.10.3) where the QNH is displayed before announcing it on the frequency. However, she could not remember whether she did so on this particular occasion.

[10] It is the serious incident to the Beech 90 registered F-HHAM and the Airbus A320 registered D-AIZI operated by Lufthansa on 23 May 2022 near Paris-Le Bourget, for which the BEA has opened an investigation.

With regard to the two other QNH errors that followed, with NSZ4311 and then with an easyJet flight, she indicated that she may have unconsciously kept the "musicality" of "1 0 1 1" in mind.

She specified that she was not tired and that the workload was not too heavy because the ITM positions were split.

She added that following the serious incident, she had consulted the CDG RNP Final Approach quick-reference sheet for the ITM, which is available at the position and which she rarely consulted because controllers are used to clearing RNPs. This sheet specified giving the QNH when clearing the RNP approach. However, she believed that no-one did this. She indicated that the QNH must be given when giving the first altitude clearance, whatever the type of approach, and possibly by reflex on subsequent altitude clearances.

With respect to the possibility of detecting an inconsistency between the altitude displayed on the radar screen and the expected flight path, she said that, even if the level flight at 5,000 ft had been longer, she did not think she would have noticed an anomaly on the first approach. Indeed, she did not detect an inconsistency in altitude during the ten minutes or so that she had the crew on the frequency and the aeroplane was in level flight at 5,000 ft between the go-around and the second approach. She added that she did not use the "Alt" button to display the QNH altitude[11] of the aeroplanes (see paragraph 1.10.3.2).

Regarding the procedure in the event of a MSAW alert, she said she did not know how to react to it and could not remember the standard phraseology [*Note: several other controllers questioned by the BEA during the investigation indicated the same lack of familiarity*]. She thought that in the event of a MSAW alert being triggered, she would impose a go-around. She observed that this alert was not very frequent and that it most often concerned aircraft that were not in contact with CDG, particularly for approaches to Le Bourget airport. As a result, the CDG controllers were not particularly alarmed when a MSAW alert was triggered. She recalled having had a briefing or training when the MSAW system was introduced. She had not had any since then.

1.5.2.3 N TWR controller for first approach

Licence, rating, training and checks

Age, nationality	Aged 46, French
Valid ratings and endorsements	ADI/(GMS, TWR, RAD), APS
Unit endorsement	LFPG/ZZ
Endorsement expiry date	14 December 2023
Other endorsements and expiry dates	OJTI/ STDI valid until 14 December 2023
English language endorsement and expiry date	ICAO level 4 valid until 22 March 2025
Last refresher training	FSAU/APP 10 December 2020, FSAU/TWR 19 May 2022, PPS 21 September 2021
Medical fitness certificate	Valid

[11] This was confirmed by the actual playback of the radar data.

Experience

The controller in the N TWR position at the time of the serious incident had been appointed to the Paris-Charles de Gaulle control unit in 2001 on completing his initial training. He worked as a qualified controller and instructor up to 2018, except for a one year period between 2009 and 2010 when he had been seconded to the Environment and Safety Service Quality subdivision. He obtained his qualification for the Duty Supervisor position on 30 May 2010 and Tower Supervisor position on 1 April 2016. He had been Approach Supervisor since 1 November 2018.

Activity and duty periods prior to the serious incident

The controller had been on duty as Approach Supervisor on 21 May 2022 from 08:00 to 14:30. He was off duty on 22 May, the day before the serious incident.

The controller stated that he came on duty at 04:30 as tower controller (N TWR) and Tower Supervisor, to exercise the privileges of his unit endorsements with a view to revalidating them. He carried out this shift in the team to which he had belonged prior to becoming Approach Supervisor in 2018.

He specified that between 04:30 and 10:00, he was first N TWR controller, and then N TWR assistant, GND controller and Tower Supervisor. He took his lunch break between 10:00 and 11:00 and then resumed as N TWR controller at around 11.10.

Statement

History of the serious incident

The controller indicated that, on the day of the serious incident, the lighting had been switched off at around 07:00 local time once daylight had set in. He added that the weather conditions had been good during the morning but that a squall had passed over the airport between 10:30 and 11:15, leaving the runway wet. He stated that about ten minutes before NSZ4311 came onto the TWR frequency, he noticed that another episode of bad weather was approaching the runway and decided, in consultation with the TWR assistant, to switch the lighting on, to brightness setting three out of four. The controller stated that he thought he had switched on the PAPI, the runway lighting and the approach lights. He noted that during the final approach of NSZ4311, visibility was temporarily very poor and he could not see the aeroplane.

He indicated that he did not notice any anomaly when the aeroplane was on final, until a MSAW alert was triggered. He then reacted by informing the pilot of the alert and asking him if he could see the runway. He remembered that the crew replied rather late, reporting a go-around. The controller estimated that three or four seconds elapsed before he saw the aeroplane emerge from the clouds at low altitude in a nose-up attitude. He asked the crew to carry out a missed approach procedure to the north at 5,000 ft and specified he did not notice the incorrect QNH read-back.

The controller added that shortly afterwards they received a telephone call from the S TWR assistant controller in the south tower, who warned them that their approach lights were not switched on. He then immediately activated the lights and increased the brightness. He remembered that he was then asked if he wanted to be relieved, which he accepted because he felt slightly unsettled by the fact that he had forgotten to switch on the approach lights.

He indicated that his N TWR assistant then took the N TWR position, that another controller came to take the TWR assistant position and that he himself took the tower supervisor position at the dedicated station. He then took charge of changing the ATIS and coordinating the second approach of NSZ4311 with the approach supervisor. He thought about proposing the ILS for inner runway 27L for the second approach, but this option was ruled out in view of the improved weather conditions.

He stated that he had been surprised that a new MSAW alert was triggered on the second approach of NSZ4311. However, this time the clouds had begun to dissipate and the crew were able to finish with a visual approach.

At the end of the shift he completed an occurrence notification form about the triggering of the MSAW. He indicated that he had discussed the serious incident with two other controllers present in the tower when the MSAW was triggered. He recalled that all three had doubts about the seriousness of the incident: it had seemed to them that the aeroplane was low when they had seen it perform the go-around, without being certain of this.

After the occurrence

On the subject of RNP approaches, he believed that there is an accumulation of difficulties, namely:

- interception at a specific altitude, which complicates the task for the ITM;
- higher decision height;
- the importance of the QNH.

He indicated that the controllers were regularly reminded of these points during periodic briefings and that the Control subdivision had placed a great deal of emphasis on these aspects and the associated risks. He added that the subject of RNPs had been dealt with on several occasions and that the Control subdivision had ensured that all the controllers attended briefing sessions and had access to the relevant information. He indicated, however, that these points remained very theoretical, that "it had never happened to us" before and that it was difficult to realise the real importance of the QNH without an event to tie it to.

Asked about the pilot's incorrect read-back of the QNH during the go-around even though he had provided the correct QNH, he declared that he had not heard it. He explained that the standard phraseology for these situations was "heading-altitude-QNH" and that in the TWR position, it was very common to shorten the go-around to save time, which is what he did in this case where there was no conflicting traffic.

In the TWR position, altimeter setting information is almost never provided except in the case of go-arounds with an altitude clearance. He indicated, however, that the pilots of some operators, such as easyJet, usually asked for confirmation of the QNH when conducting RNP approaches. He added that these requests surprised controllers used to ILS approaches, but that they now made sense in the light of this incident.

Concerning the detection of an inconsistency between the altitude displayed on the radar screen and the expected flight path when the MSAW was triggered, he indicated that in this situation he did not have the time to calculate the relevant elements or to have them confirmed. In fact, the "Alt" button has to be pressed to display the QNH altitude (see paragraph 1.10.3.2), which he considered to be too time-consuming in practice.

He added that it was not easy to remember whether there was any particular phraseology to be used in the event of a MSAW alert, due to the rarity of this type of occurrence at CDG and not being used to it. He only remembered the terms "*ground proximity*" taught in initial instruction and had no recollection of having seen the subject of MSAW in subsequent training. Lastly, he indicated that in the approach room, MSAW alerts in most cases, do not concern the CDG unit, and that in the case of NSZ4311, in the control tower, the team members had immediately realised that it involved an aeroplane in contact with them.

1.5.2.4 N TWR assistant controller for first approach and N TWR controller for second approach

Licence, rating, training and checks

Age, nationality	Aged 29, French
Valid ratings and endorsements	ADI/(GMS, TWR, RAD), APS
Unit endorsement	LFPG/ZZ
Endorsement expiry date	15 August 2024
Other endorsements and expiry dates	OJTI/STDI valid until 15 August 2024, assessor valid until 24 November 2024
English language endorsement and expiry date	ICAO level 4 valid until 1 November 2022
Last refresher training	FSAU/TWR course on 13 January 2022, FSAU/APP and PPS courses attended in 2018 - 2021 period
Medical fitness certificate	Valid

Experience

The controller in the N TWR assistant position at the time of the serious incident had been appointed to Paris-Charles de Gaulle in 2015 on completing his initial training. He had become a qualified controller in 2018 and instructor in 2019. He obtained his assessor rating in 2021.

Activity and duty periods prior to the serious incident

The N TWR assistant controller had been off duty the three days preceding the day of the serious incident. His duty period began at 07:30 and he started in the PRE-FLIGHT position before changing to the N TWR assistant position at around 11:00.

Statement

The controller indicated that although the workload was heavy on the GND and PRE-FLIGHT frequencies, traffic was light on the TWR frequency. He added that the weather conditions were not a problem until about ten minutes before the serious incident, when a cloud mass arrived from the east. This severely hampered the controllers' sight of the aeroplanes on final. However, he indicated that the unit had not switched to Low Visibility Procedures (LVP), as the deterioration was very localised and conditions at the airport as a whole were still favourable.

He stated that, during the serious incident, it was the MSAW alert that drew his attention. He declared that in his opinion, the procedure in the event of a MSAW alert was to report the alert to the crew and ask them if they had sight of the ground. He specified that if the aeroplane was not being radar vectored, the recommended phraseology was "*Check your altitude*".

The N TWR assistant controller reported that after hearing the MSAW alert, he tried to get sight of the aeroplane, without success, while the N TWR controller was communicating with the crew. The crew then replied that they were going around. He remembered seeing the aeroplane then exit the clouds in climb before the threshold of the runway at what he considered to be a very low height.

The N TWR assistant controller then coordinated the missed approach procedure with the DEP coordinator controller for a standard downwind leg at 5,000 ft and passed the information to the N TWR controller who gave the crew a northerly heading and an altitude clearance of 5,000 ft. Once these actions had been completed, the N TWR assistant controller suggested to the N TWR controller that he relieve him, which he considered to be standard procedure for this type of situation.

The controller added that at one point during the sequence, he received a call from the S TWR assistant controller informing him that his team had forgotten to switch on the approach lights for their parallel runways and had also noticed that the approach lights for the north parallel runways were not switched on either. He remembered passing this information on to the N TWR controller, which seemed to unsettle him and perhaps contributed to him agreeing to be relieved. Immediately afterwards, the approach lights were switched on. Shortly after the go-around, the N-TWR assistant controller moved to the N TWR position.

On the second approach and following the triggering of the MSAW, he remembered informing the crew that the ground proximity warning had been triggered and asking them if everything was OK. The crew replied that they had sight of the ground and the controller then cleared them for landing.

The controller also indicated that he had seen the aeroplane emerge from the cloud layer in level flight, during the radio exchanges, at a height he considered too low. He then observed the aeroplane intercept the vertical approach path and land without incident.

After the occurrence

The controller indicated that after the serious incident and before reading the report produced by the Environment and Safety Service Quality subdivision concerning the serious incident, he had not suspected that a controller error in the transmission of the QNH could have been the cause.

He also declared that he was surprised that the read-back error had not been picked up during the go-around. He thought it was possible that this had occurred when he was relieving the TWR controller and the latter was disconnecting his audio equipment and he was connecting his own. He thought that it was possible that the similarity in sound between the call sign and the QNH may have played a role in the read-back error.

Asked about RNP approaches at CDG, he replied that because the ILS for runway 27R had been out of service for several days, controllers were only offering RNP approaches to this runway. He added that they were used to this type of approach and that the procedures and associated phraseology were mastered. However, he felt "less composed" than for ILS approaches. He felt that, although there had been a volume of training on RNP procedures which he described as large, some aspects were more problematic. He gave as an example, the importance of the QNH. He observed that he had not grasped to what extent it was important before the serious incident, or the need for controllers to ensure that the vertical approach path is intercepted at the correct altitude. He added that altimeter setting information was generally only provided by the TWR controller at the explicit request of the crew or in the event of a go-around.

Concerning the detection of an inconsistency between the altitude displayed on the radar screen and the expected flight path when the MSAW is triggered, he indicated that, in his opinion, even if the "Alt" button for displaying the QNH altitude was pressed, calculations would be necessary and that, given the approximations, it would be difficult to determine whether or not the aeroplane was on the published flight path.

On the subject of the MSAW, he said that the CDG controllers were not used to this alert being triggered for aeroplanes which were on the frequency with them. He stated that he had not been briefed on this point, although he recalled the existence of an associated procedure in the OM. However, he added that the OM contained a large number of procedures.

1.6 Aircraft information

1.6.1 General Information

Manufacturer	Airbus
Type	A320-214
Serial number	1087
Registration	9H-EMU
Delivery date	19 October 1999
Operator	Airhub Airlines
Engines	CFM56-5B

The aeroplane was within the weight and balance envelope specified in the flight manual. During the first approach, the weight was around 63 T, with a centre of gravity at around 28% of the mean aerodynamic chord.

There were no specific items recorded in the aeroplane's Technical Log Book (TLB) or equipment included in the Minimum Equipment List (MEL) that could have had an impact on the serious incident.

The aeroplane was not equipped to carry out an RNP APCH operation down to LPV minima, an operation which uses Satellite-Based Augmentation System (SBAS) vertical guidance.
The aeroplane was not equipped with Digital-ATIS.

1.6.2 Altimetric system

1.6.2.1 General

A barometric altimeter measures the outside atmospheric pressure via static pressure ports located on the fuselage and compares it with the altimeter setting, a reference value defined by the crew. Based on the variation in pressure as a function of the altitude in an ICAO[12] standard atmosphere, the altimeter displays one of the following parameters to the pilot, depending on the altimeter setting:

- the flight level, using an arbitrary pressure reference set to 1013.25 hPa (or 29.92 inches of mercury), also known as the "Standard/STD" value. The flight level is used by all aircraft above the transition level to provide them with the same reference to avoid mid-air collisions;

[12] International Civil Aviation Organisation.

- the Altitude above Mean Sea Level (AMSL), based on the atmospheric pressure value at the aerodrome's altitude, corrected to correspond to the mean sea level. This is the QNH;
- the height above ground, using the atmospheric pressure value at the aerodrome's altitude. This is the QFE.

1.6.2.2 Airbus A320 altimetric system

An Airbus A320 has three altimetric systems: one for the altitude on the captain's side, one for the altitude on the co-pilot's side and one for the standby system[13]. Each altimetric system uses two pressure measurement systems located on either side of the front fuselage.

The altimeter setting value for each Electronic Flight Instruments System (EFIS) on the captain's/co-pilot's side is set on the Flight Control Unit (FCU). For these two altimetric systems, the QNH setting is selected by pressing the barometric reference selector. The knob is used to choose the desired altimeter setting value. To switch to the standard setting, the selector must be pulled. It is also possible to select the barometric pressure unit (hPa or in Hg, the latter being for example the reference unit for altimeter settings in the United States).

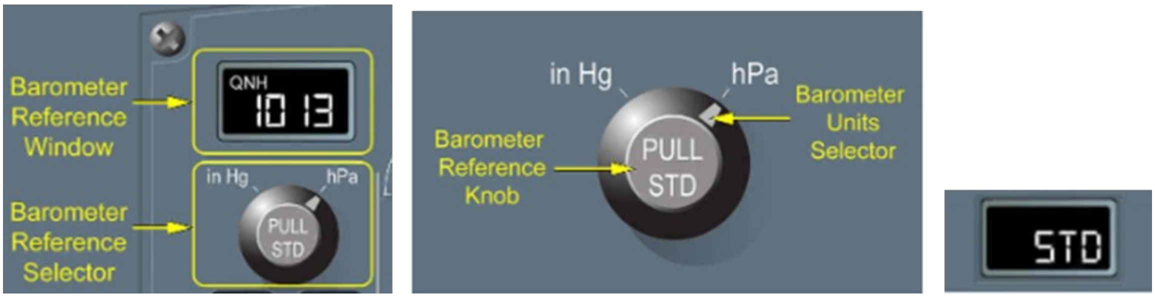

Figure 4: setting of the altimeter reference on the captain's FCU, with a QNH set at 1013 hPa (left) or at the standard value (right) (source: Airbus FCOM)

The barometric reference is displayed on the PFD below the altitude scale:

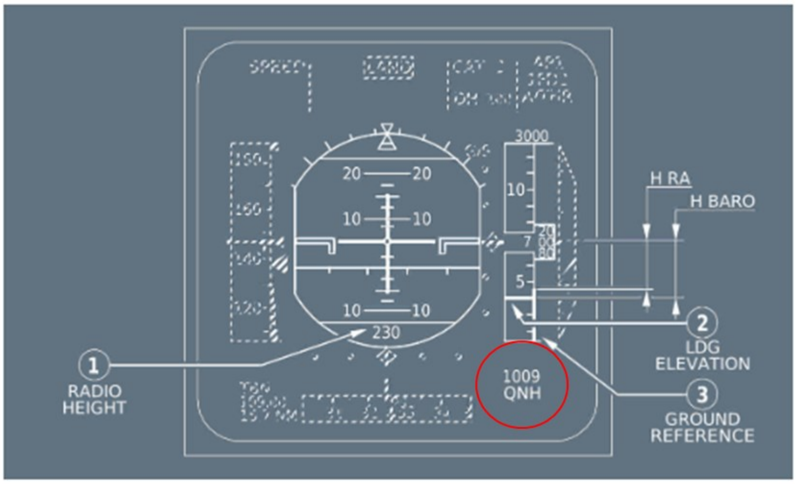

Figure 5: altimeter setting on the PFD (source: Airbus FCOM)

[13] Older A320s may have an altimeter rather than an altimetric system.

According to the Airbus Flight Crew Operating Manual (FCOM) and regardless of the type of approach, the altimeter reference must be set during descent when the aircraft is approaching the transition level and the crew is cleared to an altitude. This change of setting must be entered manually on the three altimetric systems and checked by the PF and PM.

On the Airbus A320, there is no QNH value preset function; the only option is to change the current value.

1.6.3 Radio-altimeter

The radio-altimeter is designed to measure the height above the ground or water surface. It is based on the radar principle. A transmitting antenna directs a wave towards the ground, where it is reflected and then received by the receiving antenna. By measuring the time between transmission and reception of the wave, the distance to the ground, i.e. the Radio-Altimeter (RA) height, can be calculated after the instrument has been calibrated.

The calculated values are displayed on the Primary Flight Displays (PFDs) below an RA height of 2,500 ft. The A320 has two separate radio-altimeters. The values measured by radio-altimeter No. 1 are displayed on PFD1 (captain) and those measured by radio-altimeter No. 2 appear on PFD2 (co-pilot).

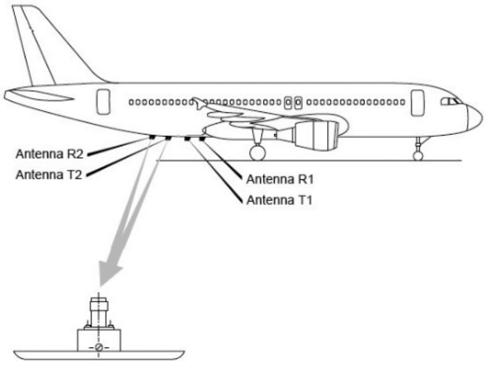

Figure 6: locations of the receiving (R) and transmitting (T) antennas of radio-altimeters 1 and 2 on an A320 (source: Airbus)

The radio-altimeter height values recorded in the 9H-EMU flight data and displayed on the PFDs were corrected by an increment of +5 ft, since the values recorded were -5 ft when the aeroplane was on the ground. This correction gives a value of 0 ft RA during the aeroplane's landing run. The minimum radio-altimeter height value recorded in the flight data during the near-collision with the ground was 1 ft before correction (6 ft after correction).

The "*summary for each phase*" section in the Airbus FCOM stipulates in particular that the crew must keep the radio-altimeter in their scan during the approach and landing. Apart from this point, no call out or specific criteria associated with monitoring the radio-altitude parameter are included in the LNAV/VNAV or LPV SOP.

1.6.3.1 Display of the height value measured by the radio-altimeter

Different data from the radio-altimeters is displayed on the PFD, which may give pilots an indication that the aeroplane is getting closer to the ground. These are secondary parameters designed to give the crew a better grasp of the situation in the context of CATII/CATIII operations which, with a DH below 200 ft, require visual acquisition of references close to the ground or runway.

The aeroplane's height above ground value is displayed at the bottom of the PFD attitude sphere, for an RA height less than or equal to 2,500 ft. The colour and size of the digits change according to the radio-altimeter (RA) height value:

- 400 ft < RA < 2,500 ft: digits in green
- RA ≤ 400 ft: slightly larger amber digits

The display of the digits also depends on the height:

- RA > 50 ft: 10 ft variations
- 50 ft ≥ RA ≥ 5 ft: 5 ft variations
- RA < 5 ft: 1 ft variations

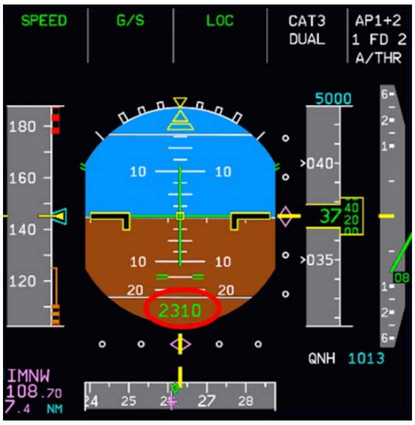

Figure 7: display of the radio-altimeter height value in the PFD, in this case 2,310 ft RA (source: Airbus)

1.6.3.2 Red ribbon on the altitude scale

When the aeroplane is at a RA height of less than 570 ft, a red ribbon appears at the bottom of the altitude scale, the length of which varies depending on the RA height.

When the aeroplane is on the ground, the top of this ribbon is at the centre of the altitude window. This ribbon is only based on the RA height and is not affected by the altimeter setting.

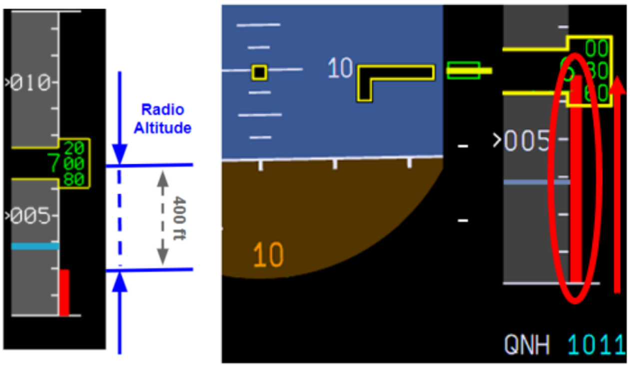

Figure 8: display of the PFD with a RA height of 400 ft (on the left), and when 9H-EMU was getting closer to the ground (on the right) with the incorrect QNH (source: Airbus)

1.6.3.3 Representation of the aerodrome's altitude on the altitude scale

The aerodrome's altitude is represented on the altitude scale by a blue line on older instrument models[14] (as is the case for 9H-EMU), or by a brown strip on more recent instrument models[15], which are prevalent in the current Airbus fleet.

If the altimeter setting is correct and the terrain is flat before the runway threshold, the blue line (or the top of the brown strip), representing the aerodrome's altitude, should align with the top of the radio-altimeter red ribbon during the final approach. On landing, these elements are at the same level as the altitude window on the altitude scale. When the terrain is flat before the runway, an incorrect altimeter setting will result in a positional inconsistency between these two elements, as shown in the figure below.

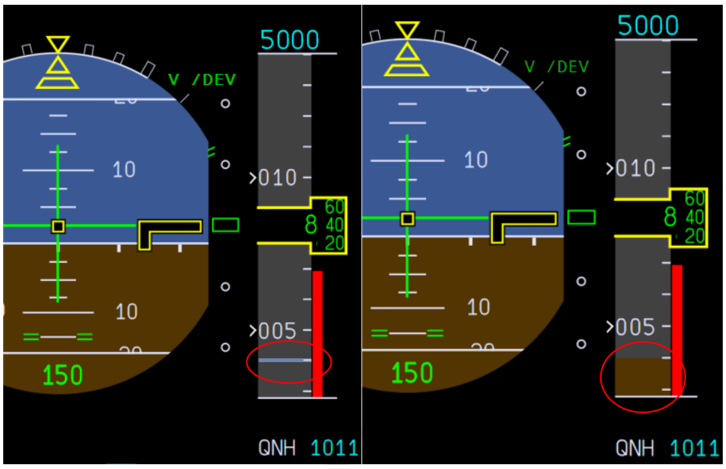

Figure 9: representation of the aerodrome's altitude with an incorrect QNH and flat terrain before the runway, according to the two Airbus EIS models (left: EIS1, as used on 9H-EMU; right: EIS2) (source: Airbus)

1.6.3.4 Representation of height on the PFD

Below 300 ft RA, the height is also given by the distance between the horizon line and the line above the radio-altimeter height value. This line moves upwards when the aeroplane is in the descent phase. As it moves upwards, the attitude graduation marks progressively disappear, until this line is superimposed on the horizon line, once the aeroplane is on the ground.

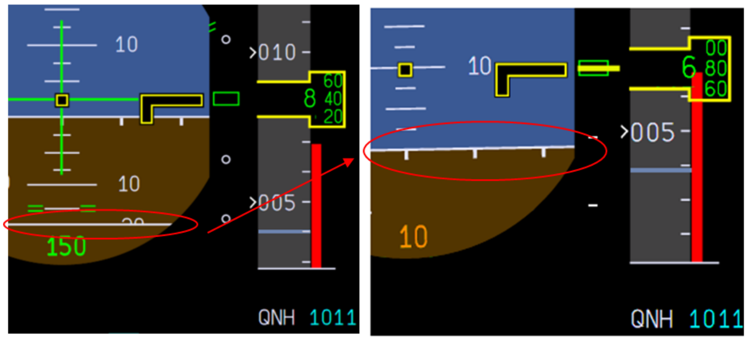

Figure 10: representation of the radio-altimeter height on the PFD of 9H-EMU (source: Airbus)

[14] *Electronic Instrument System* (EIS), which includes PFDs, NDs, E/WD and SD. Older models are known as EIS1.

[15] EIS2.

1.6.4 Auto-callouts

The purpose of the radio-altimeter height Auto-Callouts (ACO) is to ensure the flight crew's awareness of the proximity to the ground. Such callouts are triggered when the descending aircraft passes through certain pin-programmed heights above the terrain.

On the Airbus A320, the Flight Warning Computer (FWC) generates these synthetic-voice callouts using data from the radio-altimeters. These callouts are broadcast via the cockpit loudspeakers, even when the latter are switched off or when the crew are using headsets. The A320 includes 20 callouts which are fully programmable by the operator (except for the mandatory "FIVE HUNDRED" callout). The following callouts were implemented on 9H-EMU:

Height (feet)	Call out
2 500	TWO THOUSAND FIVE HUNDRED OR TWENTY FIVE HUNDRED
1 000	ONE THOUSAND
500	FIVE HUNDRED
200	TWO HUNDRED
100	ONE HUNDRED
50	FIFTY
40	FORTY
30	THIRTY
20	TWENTY
10	TEN
DH (or MDA/MDH) + 100	HUNDRED ABOVE
DH (or MDA/MDH)	MINIMUM

Figure 11: programmed auto-callouts for 9H-EMU (source: Airhub Airlines)

The "HUNDRED ABOVE" and "MINIMUM" (barometric) callouts were activated on the FWC, but were not available during the serious incident (limitation related to non-precision approaches[16] with EIS1). In this case, the FCOM stipulates that the PM is responsible for making these callouts. The crew stated that they were aware that they had to make these two callouts, and the co-pilot (PM) stated that he made them.

The pilots of 9H-EMU indicated in their statements made to the BEA that they only heard the callouts at 2,500 ft RA and 1,000 ft RA and that they did not hear the other callouts, in particular those triggering as part of the "FIFTY, FORTY, THIRTY, TWENTY" sequence. According to them, if they had heard this sequence, they would have immediately realised the seriousness of the situation.

At the request of the BEA, the two FWC of 9H-EMU were removed to be tested on an Airbus test bench on 18 October 2022, in order to check the generation of the auto-callouts in a simulator, for a nominal approach and for the two approaches in the conditions of the serious incident. These three simulations were made for each FWC.

[16] According to this logic, Baro-VNAV approaches are classified as non-precision approaches as opposed to precision approaches.

During the simulations, all the programmed callouts were generated and the tests did not reveal any malfunction of the system[17].

However, it should be noted that during the serious incident playbacks in the development simulator, the pilots, who were "type-rated" on the aeroplane, did not necessarily remember or perceive all the callouts that were activated during the approach, even though the aim of the session was to check that these callouts were triggered.

1.6.5 Barometric approaches on the Airbus A320

1.6.5.1 Barometric vertical navigation

1.6.5.1.1 General information on Baro-VNAV and the consequences of an incorrect altimeter setting

Barometric vertical navigation (Baro-VNAV) is a function of the aeroplane's navigation system providing vertical guidance based on the barometric altitude. The Flight Management System (FMS) generates the descent profile based on the following parameters included in the navigation database:

- Missed Approach Point (MAPt);
- Flight Path Angle (FPA);
- Final Descent Point (FDP).

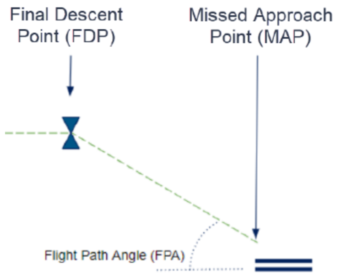

Figure 12: generation of the Baro-VNAV descent profile (source: Airbus)

Vertical guidance uses the differences between the indicated pressure altitude and the barometric altitude of the FMS descent profile to generate vertical deviations (V/DEV). However, by design, the same source of information (i.e. the barometric altitude) is used to both generate the descent profile and calculate vertical deviations from this profile.

For example, if an incorrect barometric altitude is used due to an incorrect altimeter setting, the aeroplane will follow a flight path that is parallel to but below/above the flight path designed and published to avoid terrain and obstacles. An incorrect altimeter setting, 10 hPa higher than the expected value (e.g. 1011 hPa instead of 1001 hPa) will mean that the aeroplane's actual altitude is around 280 ft below the published vertical profile, all along the path.

Lastly, whatever the type of approach operation, an incorrect altimeter setting will impact the altitude given to the pilots. When indicated to the crew, the Decision Altitude (DA) or the Minimum Decision Altitude (MDA) will therefore not correspond to the aeroplane's actual altitude.

[17] According to Airbus' analysis of the flight data, the "RETARD" callout was made during the event. However, the sampling and accuracy of the data made it impossible to determine whether the "TEN" callout was also made during this dynamic phase.

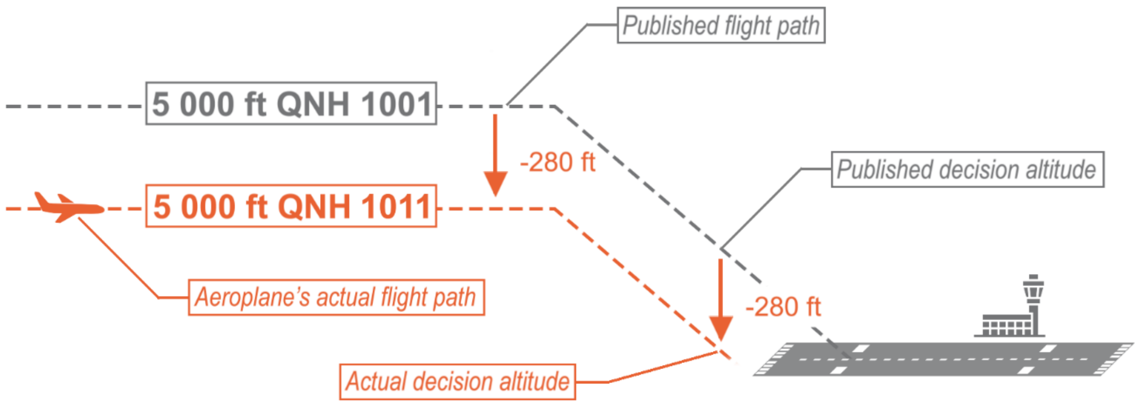

Figure 13: representation of an incorrect altimeter setting of 10 hPa (source: BEA)

The vertical guidance principle in Baro-VNAV cannot detect an incorrect altimeter setting, and the vertical deviations (V/DEV) indicator and flight director (FD) bars displayed on the PFD remain centred as long as the aeroplane is at the barometric altitude of the FMS descent profile.

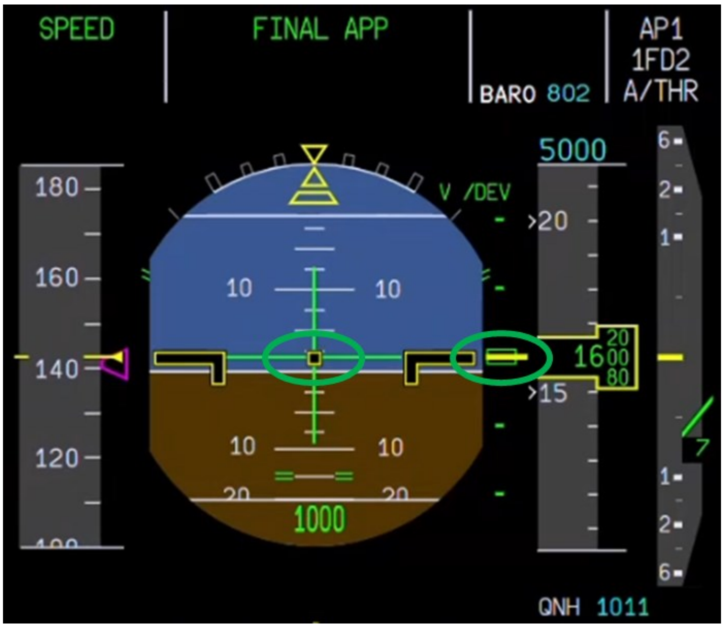

Figure 14: PFD simulation of the serious incident, with V/DEV and FD bars centred (source: Airbus)

Similarly, the altitude in relation to distance checks provided by the approach charts and required by the procedures (see paragraph 1.6.5.2) is ineffective to detect a QNH setting error shared by both altimeters during barometric approaches, since this incorrect altimeter setting information is used to both generate the descent profile and check the altitude.

Lastly, it should be noted that the descent profile generated from the Baro-VNAV function may be affected by temperature variations, and that satellite approaches may be subject to all types of disturbance affecting a Global Navigation Satellite System (GNSS) signal, such as jamming or spoofing[18].

[18] Jamming and spoofing for GNSS navigation are threats currently being intensively addressed by the aviation community. Although important, these subjects were not directly related to the event, and were therefore not analysed by the BEA as part of this investigation.

1.6.5.1.2 The different existing alerts

Several alerts are available to warn crews of inconsistencies in the altitude or altimeter setting:

- If there is a difference between the barometric altitude of the captain's and co-pilot's altimetric systems, an amber alert "NAV ALT DISCREPANCY" is triggered, associated with the message "CHECK ALT" displayed on the right side of the altitude scale;
- If there is a difference between the barometric reference used by the captain's and co-pilot's altimetric systems (STD vs QNH/QFE, or QNH vs QFE), an amber alert "NAV BARO REF DISCREPANCY" is triggered;
- If there is a difference between the altimeter setting value selected on the captain's and co-pilot's FCU control panels, an amber alert "NAV BARO VALUE DISAGREE" is triggered;
- Finally to compensate for an omission to change the reference, the "STD" or "QNH" message flashes on the PFD when STD is not selected above the transition altitude entered in the FMS, or when STD is still selected during the approach phase below the transition level.

However, there is no alert when:

- a same incorrect QNH is entered in both the captain/co-pilot altimetric systems, since the aeroplane does not know what the actual local QNH is;
- the QNH displayed on the PFD is different from that of the FMS or from the setting defined on the standby altimeter or on the ISIS (Integrated Standby Instrument System).

1.6.5.1.3 The different guidance modes available on the Airbus A320

Baro-VNAV approaches are available on all Airbus aeroplanes. On Airbus A320s (such as 9H-EMU) which are not equipped with the FMS Landing System (FLS) or SBAS Landing System (SLS) functions, the Baro-VNAV function is used in FINAL APP managed guidance mode. Here are the different managed guidance modes available depending on the type of approach operation (see paragraph 1.8.1 for the different types of approach operation):

APPROACH NAME	ILS	GLS	RNP		RNP AR	LOC only	VOR	NDB
	ILS	GBAS LS	RNAV(GNSS) RNAV(GPS) RNP APCH		RNAV(RNP) RNP(AR) RNP AR APCH	LOC	VOR DME	
			LNAV/VNAV	LNAV				
FMS selection	ILS14R-Z	GLS14R-Z	RNV14R-Z		RNV14R-Z RNP14R-Z (AR)	LOC14R-Z	VOR14R-Z	NDB14R-Z
APPROACH MODE ARMING	APPR	APPR	APPR	APPR	APPR	LOC	APPR	APPR
GUIDANCE MODE FMA	G/S | LOC	G/S | LOC	FINAL APP	FINAL APP	FINAL APP	FPA | LOC	FINAL APP	FINAL APP
PFD								
ND			0.2R	0.2R	0.08R		0.2R	0.2R
LATERAL SOURCE	LOC	GPS GBAS	FMS	FMS	FMS	LOC	FMS	FMS
VERTICAL SOURCE	G/S	GPS GBAS	Baro Alt	Baro Alt	Baro Alt	Baro Alt	Baro Alt	Baro Alt
TEMPERATURE compensation for Final leg guidance	Not needed (Geometrical beam)	Not needed (not baro sensitive)	Not Compensated	Not Compensated	Not Compensated	Not Compensated	Not Compensated	Not Compensated
Recommended mode	★	★	★	★	★	★	★	★

Figure 15: the different managed guidance modes depending on the type of approach on Airbus A320s without the FLS or SLS functions (source: Airbuswin)

The Airbus terminology for RNP APCH down to LNAV/VNAV minima is: "RNAV(GNSS) down to LNAV/VNAV minima". Approaches carried out in FINAL APP mode are performed using the Continuous Descent Final Approach (CDFA) technique. For the FINAL APP mode and as shown in the figure above:

- lateral guidance is provided by the FMS system. During an RNP APCH approach, lateral guidance is based on a satellite source;
- vertical guidance uses the Baro-VNAV function. The altimeter setting value (QNH) used by the crew will thus determine the descent profile and associated guidance. The temperature is not compensated by the system. The QNH and temperature must therefore be known by the pilots.

1.6.5.2 Approach operation in FINAL APP guidance mode

The Standard Operating Procedure (SOP) is available in Appendix 1 of this report.

During flight preparation, the GPS PRIMARY mode's availability must be ensured. When preparing for descent, the crew must check that the temperature at the airport is higher than the minimum temperature authorised for the type of approach, and obtain the airport's QNH information. Using a QNH from a remote station is prohibited for an RNAV(GNSS) approach down to LNAV/VNAV minima. The PERF APP page of the FMS is completed by the PF and cross-checked by the PM. The approach operation is selected on the ARRIVAL page of the FMS.

During the descent, the altimeters are set by switching from the standard setting to the QNH setting, and the maximum permitted discrepancy between altimeters is 100 ft. There is no requirement to confirm the altimeter setting with another information source.

If the flight plan is valid (lateral and vertical profile) and the selected approach is compatible with the FINAL APP mode, when the crew press the APPR push-button on the Flight Control Unit (FCU), the APP NAV (lateral) and FINAL (vertical) modes are activated. When the vertical profile is intercepted, the APP NAV and FINAL modes merge into the FINAL APP mode. Energy and configuration management is identical to that of an ILS approach.

From the Final Approach Fix (FAF), which in most cases at Airbus corresponds to the Final Descent Point (FDP), the PM must check the distances in relation to the altitudes as published on the approach chart. They must also announce excessive deviations:
- X-TRK (horizontal deviations) greater than 0.1 NM;
- V/DEV (vertical deviations) greater than ½ point.

When approaching the minima, the ONE HUNDRED ABOVE callout must be monitored (in the case of an auto-callout) or called out by the PM 100 ft above the minima. Once the minima have been reached, the MINIMUM callout must be monitored (in the case of an auto-callout) or called out by the PM.

At the minima, if the visual references are sufficient, the approach is continued. If visual references are not acquired, a go-around must be carried out.

In the event of a reduction in navigation performance on final approach, a procedure is provided and must be briefed when preparing for the descent.

To summarise, as applicable to 9H-EMU at the time of the event:
- The SOP do not mention the CFIT risk (QNH entered in the EFIS higher than the actual QNH) or the risk of a non-stabilised approach (QNH entered in the EFIS lower than the actual QNH) in the event of an incorrect QNH setting on all the aeroplane's altimeters).
- The SOP do not ask for the QNH value to be preset in anticipation on the EFIS (this cannot be done directly on the system) before the descent, once the crew have obtained the ATIS information and when the altimeter setting is still set to the standard value.
- When the aeroplane is approaching the transition level, or the crew are cleared to a lower altitude by the air traffic controller, the QNH must be displayed on the EFIS control panel and on the standby altimeter. The QNH values must be compared with each other, as must the altitudes.

- The SOP do not require the QNH value provided by the air traffic controller on approach to be compared with other available sources (METAR, ATIS, QNH entered in the FMS, etc.)
- The SOP require regular checks of the distances in relation to the altitudes, as published on the approach chart. These checks do not allow the crew to detect an incorrect altimeter setting.

1.6.6 Procedures and instruments for other aeroplane types and operators

The Airbus SOP applicable to the entire Airbus fleet, as well as the Boeing SOP applicable to the Boeing fleet of 737, 747, 757, 767, 777 and 787, are similar to those applicable to the A320. In particular, at the time of the incident, there were no requirements for confirming the altimeter setting with another information source so as to prevent the use of an incorrect altimeter setting. Similarly, the instruments and systems available to the crew do not allow the crew to directly detect that all the altimeters have the same incorrect altimeter setting except when aeroplanes are equipped with an ALTSM or CAM-BTA system (see paragraph 1.18.3.1).

The reading of the manuals of other manufacturers such as Embraer, Bombardier and ATR did not reveal any marked differences regarding the aforementioned topics.

However, it should be noted that some air operators explicitly require that their crews, when switching from the standard altimeter setting to the QNH setting, validate the QNH value communicated by the ATC using another information source (ATIS, METAR, flight file, ACARS, etc.)

On the A350 and A380, as well as on part of the Boeing fleet, the altimetric systems include a QNH standby preset function. The SOP of these fleets require a standby preselection of the QNH when preparing for the approach. Airbus indicated during the investigation that this QNH preset procedure is not a requirement on the A320, A330 and A340 fleets, because the instruments are not designed for it, and because the operation would require modifying the current altimeter setting value and could also generate in some situations, alerts and altitude deviations.

Some air operators have also established specific procedures in the event of a MSAW/terrain/low altitude alert being transmitted by air traffic controllers to the crew when the latter have no external visual references. These procedures may require the PULL UP operation to be applied, for example.

1.6.7 Terrain Awareness and Warning System (TAWS)

1.6.7.1 System description

The Terrain Awareness and Warning System (TAWS) is an on-board system designed to warn the crew of a risk of the aircraft colliding with the ground. 9H-EMU was equipped with a Honeywell MARK V Enhanced Ground Proximity Warning System (EGPWS) type TAWS.

The EGPWS comprises the following:

- The GPWS five basic protection modes, which are reactive functions mainly based on the aeroplane's radio-altimeters:
    1. Excessive rate of descent.
    2. Excessive closure to terrain rate.
    3. Negative climb rate or altitude loss after take-off.
    4. Flight into terrain when not in landing configuration.

5. Excessive deviation below the precision approach slope for ILS, MLS, GLS[19] and RNP APCH down to LPV minima, with the "GLIDE SLOPE" callout. This function does not therefore work for Baro-VNAV approaches.

- Several other enhanced functions (Enhanced GPWS), which also use a database of terrain and obstacles in addition to the aeroplane's parameters, and which provide a number of predictive functions, such as:
  - Forward Looking Terrain Avoidance (FLTA);
  - Premature Descent Alert (PDA), which is included in the Terrain Clearance Floor (TCF) function on Honeywell systems.

Given the aeroplane's nominal vertical speed and landing configuration, none of the TAWS five basic modes would have triggered an alert during the serious incident. In the circumstances of this serious incident, the function likely to trigger an alert was the PDA's TCF function.

Honeywell's TCF function calculates a terrain clearance envelope around the airport runway and triggers an alert if the terrain clearance is not sufficient, even when the aeroplane is in landing configuration. It also protects against an attempted landing where there is no aerodrome.

The TCF function uses the aircraft position parameters, the aeroplane parameters (in particular speed, altitude, descent rate and RA height), as well as the landing runway's position (extracted from the database) and the obstacle database. If the aircraft enters the protection envelope, the following alerts are triggered:

- "TOO LOW TERRAIN" voice alert. If the aircraft continues to descend, a voice alert is triggered every time the height above ground drops by 20%.
- Visual alert on the instrument panel, by means of an indicator light.

The TCF envelope includes an inhibition zone around the aerodrome to prevent false alarms. This zone depends on the EGPWS software version and the incoming data, in particular the aeroplane's position source.

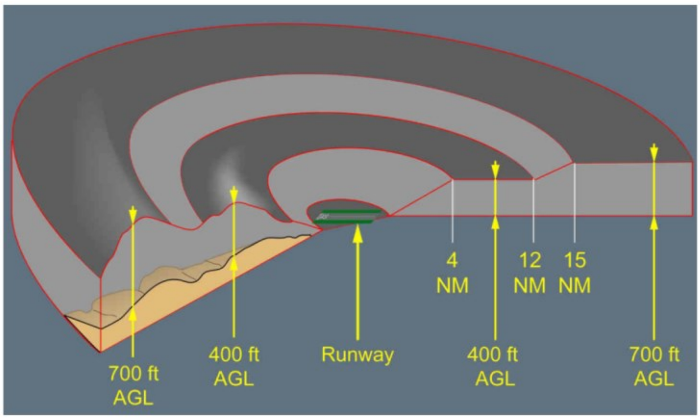

Figure 16: descriptive diagram of TCF mode (source: Airbus FCOM)

[19] Instrument-based Landing System, Microwave Landing System, GBAS Landing System.

The TCF "TOO LOW TERRAIN" message is a "caution" alert and not a "warning" alert like the "TERRAIN AHEAD, PULL UP" type alerts. The Airbus philosophy regarding operating procedures in the event of a TAWS caution or warning alert may be summarised as follows:

- in the event of a "warning" alert, the crew is asked to perform an emergency manoeuvre (full nose-up input and full thrust);
- in the event of a "caution" alert, which is the case of the "TOO LOW TERRAIN" alert:
  - at night or in IMC, the crew is asked to perform an emergency manoeuvre (full nose-up input and full thrust);
  - the flight path must be adjusted if the alert triggers in daytime and in VMC, with the terrain and obstacles clearly visible;
- TAWS operations are Memory Items that the crew must know by heart.

1.6.7.2 9H-EMU EGPWS test

Honeywell conducted the EGPWS examination on 16 September 2022 under the supervision of a Federal Aviation Administration (FAA) representative. The examination and downloading of the EGPWS data from 9H-EMU did not reveal any alert activation or system failures during the serious incident. The system operated in accordance with the specifications. The EGPWS used the FMS position data and was not wired to use the GNSS position data.

The EGPWS P/N was 965-0976-003**-206-206**. The first ten digits correspond to the hardware, the next three (-206) are the operating software version, and the last three (-206) are the configuration software version. The operating software includes in particular the version of the terrain database and detection envelopes. As for the configuration software, it includes the version of the aeroplane interface files. Version -206-206 dated back to 1998. In subsequent versions, Honeywell allocated dedicated P/Ns for each aircraft manufacturer.

The TCF detection envelope depends on the quality of the positioning data. In the circumstances of the serious incident, Honeywell estimated, using a FMS positioning source without Nav mode, that the TCF envelope ended 1.9 NM from the threshold. During the serious incident, the EGPWS did not trigger an alert because the aircraft was outside the TCF envelope, in the inhibition zone. An error of 23 hPa, bringing the vertical profile 650 ft below the published vertical profile, would have been necessary for an alert to be triggered in the circumstances of the serious incident, with the EGPWS TCF envelope of 9H-EMU.

Honeywell carried out simulations to determine whether EGPWS versions subsequent to that involved in the serious incident would have triggered alerts. The TCF envelope was improved in 2003 with version -218-218 (equivalent to P/N 965-1676-002 on Airbus aeroplanes), which reduced in particular, the inhibition zone around the aerodrome. On versions -218-218 and later, using GNSS positioning, Honeywell estimated that a "TOO LOW TERRAIN" alert would have been triggered at 200 ft RA, 617 ft QNH 1001, at 11:41:35, i.e. 15 seconds before the "6 ft" callout. The alert would have been triggered 1.4 NM from the runway threshold.

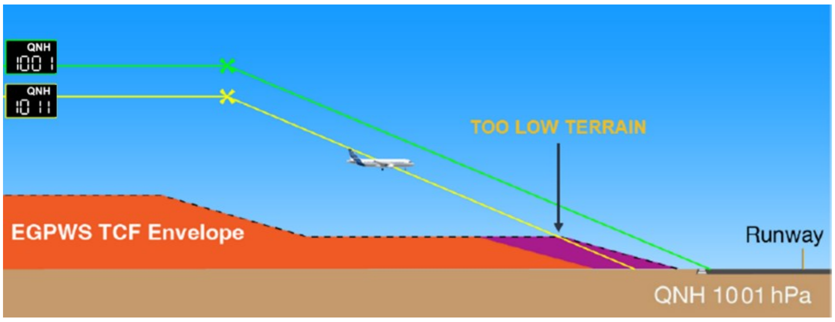

Figure 17: diagram of the aeroplane's path and the more protective TCF envelope (purple area) with an EGPWS using version -218-218 or later and GNSS positioning
(source: Airbus)

1.6.7.3 Regulatory requirements

Applicable specifications

As regards equipment carrying, ICAO Annex 6, paragraph 6.15.1, requires the following: "*All turbine-engined aeroplanes of a maximum certificated take-off mass in excess of 5 700 kg or authorized to carry more than nine passengers shall be equipped with a ground proximity warning system.*"

In Europe, the provisions of amended Regulation (EU) No 965/2012 (known as "AIR OPS"), regarding commercial air transport, require as per CAT.IDE.A.150 Terrain awareness warning system (TAWS) that, "*Turbine-powered aeroplanes having an MCTOM* [maximum certified take-off mass] *of more than 5700 kg or an MOPSC* [maximum operational passenger seating configuration] *of more than nine shall be equipped with a TAWS that meets the requirements for Class A equipment*[20] *as specified in an acceptable standard.*" The associated guide indicates that the European Technical Standards Order (ETSO) can be used as an appropriate standard.

With respect to the certification of TAWS equipment in Europe, two Certification Specifications have additional requirements:

- the CS-ACNS (defining certification requirements related to air operations at aircraft level) sets out, through CS ACNS.E.TAWS.005, that the class A TAWS equipment can be approved in accordance with standard ETSO-C151b,
- the CS-ETSO (defining certification standards at equipment level) sets out, through standard ETSO-C151, the requirements applicable to TAWS intended for installation in fixed-wing aircraft.

From 25 July 2020 onwards, the newly designed and manufactured TAWS (for which the equipment manufacturer applies for an ETSO approval/authorisation) shall comply with EASA standard ETSO-C151d, equivalent to FAA standard TSO-C151d, referring almost exclusively to RTCA document DO-367, dated 31 May 2017. However, TSO standard 'C151d' specifies that the Authorisations granted for the TAWS designed and manufactured in accordance with previous standards are still valid.

[20] Class B TAWS are intended for certain types of piston engine aeroplanes, while Class C TAWS are intended for general aviation aircraft.

Thus, operationally in commercial air transport, there is no requirement to update TAWS designed and manufactured in accordance with previous ETSO/TSO standards (ETSO-C151b being the minimum standard), and consequently, standard RTCA DO-367 does not apply to the TAWS equipping the A320 registered 9H-EMU[21] at the date of publication of this report.

Latest TAWS specifications: RTCA DO-367

In paragraph 2.2.1.1.7.2.1 regarding caution alert criteria, RTCA DO-367 requires Class A TAWS to provide PDA cautions in less than 1.3 seconds, based on a height/distance volume at the runway threshold as defined in the following diagram. This protection volume is the result of a compromise between several TAWS manufacturers.

TAWS manufacturers must test the activation conditions of their product and that it complies with the PDA alert activation height based on speed (descent rate and ground speed) and distance criteria in relation to the runway threshold. The tests must be carried out at different ground speeds, different descent rates and different distances from the runway threshold.

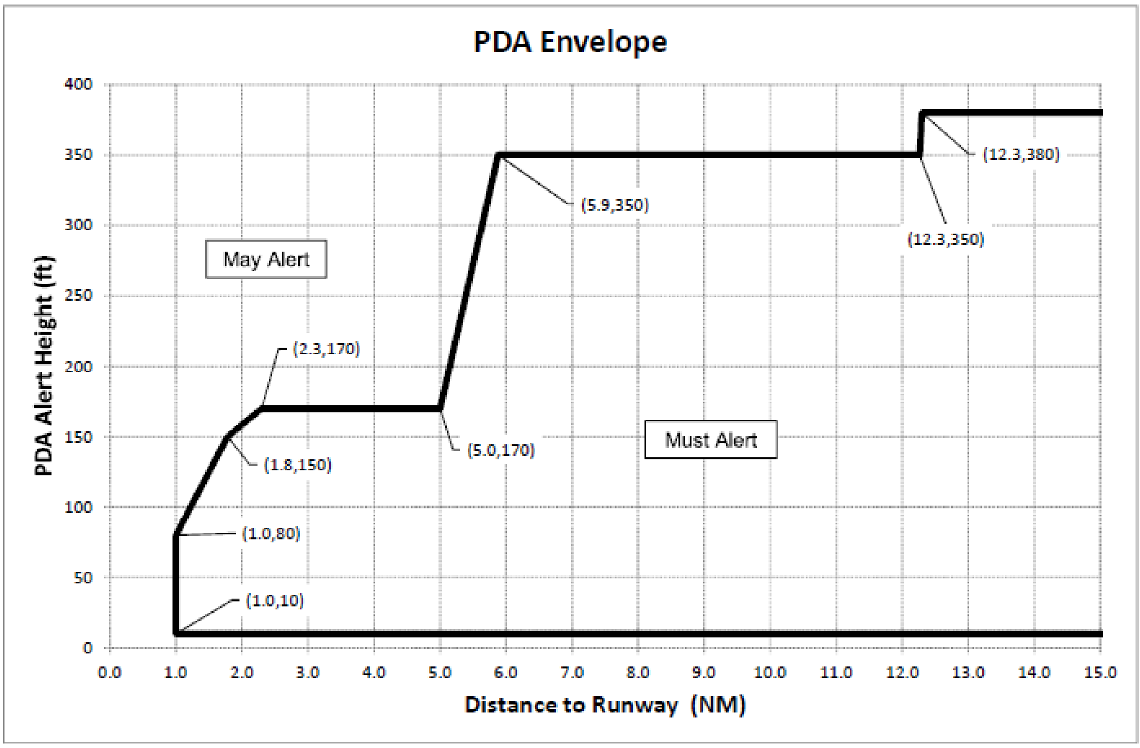

Figure 18: PDA envelope (source: RTCA DO-367)

The following diagram shows the positions of the different detection envelopes:

- "Must alert" PDA envelope according to RTCA DO-367 (in red)
- Honeywell TCF envelope (in light blue for version -206-206 equipping 9H-EMU and in dark blue for -218-218)
- standard 3° vertical profile (in green)
- As well as a 3° vertical profile approximately 280 ft below the published vertical profile, associated with an incorrect altimeter setting of 10 hPa (in grey).

[21] Given the provisions of TSO-C151d paragraph 2.b., and the actual ETSO/TSO Authorisation granted to the TAWS equipping the A320 registered 9H-EMU, the aircraft configuration complies with regulations CS-ETSO/CS-ACNS/CAT.IDE.A.150 and satisfies at least the ETSO-C151b requirements for Class A equipment.

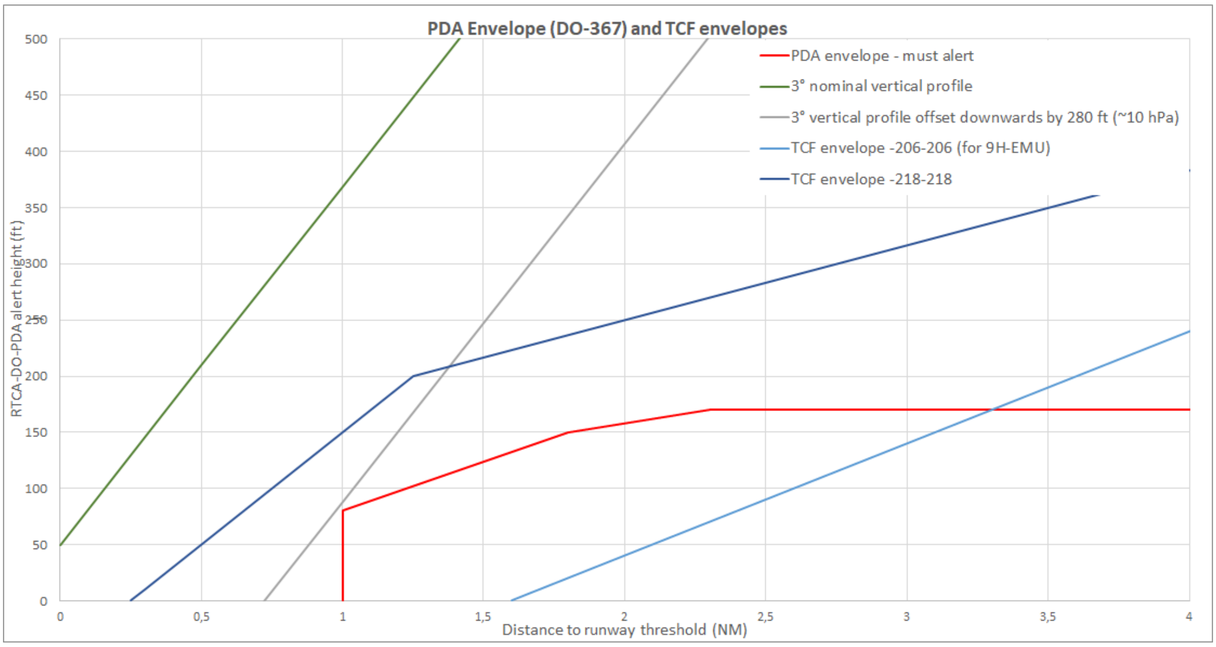

Figure 19: comparison of the PDA envelopes with a 3° approach slope approximately 280 ft below the published vertical profile (source: BEA)

Firstly it can be seen that the TCF envelope of an EGPWS using software version -206-206 without GNSS positioning, such as the one equipping 9H-EMU, is much less restrictive than the envelope of standard RTCA DO-367 applicable almost 20 years later.

It can also be seen that the 3° slope, approximately 280 ft below the published vertical profile and associated with an incorrect altimeter setting of 10 hPa, does not fall into the "*must alert*" PDA envelope of the current standard RTCA DO-367. Therefore, for all TAWS of aeroplanes designed and produced today, there is no requirement for a PDA alert to be triggered in conditions similar to those of the serious incident involving 9H-EMU.

However, it can be observed that Honeywell's TCF envelope with software version -218-218 or later is safer than the standard's minimum requirements and therefore provides an alert at around 200 ft above ground in such circumstances.

1.6.7.4 Status of Airbus and Boeing fleets with regard to carrying TAWS

1.6.7.4.1 Airbus

Airbus uses two TAWS suppliers: Honeywell (historically) and ACSS[22] (more recently).

ACSS

As part of the investigation, the BEA contacted ACSS to ask them to carry out approach simulations in circumstances similar to those of the incident and with the same hypotheses as for the simulations carried out by Honeywell (see paragraph 1.6.7.2).

The simulation results showed that all the ACSS standards triggered alerts under the conditions of the serious incident. In these simulations, the PDA alerts were triggered more than 20 s before the lowest point at 6 ft RA, i.e. at a distance of more than 1.6 NM from the runway threshold and at a height above 270 ft RA.

[22] Joint venture between L3Harris Technologies and Thales.

It should also be noted that several FLTA "TERRAIN AHEAD" caution alerts and then FLTA "TERRAIN AHEAD PULL UP" warning alerts were triggered in the last 15 s before the lowest point.

It can therefore be considered that no Airbus aeroplane equipped with an ACSS TAWS is impacted by the absence of a PDA alert in circumstances similar to those of the serious incident.

Honeywell
Airbus estimated that approximately 600 aeroplanes still in service (around 500 A320s and around 100 A330s/A340s) could currently be equipped with a Honeywell EGPWS using a software version earlier than -218-218, which will not trigger a TAWS alert in the circumstances of the serious incident. It is difficult for aircraft and TAWS manufacturers to estimate the number of aeroplanes concerned because operators do not systematically inform them of changes made to their aeroplanes, and they may also make modifications covered by a supplemental type certificate (STC).

It should be noted that between 2004 and 2010, Airbus[23] and Honeywell[24] conducted a communication campaign by means of non-mandatory Service Information Letters (SIL), which encouraged operators to upgrade their TAWS to more recent standards, and to retrofit their aeroplanes so that the GNSS information becomes the source for positioning data. No retrofit operation was conducted on 9H-EMU.

Today, in concrete terms, these SIL are no longer really applicable due to compatibility reasons and the technological jump between the older generation equipment concerned by the issue raised by this serious incident and the equipment currently produced. Today, aeroplanes can only be modified on a case-by-case basis, according to the level of equipment installed on board. For example, retrofitting 9H-EMU to a currently available standard which would trigger a TAWS alert in the circumstances of the serious incident would require an investment entailing a significant cost for an operator. Indeed, such an operation would involve updating the TAWS software, changing the hardware (MMR, ADIRU), modifying the FWC pin-programming and modifying the wiring.

1.6.7.4.2 Boeing

Boeing was also consulted during the investigation to determine the approximate number of aeroplanes impacted by the TAWS issue raised by this serious incident. The aircraft manufacturer was faced with the same difficulties as Airbus in providing a number, due to the fact that operators are not required to inform them about the changes made to their aeroplanes, and that they can also be subject to STC. However, Boeing estimated that, based on the information at its disposal, around 1,000 aeroplanes in service could be equipped with a Honeywell EGPWS using a software version earlier than -218-218, which would not trigger a TAWS alert in the circumstances of the serious incident. Retrofit difficulties similar to those mentioned with respect to the Airbus fleet in the previous paragraph may also be encountered.

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[23] Service Information Letter (SIL) No 34-080.
[24] SIL D201504000056 in addition to the FAA [Special Airworthiness Information Bulletin (SAIB) NM-15-11] following the fatal accident to the Airbus A300 registered N155UP and operated by UPS Airlines on 14 August 2013 at Birmingham Airport (Alabama, USA).

1.6.7.5 Summary regarding TAWS

- The aeroplane's EGPWS functioned in accordance with its specifications and did not trigger any caution or warning alerts during the serious incident.
- Subsequent software versions using GNSS positioning would have provided "TOO LOW TERRAIN" alerts at around 200 ft RA.
- The estimated number of Airbus and Boeing aeroplanes currently in service which use a TAWS standard equivalent to that of 9H-EMU (not triggering an alert in the circumstances of the serious incident) was approximately 1,600.
- Operationally, there is no mandatory requirement to update the TAWS standards of an aircraft used in commercial air transport. As a result, an older aircraft can currently still fly with the TAWS standard it had when it was manufactured.
- The current certification standards applicable to TAWS do not require any kind of ground proximity caution or warning alert to trigger in the conditions of the serious incident, i.e. a nominal vertical profile of 3° approximately 280 ft below the published vertical profile.

1.7 Meteorological information

1.7.1 Flight preparation information

The meteorological information available to the crew in flight file NSZ4311 dated 23 May 2022 regarding arrival at CDG was as follows:

Destination airport PARIS/CHARLES DE GAULLE RWY 08L 08R 09L 09R 26L 26R 27L 27R:
TAF 222300Z 2300/2406 06005KT CAVOK TX19/2310Z TN10/2405Z PROB30 TEMPO 2300/2308 4000 -TSRA SCT060CB BECMG 2306/2308 22010KT BKN012 **TEMPO 2309/2314 22015G25KT 2000 TSRA BKN008 BKN040CB BECMG** 2313/2315 28010KT BKN020 PROB40 TEMPO 2319/2323 25015G25KT 4000 SHRA BKN012 SCT012CB=

The TAF message issued on 22 May at 23:00 and valid for 23 May, forecast moderate to heavy rain showers with reduced visibility to 2,000 m, broken clouds at 800 ft and 4,000 ft and cumulonimbus clouds temporarily between 9:00 and 14:00.

1.7.2 Weather conditions at the time of the serious incident

General situation

At Paris-Charles de Gaulle airport, an unstable cold front was circulating in the morning and moved away at approximately 13:00-13:30, leaving behind a relatively inactive tail end of a depression. The south-westerly winds of the front were blowing in a west to north-west direction in the tail end zone. No lightning strikes were detected at CDG between 11:00 and 12:00, i.e. the period during which the serious incident occurred.

The METAR for CDG at 11:30 and 12:00 were as follows:

- *LFPG 231130Z 26008KT 9999 SCT016 BKN028 18/15 Q1001 RESHRA TEMPO 3500 SHRA SCT060CB*

At 11:30 UTC on 23 May at LFPG: wind direction 260°, wind speed 8 kt, visibility greater than 10 km, scattered clouds (SCT, 3 to 4 oktas) with a base at 1,600 ft AAL, broken clouds (BKN, 5 to 7 oktas) at 2,800 ft, temperature 18 °C, dew point temperature 15 °C, QNH 1001 hPa, recent rain showers, temporarily a visibility of 3,500 m, rain showers, scattered clouds at 6,000 ft with cumulonimbus (CB).

- *LFPG 231200Z 29010KT 5000 SHRA FEW010 BKN015 BKN028 FEW050CB 16/15 Q1001 TEMPO 3500 SHRA SCT060CB*

At 12:00 UTC on 23 May at LFPG: wind direction 290°, wind speed 10 kt, visibility 5,000 m, few clouds (FEW, 1 à 2 oktas) at 1,000 ft, broken clouds at 1,500 ft, broken clouds at 2,800 ft, few clouds at 5,000 ft with cumulonimbus, temperature 16 °C, dew point temperature 15 °C, QNH 1001 hPa, temporarily a visibility of 3,500 m, rain showers, scattered clouds at 6,000 ft with CB.

Precipitation radar images

Radar images can display areas of precipitation in real time, without providing any information about their nature or their liquid or solid state.

The radar images centred on CDG at 11:40 and 11:55, corresponding approximately to when the MSAW alerts were triggered during the two approaches made by 9H-EMU, show rain showers in the vicinity of CDG, with greater intensity during the first approach:

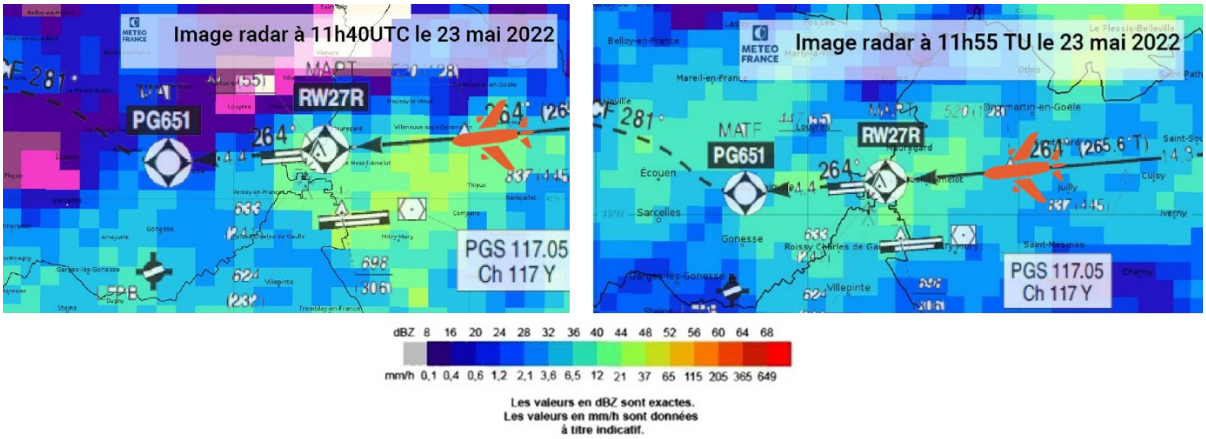

Figure 20: precipitation radar images at 11:40 and 11:55 (source: Météo-France)

Observations and measurements at CDG

Human observations made by the Météo-France agent during the two approaches were as follows:

Time (UTC)	Observed visibility (m)	Observed phenomena	Cloud cover
11:31	15,000	NTR	Overcast, CB
11:40	1,000	Shower	Overcast, CB
11:43	1,500	Shower	Overcast, CB
11:52	2,500	Shower	Overcast, CB
11:56	2,500	Shower	Overcast, CB
11:57	2,500	Shower	Overcast, CB

The measurements on runway 27R for both approaches indicated a Runway Visual Range (RVR) of more than 2,000 m.

All these measurements and human observations made by the Météo-France agent during the two approaches showed that the weather conditions at CDG deteriorated, with the onset of a rain shower and the associated decrease in visibility from 11:40, i.e. roughly coinciding with when the first approach ended and 9H-EMU got close to the ground.

A rain shower was still present during the second approach, although this was less intense than during the first approach, with an improvement in visibility.

1.7.3 QNH variations over a 30-minute period

Following the serious incident, the "Altimetry" working group set up by the DSAC (see paragraph 4.4), raised the question of the feasibility and relevance of installing an aeroplane system that would alert pilots in the event of a marked discrepancy between the QNH used when preparing for the approach, generally entered in the FMS, and the QNH value provided by air traffic control, which the pilots then enter in the altimeters to set the altitude on the aeroplane's systems.

In order to understand the natural variations in QNH and thus eventually establish an appropriate alert threshold, Météo-France conducted a detailed study on QNH variations over a 30-minute period, based on METAR message data. The English and French versions of this study are provided in Appendix 2.

In order to be as broad and comprehensive as possible, the database included all the METAR available worldwide for the year 2022, less the METAR that could not be used (coding or date issue, no QNH value or QNH value joined to the previous/next group, etc.). The study retained in total 38,877,820 METAR from approximately 3,700 airports throughout the world[25], representing 97.97% of the total METAR database for 2022.

The study showed that QNH variations over a 30-minute period are generally low, and that the QNH value is a very stable parameter:

- no QNH variation in 70.96% of cases;
- 0 or 1 hPa variation in 99.77% of cases;
- 0 to 2 hPa variation in 99.973% of cases;
- 0 to 3 hPa variation in 99.989% of cases;
- 0 to 4 hPa variation in 99.993% of cases.

With regard to marked QNH variations, i.e. variations greater than or equal to 5 hPa (representing approximately 2,700 METAR), the study showed that only 8% of these cases were due to a natural meteorological phenomenon, the remainder being explained by:

- a human error when transferring the QNH to the METAR, when the QNH was not automatically transferred (approximately half of the METAR in the database). In particular, digit transposition errors were highlighted, as well as peaks in the number of errors around values of 10 and 20 hPa;
- a ground pressure sensor failure.

In the event of a natural meteorological phenomenon, marked natural QNH variations over a 30-minute period can occur:

- when organised storm systems are present (mainly in the United States, but potentially anywhere in the world);
- when a cyclone is present (tropical zone, June to November in the Northern Hemisphere, November to May in the Southern Hemisphere);

[25] It should be noted that, given the distribution of these airports, this database tends to represent the climate in the mid-latitudes of the Northern Hemisphere.

- during winter storms (airports located at latitudes above 50°);
- in situations of strong winds over the terrain (mountain airports or airports close to mountainous areas).

The study also established that the natural meteorological variation in pressure never exceeded 11 hPa over a 30-minute period in 2022.

1.8 Aids to navigation

1.8.1 General information on the different types of IFR approach and their specific characteristics

1.8.1.1 History and context associated with the development of Baro-VNAV approaches

The development of landing aids began in the 1920s using radio aids providing lateral guidance only, with systems such as Non-Directional Beacons (NDB). It then expanded with Localizers (LOC) and VHF Omni-Range (VOR). These systems provided and continue to provide lateral guidance data for non-precision approaches. The descent slope (and therefore vertical profile) was managed by pilots using their barometric altimeter and by sight. The applicable minima for these approaches were relatively high.

At the same time, Instrument-based Landing Systems (ILS) developed, providing vertical guidance (Glide Slope) by means of a radio signal received from an antenna on the ground, in addition to the lateral guidance provided by the LOC. ILS systems thus created the concept of Precision Approach (PA), which is better suited to operations in adverse weather conditions, as opposed to the Non-Precision Approach (NPA), which does not provide vertical guidance. However, as ILS systems are expensive to buy and maintain, bulky and have numerous installation constraints, they were only installed on certain QFU at the largest airports.

Therefore, until the 1970s or thereabouts, the CFIT risk during non-precision approaches due to incorrect altimeter settings (among other things) was high. It was nevertheless tolerated in the context of the overall safety requirements of the time. Commercial air transport significantly developed over the decades that followed, and societal expectations evolved both in terms of safety and airport accessibility not being affected by weather conditions. ILS installations thus became widely used, becoming an equipment standard worldwide even to this present day. Since the associated vertical guidance is based on a ground radio source, the vertical profile and associated vertical guidance are not affected by incorrect altimeter settings or temperature variations.

In the 1980s and 1990s, the development of Flight Management Systems (FMS) and the introduction of the Global Navigation Satellite Systems (GNSS) made it possible to use satellite-based area navigation (RNAV). This initial concept of Required Navigation Performance (RNP) was taken up by ICAO in the 2000s in the Performance Based Navigation (PBN) manual, doc 9613. Initially implemented en route and in terminal manoeuvring areas (TMA), satellite-based navigation was then applied to all phases of flight, including final approaches.

ICAO then created an approach procedure category to supplement NPA and PA: Approach Procedure with Vertical guidance (APV), using the Baro-VNAV function or SBAS systems[26]. APV offered vertical guidance, but without the vertical guidance performance of ILS-type precision approaches. They facilitated the replacement of the Dive and Drive technique by the Continuous Descent Final Approach (CDFA) technique.

Baro-VNAV approaches have played a major role in improving safety and continue to do so today, as they reduce the risk of collision with the ground in the absence of a precision approach procedure and on runways without radionavigation equipment, by providing vertical guidance information.

1.8.1.2 Types of IFR approach procedures and operations

1.8.1.2.1 NPA, APV and PA

APV procedures differ from non-precision approaches in that they take into account vertical guidance of the aircraft, and from precision approaches in that they are not compatible with Decision Heights (DH) equal to or less than 200 ft due to the vertical guidance performance (DH of APV is limited to 250 ft).

There are two types of APV: Baro-VNAV APV (using barometric vertical guidance, called RNP APCH down to LNAV/VNAV minima in the ICAO PBN Manuel) and SBAS APV (using satellite vertical guidance, called RNP APCH down to LPV minima (Localiser performance with vertical guidance) in the ICAO PBN Manuel).

The PBN also introduced RNP APCH procedures with LNAV minima, which only take into account the lateral guidance of aircraft. They are therefore associated with non-precision approaches.

It should also be noted that in the 2010s, RNP APCH procedures to LPV minima benefited from an improvement in the performance of SBAS systems, some of which can offer a DH down to 200 ft. These procedures are generally called LPV 200 or SBAS CAT I, and are associated with precision approaches.

Lastly, ICAO introduced the concept of Type A and Type B instrument approach operations, which was taken up by the European Union Aviation Safety Agency (EASA) in 2021:

- a ‘type A instrument approach operation’ is an instrument approach operation with a Minimum Descent Height (MDH) or a Decision Height (DH) at or above 250 ft;
- a ‘type B instrument approach operation’ is an operation with a DH below 250 ft. They are broken down into the following categories:
    - (a) Category I (CAT I): DH not lower than 200 ft and with either a visibility not less than 800 m or an RVR not less than 550 m.
    - (b) Category II (CAT II): DH lower than 200 ft but not lower than 100 ft, and an RVR not less than 300 m.
    - (c) Category III (CAT III): DH lower than 100 ft or no DH, and an RVR less than 300 m or no RVR limitation.

[26] The WAAS system was certified in 2003 in the United States, while EGNOS was certified in 2011 in Europe.

1.8.1.2.2 2D or 3D operations

Airborne navigation systems were initially limited to receivers of signals transmitted by conventional radionavigation means. As a result, pilots only had, and used, lateral guidance information for non-precision approaches. In this context, the term “2D operations” is used.

Precision approaches and APVs, given their vertical guidance, are by definition “3D operations” which additionally offer vertical guidance. The introduction of the Baro-VNAV function made it possible, subject to specific coding in the FMS databases, to conduct non-precision approaches as 3D operations, using barometric vertical guidance information derived solely from the aeroplane’s systems, such as an APV Baro-VNAV. Nowadays, most modern aircraft used in commercial air transport have the Baro-VNAV capability. Therefore, non-precision approaches (conventional or RNP APCH down to LNAV minima) may be conducted as 2D or 3D operations when using Baro-VNAV.

1.8.1.2.3 Augmentation systems and RNP approaches

The common factor between all RNP approaches is that they use the GNSS system. The use of GNSS for approach operations requires enhancing the accuracy and integrity of the positioning provided by a satellite constellation.

Two augmentation systems are available for RNP approaches:

- Aircraft-Based Augmentation System (ABAS): this airborne system detects and rejects a satellite with a faulty signal;
- Satellite-Based Augmentation System (SBAS): this system measures the offset between the actual positions of a network of ground beacons and their positions calculated by a GNSS system and transmits this information via satellite to aircraft to apply position corrections. The SBAS system is not available everywhere in the world). In most of Europe, SBAS is provided through the EGNOS service (see paragraph 1.8.4.1).

RNP APCH operations down to LNAV minima and LNAV/VNAV minima can use either an ABAS or an SBAS system. RNP APCH operations down to LPV minima can only use SBAS augmentation systems, as only these systems provide sufficient vertical position accuracy.

There is also the Ground-based Augmentation System (GBAS) which provides differential corrections and monitors GNSS data integrity using the satellite signals received by several ground antennas on a given aerodrome. The differential correction message calculated from this data is then transmitted omnidirectionally by a ground transmitter using a VHF broadcasting frequency. Equipped aircraft[27] can then carry out GLS (GBAS Landing System) operations, which are alternatives to ILS and LPV approaches. In Europe, only a few aerodromes are currently equipped with GBAS (CDG is not one of them) and few procedures are published. GBAS is not part of the RNP as per the ICAO PBN concept.

[27] In the first quarter of 2023, according to Eurocontrol data based on the capability declared in flight plans within the European Civil Aviation Conference (ECAC) area, 8% (15% for scheduled flights) of aircraft were declared GBAS, handling 11% (13%) of flights.

1.8.1.2.4 Requirements for RNP approaches

As for any operation covered by the PBN concept, the following requirements apply when conducting a published RNP approach in Europe:

- the aircraft must have the specified equipment for this type of operation, for which the operator ensure the airworthiness[28];
- the operator must have defined appropriate operating procedures[29];
- pilots must be trained and hold PBN privileges, which is now systematic in Europe for all pilots holding an instrument rating (IR), in accordance with Regulation (EU) No 1178/2011, known as "AIR CREW".

1.8.1.2.5 IFR approach minima

The minima for landings, defined[30] as the "aerodrome operating minima", are the limits of usability of an aerodrome for a crew, expressed in terms of:

- visibility and/or RVR;
- Minimum Descent Altitude/Height (MDA/H) for 2D operations, below which a descent must not be conducted without the required visual references;
- Decision Altitude/Height (DA/H) for 3D operations, at which a missed approach operation must be initiated if the visual references required to continue the approach has not been acquired.

The MDA/H or DA/H is determined by the air operator[31] using several criteria and must correspond to the maximum of several values, in particular the Obstacle Clearance Height (OCH) and the lowest minima permitted by the instrument approach operation (the lowest DH permitted for a Category I ILS approach or an RNP APCH down to LPV minima is 200 ft. The lowest DH permitted for an RNP APCH down to LNAV or LNAV/VNAV minima as well as for a LOC or a VOR/DME approach is 250 ft).

The OCH is determined when establishing the approach procedure. The method for calculating it varies according to the type of approach operation (NPA, APV, PA). Margins are greater for NPAs than for APVs, and greater for APVs than for PAs.

For example, and according to the Aeronautical Information Publication (AIP), for runway 27R at Paris CDG and for Category C aircraft (which includes the Airbus A320), in the context of RNP APCH operations down to:

- LPV minima (and ILS CAT I): the DA/DH is 600/200 ft for an OCH at 180 ft;
- LNAV/VNAV minima: the DA/DH is 750/360 ft for an OCH at 358 ft;
- LNAV minima: the MDA/MDH is 880/490 ft for an OCH at 484 ft.

[28] See Regulation (EU) No 965/2012 - CAT.OP.MPA.126.
[29] Some specific operations, such as approaches with authorisation required (RNP AR APCH), need approval by the operator, in accordance with Regulation (EU) No 965/2012 - SPA.PBN.100. This is not the case for the RNP APCH operation down to LNAV/VNAV minima used by the crew during this serious incident, which is a "standard" approach.
[30] According to amended European Regulation (EU) No 965/2012 (known as "AIR OPS"), for example and in particular point CAT.OP.MPA.110 and its associated AMC and GM.
[31] In this respect, the French aeronautical information publication directly providing an MDA/H or DA/H in addition to the OCH is unusual.

The RVR is based on several parameters, including the DH/MDH, which in turn depends on the OCH. Thus, the lower the OCH, the lower the minimum RVR authorised for the approach.

1.8.1.3 Vulnerability to altimeter setting

The different types of approach operations have a descent profile that may or may not be affected by an altimeter setting error. In the rest of the report, the approaches where the descent profile is affected by an altimeter setting error will be referred to as "barometric approaches ", as shown in the red box in the table below:

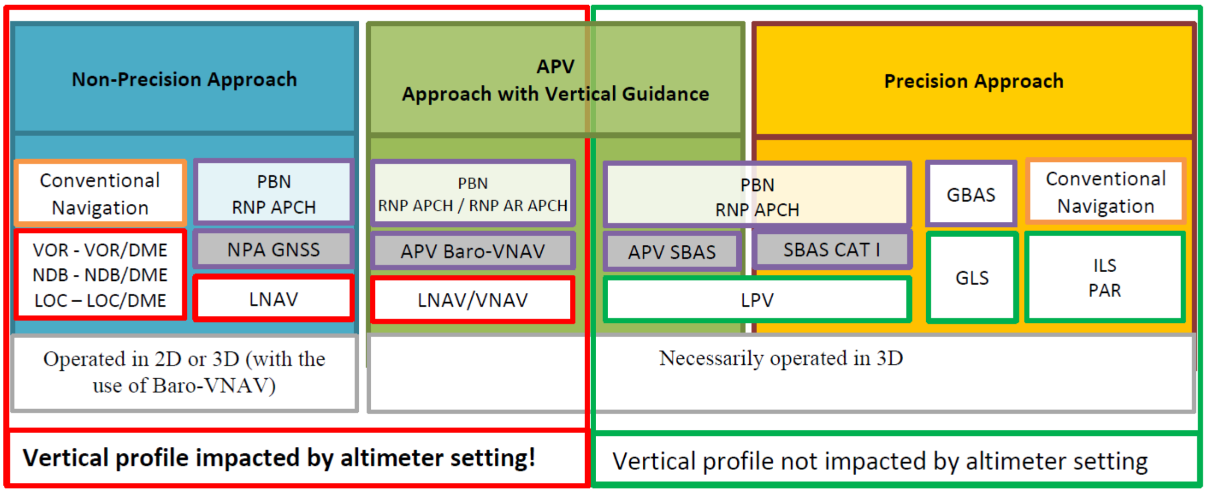

Figure 21: summary table from EUR OPS bulletin 2023_001, "Risks related to incorrect altimeter settings during APV Baro-VNAV and non-precision approach operations", published by the ICAO's EUR/NAT Regional Office in July 2023

The Baro-VNAV function was not designed to be an autonomous approach and landing system, and vertical guidance is based solely on data internal to the aircraft, in particular the barometric altitude, which depends on the altimeter setting. Thus, while 2D approach operations are systematically particularly vulnerable to altimeter setting errors, carrying out a 3D approach operation does not mean less exposure to this danger, since those based on the Baro-VNAV function are just as vulnerable.

In contrast, ILS approaches, or approaches based on a navigation performance augmentation system (GBAS or SBAS) are less vulnerable to altimeter setting errors because the vertical guidance and therefore the descent profile comes from a source outside the aircraft (signal from a ground radio transmitter or satellite signal) independent of the altimeter setting.

The actual altitude of the aircraft at the decision altitude read by the crew is nevertheless affected in all cases[32] by an altimeter setting error and can lead to hard landing type events.

[32] excluding CAT II/III operations where only the radio altimeter height is used for minima.

1.8.2 Development of APV Baro-VNAV approaches: regulatory framework and safety assessment

1.8.2.1 ICAO PBN concept, specifications and development plan

The PBN concept is presented in the ICAO PBN Manual[33]. This navigation method relies on performance requirements which cover, in particular, the aircraft, the crew, the design of procedures, or the performance of navigation signals capable of supporting the operational performance required in a given airspace. These requirements establish accuracy, integrity, continuity and availability conditions for the navigation function.

Annex 10 to the Convention on International Civil Aviation – Aeronautical Telecommunications[34] describes the performance requirements for GNSS systems, in particular those intended to provide horizontal guidance for RNP approach operations (whatever the minima) as well as vertical guidance for RNP approach operations down to LPV minima.

For GNSS systems, the integrity risk, which determines their ability to provide timely warnings when the system can no longer be used safely, is set at 2×10^{-7}/approach for lateral guidance associated with RNP APCH operations down to LNAV/VNAV and LPV minima, and for vertical guidance associated with RNP APCH operations down to LPV minima only. It does not take into account operational hazards such as incorrect altimeter settings.

Supplement B to Volume I of Annex 10 sets out a strategy for the introduction and use of non-visual approach and landing aids. This strategy is not prescriptive regarding ILS, their retention or removal. In addition, it recognises that "*GNSS-based approaches providing lateral and vertical path guidance may offer a cost-effective option when considering introduction of Category I approach service or when replacing or removing an existing ILS*" and that this must take into account "*user equipment*."

One of the objectives included in ICAO Resolution A37-11 adopted in 2011 was to encourage the development of PBN approaches, in particular with vertical guidance. This resolution stipulates that all instrument runway ends or all runway ends serving aircraft with a maximum certificated take-off mass of 5,700 kg or more should have approach operations with vertical guidance, where possible. This objective was considered as a lever for reducing the CFIT risk in relation to the existing situation, in which some of these runways were provided with NPA procedures only. This resolution also stipulates that ICAO will develop a safety assessment methodology as part of the information to be made available to States.

During the investigation into this serious incident, ICAO informed the BEA that it had not developed this assessment methodology.

[33] Doc 9613 (fourth edition – 2013); version in force on the date of the serious incident.

[34] Seventh edition (2018); version in force on the date of the serious incident – See Table 3.7.2.4-1 in Volume I.

1.8.2.2 Development of Baro-VNAV function

The introduction of the FMS on board aeroplanes opened up the possibility of continuously providing vertical navigation (VNAV) information based on barometric information: this corresponds to the Baro-VNAV function. The initial goal of this new function was to optimise fuel consumption by making continuous descents. This capability was recognised in particular by the FAA in 1988 with the publication of circular AC20-129[35].

During the decade that followed, the high CFIT risk associated with non-precision approaches without vertical guidance led the international aviation community to recommend and then require continuous descent, including for final approaches, using the CDFA flight technique. The use of the Baro-VNAV function was therefore also extended to final approaches.

To this end, in 2001, ICAO introduced criteria specific to Baro-VNAV in the doc 8168 PANS-OPS. These criteria were subsequently amended by introducing specific performance hypotheses in addition to those defined in AC20-129. In the 12th amendment to PANS-OPS Volume II on procedure design, published in 2004, a new method for calculating obstacle clearance margins in the OCH calculation was defined for RNP APCH down to LNAV/VNAV minima. As PANS-OPS are based on normal operations, the threats inherent in the Baro-VNAV function, such as an erroneous altimeter setting, were not taken into account when this method was introduced, and the reduction in minima for these approaches did not give rise to a safety study by ICAO.

The PANS-OPS mention the risk of incorrect altimeter settings and the fact that some operational protection measures are not effective: *"An independent altimeter cross-check which is available for ILS, MLS, GLS, SBAS APV-I/CAT I is not available with APV/baro-VNAV since the altimeter is also the source on which the vertical guidance is based."*

However, the PANS-OPS specify that "*mitigation of altimeter failures or incorrect settings shall be accomplished by means of standard operating procedures similar to those applied to non-precision approach procedures"*, and Supplement A to the ICAO PBN Manual, fourth edition, specifies that control of the risk of incorrect altimeter setting depends on pilots' knowledge and training.

Performance criteria for vertical guidance of RNP APCH operations down to LNAV/VNAV minima were described in Supplement A to Volume II of the fourth edition of the PBN Manual, published in 2013. However, these criteria were based on FAA AC20-129 (published 12 September 1988, and withdrawn 8 May 2012) and were thus obsolete. Edition 5 of the PBN Manual published in 2023 no longer proposes any Baro-VNAV performance criteria.

There are currently no performance criteria for Baro-VNAV systems used for RNP APCH operations with LNAV/VNAV minima in ICAO documentation.

Furthermore, ICAO has not fixed the integrity risk level applicable to Baro-VNAV systems used in RNP APCH operations down to LNAV/VNAV minima. However, various studies show that the integrity of data manipulated by humans is limited and cannot reach the expected orders of magnitude for integrity comparable to GNSS systems used for approach guidance (10^{-7} per approach).

[35] https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentid/22188

Aside concerning the United States

It should be noted that the United States is one of the countries with the highest number of publications regarding RNP APCH operations down to LNAV/VNAV minima. Industry, associations and the authorities strongly pushed for the development of Baro-VNAV. Few noticeable events associated with incorrect altimeter settings were reported. When questioned about the reality of the operations conducted, the Federal Aviation Administration (FAA) indicated that there was no monitoring of the types of operations conducted by the crews. However, it indicated that, where available, ILS approaches are still preferred.

It is important to bear in mind that the context and organisation of airspace in the United States differ substantially from those in other parts of the world, particularly in Europe. Comparisons may therefore be inappropriate, and discussions at international level must take these differences into account. With regard to the United States, these include:

- The altimeter setting given as inches of mercury (in Hg), not as hectopascals (hPa).

Standard pressure at 1013 hPa corresponds to 29.92 in Hg. Altimeter settings in the United States therefore generally vary between 28.XX and 30.XX in Hg, with 29.XX in Hg being the most common value.

The most common error observed in Europe of ± 1 on the second digit (± 10 hPa, see paragraph 1.18.1.2) thus corresponds to an error of one tenth of an inch of mercury on an altimeter set to the US setting (e.g.: 29.82 -> 29.92), which only offsets the altitude by around 100 ft. Having an error equivalent to that in the 9H-EMU serious incident would mean an error of three tenths, which is much larger, easier to detect and therefore less frequent (see paragraph 1.18.1.2).

In addition, local best practices recommend using "*high*" before a 30.XX in Hg altimeter setting and "*low*" before a 28.XX in Hg altimeter setting to limit substantial errors.

- Transition level of FL180, and the altimeter setting provided en route by the controller during the descent.

This high transition level generally means that the altimeter setting is changed from the STD to the local reference during a low-workload phase for the crew compared with FL080-FL050, which is the transition level generally used in Europe. This also gives the crew and controllers more time to identify any altitude deviation.

- The language used (English) is the mother tongue of air traffic controllers and of a large proportion of pilots, thereby reducing the risk of transmission errors, read-back errors or incorrect information not being detected.

1.8.2.3 European specifications for RNP approaches

In 2009, EASA published AMC 20-27[36] on RNP approach operations down to LNAV and LNAV/VNAV minima, which contained the following criteria:

- use by controllers of a phraseology appropriate to RNP APCH operations;
- controllers' knowledge of the aircraft's VNAV capability, as well as of the specificities associated with the altimeter setting and the temperature effect potentially affecting the APV BARO-VNAV operation;
- controllers' confirmation of the QNH with flight crews prior to commencement of the approach, in order to minimise the potential for miss-setting a barometric reference;
- necessity for air operators to highlight, by means of procedures and crew training, the importance of having a correct altimeter setting. A crew training syllabus was proposed, including items specific to the Baro-VNAV function, such as requirements in terms of currency, accuracy and integrity of the altimeter setting, as well as recommendations on when and how to change the altimeter setting or on the fact that altitude/distance checks do not detect such errors.

For the most part, these provisions were progressively integrated into various regulations, including amended Regulation (EU) No 965/2012 (known as "AIR OPS") regarding air operations, amended Regulation (EU) 2017/373 (known as ATM-ANS IR) regarding air navigation services and the Certification Specifications for Airborne Communications, Navigation and Surveillance (CS-ACNS), and AMC 20-27 was finally repealed.

It should be noted, however, that the issue of incorrect altimeter settings, which had been clearly identified and highlighted in AMC 20-27, was diluted in all these regulations, and no contextual information was given. For example, the following can be observed:

- the need for controllers to confirm the QNH with flight crews prior to commencement of the approach, in order to minimise the potential for miss-setting a barometric reference, was not included in the ATM-ANS IR (see paragraph 1.17.1.3.4);
- the necessity of having a correct altimeter setting in the context of a Baro-VNAV approach due to the CFIT risk was not included in the AIR OPS;
- the information that altitude/distance checks do not detect incorrect altimeter settings was not included in the AIR OPS.

1.8.2.4 Eurocontrol safety assessment of APV Baro-VNAV approaches

In 2010, Eurocontrol carried out a safety assessment on APV Baro-VNAV approach operations. The change considered was the introduction of APV Baro-VNAV operations on a runway for which an RNP APCH operation down to LNAV minima had already been published.

The report on this safety assessment has not been officially validated or published by Eurocontrol. Only a draft version of this report exists, and this was made available to several organisations.

The safety study considered various scenarios, including the case of an APV Baro-VNAV approach conducted with an incorrect altimeter setting. The CFIT risk and of an error not being detected was clearly identified throughout the study; for example, 72 altimeter setting incidents, reported by operators to the Civil Aviation Authority of the United Kingdom between February 2009

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[36] Airworthiness Approval and Operational Criteria for RNP APPROACH (RNP APCH) Operations Including APV BARO-VNAV Operations

and February 2010, were analysed. Eurocontrol proposed a number of additional safety measures:

- communication of the ATIS and QNH information by the crew to the controller prior to commencement of the initial approach;
- reminder of the QNH by the TWR controller or AFIS on first contact;
- raising the transition altitude to allow the crew to set the QNH during a phase when the workload is lower than during the approach, and to give them more time to detect any incorrect setting;
- using the radio altimeter as a means of identifying a QNH error if the terrain is flat before the runway.

The study concluded that the altimeter setting is essential for APV Baro-VNAV approaches, that the frequency with which incorrect altimeter settings occur in APV Baro-VNAV approaches should be similar to that of NPA approaches, and that APV Baro-VNAV approaches do not provide any safety benefit in this specific case, as both types of approach are equally affected by setting errors.

1.8.2.5 PBN deployment plans in France and Europe

To comply with ICAO Resolution A37-11, the French civil aviation authority (DGAC) published its PBN implementation plan in 2012. The plan drafted by the DGAC contained short-, medium- and long-term objectives. In the long term, the aim was for aircraft to be equipped with avionics enabling them to carry out CAT I SBAS approaches using RNP APCH operations down to LPV minima, which represents the only recognised solution equivalent to ILS or GLS in terms of safety and performance.

In 2015, via the Notice of Proposed Amendment NPA 2015-01, EASA proposed regulations for implementing Performance Based Navigation (PBN) in the European Air Traffic Management Network (EATMN). With regard to approach operations, the proposed provision was that air navigation service providers and aerodrome operators implement "*PBN approach procedures with vertical guidance (APV) at all instrument runway ends where there are currently only non-precision approach procedures published before January 2024.*"

The associated safety impact assessment (included in this Notice of Proposed Amendment NPA 2015-01) was limited to this specific transition and did not consider the differences in relation to precision approaches. It concluded that the introduction of APV approach operations (whether SBAS or Baro-VNAV) would allow harmonisation of the approach types, a better separation from obstacles and an improved pilot situational awareness compared to non-precision approach operations. The vulnerability of Baro-VNAV approaches to incorrect altimeter settings, which was not a decisive parameter given the change considered, was neither studied nor mentioned in the NPA. The regulatory impact assessment carried out by EASA concluded that, from a global point of view including safety, the proposed provision was, just like the regulation as a whole, preferable to the regulatory status quo.

Opinion 10/2016 published by EASA confirmed the objective and conclusions of NPA 2015-01, while bringing forward the application date to 2020 instead of 2024.

Commission Implementing Regulation (EU) 2018/1048 of 18 July 2018 laying down airspace usage requirements and operating procedures concerning performance-based navigation (known as "IR-PBN") came into force in 2018.

In addition to the topics discussed and analysed in the preceding NPA 2015-01 and Opinion 10/2016, this regulation made it mandatory, before 24 January 2024, to implement "*at all instrument runway ends, approach procedures in accordance with the requirements of the RNP approach (RNP APCH) specification, including LNAV, LNAV/VNAV and LPV minima*[37]." Moreover, Article 5 of the regulation ("*Exclusive use of PBN*") stipulates that, from 06 June 2030, "*Providers of ATM/ANS shall not provide their services using conventional navigation procedures*[38]."

This last requirement was introduced at the very end of the regulatory process during comitology meetings under the aegis of the "Single Sky" Committee. The information gathered from the DGAC French representatives in this comitology suggests that there were two main reasons for this requirement:

- it was expected that it would encourage air operators to equip their aircraft with systems enabling them to conduct RNP APCH operations down to LPV minima, if they wished to maintain a level of accessibility comparable to that which they had with ILS CAT I. However, neither EASA nor the European Commission at that time[39] communicated on this aspect during consultations with air operators;
- the withdrawal of conventional aids such as ILS CAT I should result in substantial savings for ATM/ANS providers, and consequently for air operators.

The introduction of this provision did not give rise to a specific assessment of its impact on safety before the regulation was adopted, nor did it give rise to the definition of criteria to adjust this provision if the development of the LPV capability was not as expected by 2030. The European Commission and EASA informed the BEA during the course of the investigation that since 2021, EASA has been monitoring the evolution of aircraft PBN capabilities in Europe, including LPV, through Eurocontrol reviews on the basis of declared capabilities in flight plans (see 1.8.4.2.2).

It finally should be noted that EASA has subsequently clarified the provisions of the regulation with regard to GBAS: "*Approach operations supported by GBAS landing system (GLS) CAT I facilities are not within the scope of the PBN IR, so they are not affected by the restrictions, and can continue to be used after the referred to deadline*."

1.8.3 Rationalisation of radionavigation systems and withdrawal of ILS

In Europe, the national PBN plans drawn up before the publication of the IR-PBN included an initial reflection on the rationalisation of radionavigation means. From 2012, the document entitled "France PBN Plan" stated with regard to approaches that, in the long term (after 2020) the end of deployment of the European constellation (Galileo) associated with version V3 of EGNOS should allow the use of satellite resources alone for aircraft navigation to be consolidated and made thoroughly reliable. This phase should thus allow for a further step in rationalisation of the navaids network defined hitherto (ILS, VOR and DME).

[37] The regulation provides for two types of exemption: 1) when, "due to terrain, obstacles or air traffic separation conditions, the implementation of 3D approach procedures is excessively difficult", and 2) "at instrument runway ends without an appropriate SBAS coverage."

[38] An exception is made for CAT II, CAT IIIA and CAT IIIB operations.

[39] Since the publication of the IR-PBN, EASA has published information about the regulation, in particular to encourage operators to equip their aircraft with the LPV capability in order to maintain a level of accessibility comparable to ILS CAT I.

In practice, the DSNA, as the main air navigation service provider in France and therefore the main organisation historically responsible for operating radionavigation means, rationalised ILS CAT I, in parallel with the deployment of RNP approach operations, particularly those down to LPV minima. As a result, the number of ILS CAT I in the country fell from 116 in 2011 (in 79 airports) to 64 in 2016 (in 37 airports). In addition, management of part of the remaining ILS CAT I was transferred to aerodrome operators (see aerodromes in green on Figure 22). Aerodromes where ILS CAT I systems were removed are those with the lowest level of commercial air transport traffic.

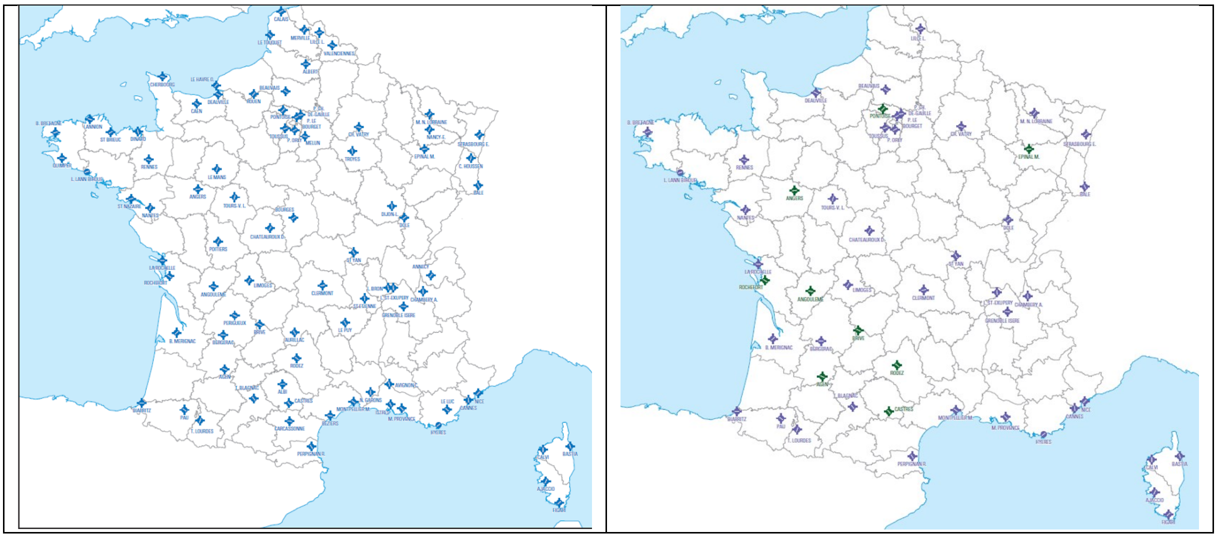


Figure 22: ILS CAT I network before 2011 (left) and after 2016 (right) in Metropolitan France (source: DGAC)

1.8.4 Development of SBAS capability to conduct RNP APCH operations down to LPV minima

Whether a rated crew can conduct an RNP APCH operation down to LPV minima depends on the following conditions:

- this type of operation must exist in the QFU in question. This means that an SBAS augmentation system (see paragraph 1.8.1.2.3) must be available in the geographical area in question, and that the environment must be suitable for the design of this type of operation;
- the aeroplane's navigation system must be able to provide SBAS guidance in the horizontal and vertical profiles;
- LPV capability must be available on board the aeroplane. Indeed, if it is not certified for, or does not have the LPV capability, an SBAS-equipped aeroplane will not be able to carry out this operation.

1.8.4.1 Development of SBAS augmentation systems

Several States or regions in the world deployed their own Satellite-Based Augmentation Systems (SBAS). These systems are compatible and interoperable. The European SBAS, known as the European Geostationary Navigation Overlay Service (EGNOS), was implemented in 2011 and covers most of the European Union (EU), as well as some neighbouring countries and regions, especially thanks to the European Galileo Global Navigation Satellite System (GNSS). It should be noted that the EGNOS areas for LPV operations do not cover the totality of the single European sky, i.e., the airspace where Regulation (EU) 2018/1048 "IR-PBN" applies.

The figure below shows the development of SBAS around the world in 2023.

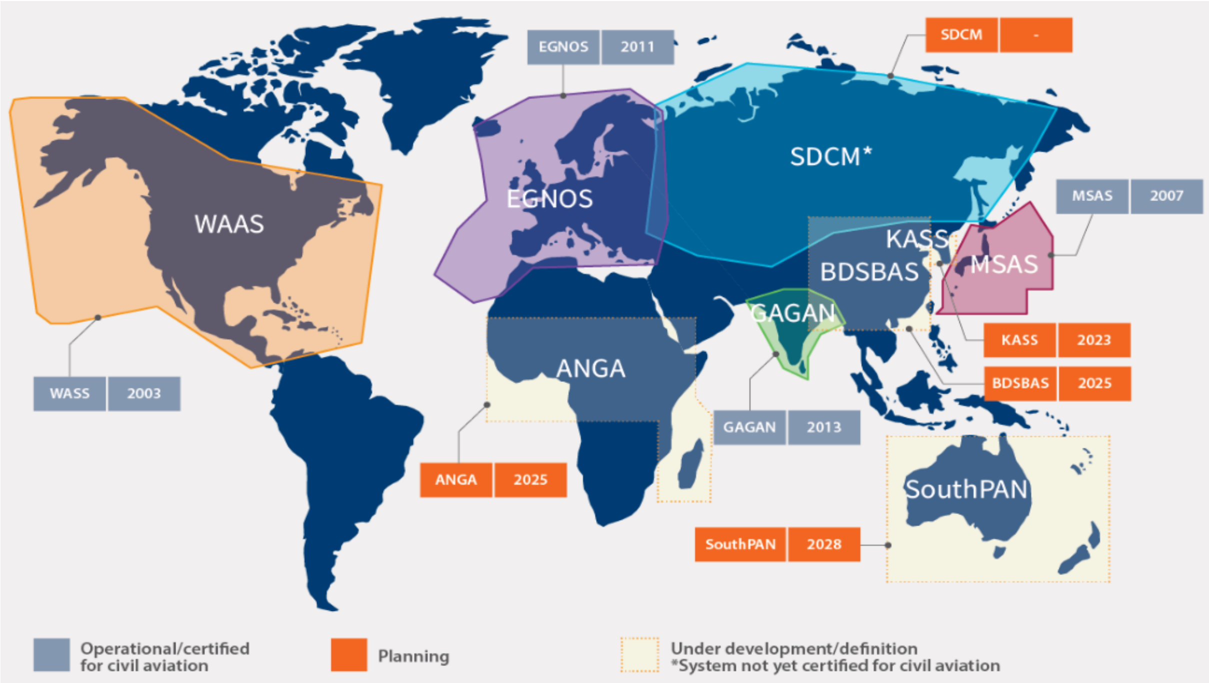


Figure 23: representation of the areas covered by the various SBAS systems already deployed or under development around the world in 2023
(source: European Union Space Programme Agency – EUSPA)

1.8.4.2 Development of LPV capability for aircraft

1.8.4.2.1 Deployment of LPV systems at Airbus and Boeing

Airbus uses the SBAS landing system (SLS) function to conduct RNP APCH operations down to LPV minima[40] when approved by national authorities. The SLS function has been available as a forward-fit option for aircraft rolling out of the factory since:

- 2014, on A350s;
- 2021, on the A320 Family;
- 2022, for A330s and A380s.

Moreover, the A220 Family also comes with the LPV capability as standard.

Airbus indicated that a retrofit operation was possible for aeroplanes not initially equipped with the function. However, depending on the age and serial number of each aeroplane, retrofit operations may require replacing many equipment items (in particular FMGC, MMR, EFIS), which is costly.

Airbus indicated that, at the end of 2022, less than 500 aeroplanes out of the total Airbus fleet in service (comprising approximately 10,000 aeroplanes) were equipped with the SLS function. Around 70% of A350 customers had decided to equip their aeroplanes with this function. Nevertheless, the recent availability of the SLS function means that the level of deployment is still low on A320 and A330 fleets.

[40] When selecting an RNP APCH operation down to LNAV or LNAV/VNAV minima on the FMS, the Airbus aircraft, even if equipped with the SLS function, will conduct the approach with the Baro-VNAV function, thereby with barometric vertical guidance.

On the date of publication of this report, Boeing had no certified function on its fleet to conduct RNP APCH operations down to LPV minima. Boeing was contacted during the investigation. The manufacturer indicated that it was in the process of certifying an LPV function as part of the development and certification of the Boeing 777-9 (which will be available for the entire Boeing 777X family once completed), and as part of the certification of the Boeing 737MAX-10 (which will be available for the entire Boeing 737MAX family once completed).

Boeing also indicated it was looking into the possibility of providing the LPV capability on other models in its fleet.

1.8.4.2.2 Deployment status of LPV capability

Each quarter, Eurocontrol publishes on its Extranet site, a report on the PBN capability of aircraft in Europe, based on the information declared on flight plans. During the investigation, the BEA consulted the report for the first quarter of 2023:

- in Europe[41], 26% of aeroplanes were declared with LPV capability. These aeroplanes represented 10% of flights (not necessarily including RNP APCH operations down to LPV minima each time). These values were broken down as follows:
    - 3% of aeroplanes conducting scheduled flights were equipped, representing 4% of these flights,
    - 49% of aeroplanes involved in other types of civil operations were equipped, representing 42% of these flights;
- data was also given for the main European airports. For example, at the three French airports for which details are provided:
    - Paris-Charles de Gaulle (LFPG): 4% of aeroplanes were equipped, representing 9% of flights,
    - Paris-Orly (LFPO): 3% of aeroplanes were equipped, representing 4% of flights,
    - Nice-Côte d'Azur (LFMN): 26% of aeroplanes were equipped, representing 21% of flights.

All these figures tend to confirm the difference between commercial aviation (few equipped aircraft) and IFR general aviation or business aviation (aircraft equipped to a greater extent) in terms of LPV capability.

1.8.4.2.3 Strategies to encourage LPV deployment

As things stand in Europe, the strategy is to promote LPV equipment on aircraft to operators. The arguments put forward are accessibility and safety.

- ICAO Annex 10 sets out the global strategy for the introduction and application of non-visual aids to approach and landing, one element of which is to "*promote the use of APV operations, particularly those using GNSS vertical guidance, to enhance safety and accessibility*."
- In the foreword of the IR-PBN regulation, the European Commission explained that "*the use of satellite-based augmentation systems (SBAS), in particular in the form of the European Geostationary Navigation Overlay Service (EGNOS), should be promoted, as safety and cost-efficiency considerations support the establishment of localiser*

[41] Eurocontrol takes into account the ECAC (European Civil Aviation Conference) area. According to EASA, the values applicable to the EASA Member States to which the IR-PBN regulation applies were, for the first quarter of 2023: 35% of declared aircraft with LPV capability, operating 10% of flights.

performance with vertical guidance (LPV) minima approaches." The European Commission specified to the BEA that it offers incentives for aircraft to be equipped with SBAS through the EGNOS program and the Connecting Europe Facility instrument.
- EASA explained in 2022 on its website that "*Considering that, as of 06 June 2030, ILS CAT I approaches will only be used in case of contingency, aircraft operators should consider equipping their aircraft with [the LPV capability].*"

At the time of writing this report, no measures existed or were under consideration to impose, among the basic equipment of a newly produced or newly designed aircraft, a system to conduct RNP APCH operations down to LPV minima.

1.9 Communications

The information in this paragraph is intended to supplement the communication information already provided in the history of the flight.

1.9.1 Exchanges during first contacts with the initial approach controller

The crew of flight NSZ4311 contacted the initial approach controller (INI) at 11:22, they were cleared for approach LORNI 6 W for RNP 27R. No mention was made of the ATIS information to the INI controller.

However, international regulatory requirements[42] require crews to call out the ATIS information on first contact with approach services, and require control services to acknowledge receipt of the ATIS information.

Indeed, as indicated in paragraph 1.17.1.3.4, the principle of the altimeter setting provision is that it is provided twice: first via the ATIS message, then via the initial altitude clearance below the transition level.

1.9.2 Transmission or read-back errors

A number of transmission or read-back errors (corrected or not corrected by air traffic controllers) occurred during the serious incident.

- During exchanges with the INI approach controller, the PM did not correctly read back the approach instructions on several occasions: he was cleared for LORNI 6 W, but read back MOPIL 9 W; he was cleared for a radar approach for runway 27R, but read back 26R. This was detected and corrected each time by the INI controller.
- Similarly, during the initial exchanges with the ITM approach controller, the PM did not read back the approach instruction correctly: he was cleared for PG 6 5 0 but read back PG 5 6 0. This was detected and corrected by the ITM controller.
- This was followed by the ITM controller making three transmission errors, with an incorrect QNH: two of these errors concerned flight NSZ4311 (incorrect QNH was repeated in the read back both times), and one concerned easyJet flight EZY75VA (error in announcing call sign *Mike Alpha* instead of *Victor Alpha*, and the crew not repeating the incorrect QNH but reading back the correct QNH of a different value, which the controller did not pick up).
- During the go-around, the TWR controller instructed the crew of NSZ4311 to turn right, heading 360°, and to climb to 5,000 ft QNH 1001. The PM read back the first part of the

[42] ICAO Doc 4444 PANS-ATM, SERA 9010, ATS.TR.320.

message correctly, but read back the altimeters' QNH setting at 1011 hPa. This was not picked up by the N-TWR controller, nor by the N-TWR assistant, who was coordinating with the S-TWR assistant (see below) by telephone.
- Lastly, during the second approach, the ITM controller, who was managing both the North ITM position and the BA ITM position, mistakenly sent the crew of flight NSZ4311 to the Bourget frequency, to which she had just sent several aeroplanes. The PM then called back to request the frequency of the North tower, which was correctly transmitted.

1.9.3 Exchanges on the approach lights

During the first approach of flight NSZ4311, the N-TWR controller switched on the runway lights, but forget to switch on the approach lights. Several crews and air traffic controllers had a number of radio-communication and telephone coordination exchanges regarding the lights.

- Firstly, on the South tower frequency, at 11:40:58, a crew asked the S-TWR controller to switch on the lights. All the lights for runway 26L were then switched on by the controllers in the South tower.
- At 11:42:06 and during the crew's exchange with the N-TWR controller about the go-around, the S-TWR assistant contacted the N-TWR assistant to inform him that the approach lights for runway 27R were not switched on.
- At 11:42:30, the approach lights for runway 27R were switched on by the N-TWR controller.
- The N-TWR controller then asked the crew of easyJet flight EZY75VA, which was coming in behind flight NSZ4311 for runway 27R, if they could see the lights and the runway. The crew replied: "*Uh negative yet ... visual with the ground but uh ... just uh ... not yet*", then at 11:43:19: "*Okay we have visual now 1 000 feet RA*."
- Lastly, during the second approach, the crew of flight NSZ4311 asked the tower if the approach lights were switched on.

1.9.4 Use of English and French

After transmitting the three incorrect QNH items of information in English, the ITM controller cleared an Air France crew, in French, to descend to 5,000 ft with the correct QNH 1001, using the French expression "*mille un*" (a thousand and one). In France, according to Regulation (EU) No 923/2012, known as "SERA" (Standard European Rules of the Air) and the French provisions (see paragraph 1.17.1.3.2) SERA FRA.14015 a) Languages to be used in air-ground communications, the language normally used by the station on the ground is French. This means that both English and French could be used in radio-communications.

SERA FRA.14035 "*Transmission des nombres*" (Transmission of numbers) also specifies that, in French, a number can be transmitted as it is expressed in everyday life or as a sequence of numbers. When the transmissions are not satisfactorily clear or in case of ambiguity, the general rule applies. For example, QNH 1 0 0 1 must be announced in English as "*one zero zero one*", but can be announced in French as "*mille un*", which is what is done in most cases, and not "*unité zéro zéro unité*".

The Air France crew read back the message correctly. This exchange could not be understood by the crew of the serious incident, who did not speak French. However, the subsequent two exchanges, made in English with two other crews before flight NSZ4311 left the frequency, did include the correct QNH announced in English.

1.10 Aerodrome and air navigation information

Paris-Charles de Gaulle airport is an international airport open to commercial air traffic. It comprises two sets of parallel runways, each set consisting of two runways oriented east/west (084°/264°). Each set of parallel runways is generally operated in the same way for specialised operations: aeroplanes land on the outer runway (runway 09L/27R for the north parallel runways and 08R/26L for the south parallel runways) and take off from the inner runway (runway 09R/27L for the north parallel runways and 08L/26R for the south parallel runways).

1.10.1 Lights

Each of the eight runway ends is equipped with Category III precision approach lights, consisting of a series of approach lights over 900 m (with inset lights over a distance of 600 m before displaced thresholds of runways 26R and 27L), in addition to the runway centreline and side lights. Each of the eight runway ends is also equipped with a Precision Approach Path Indicator (PAPI) set at 3°/5.2%.

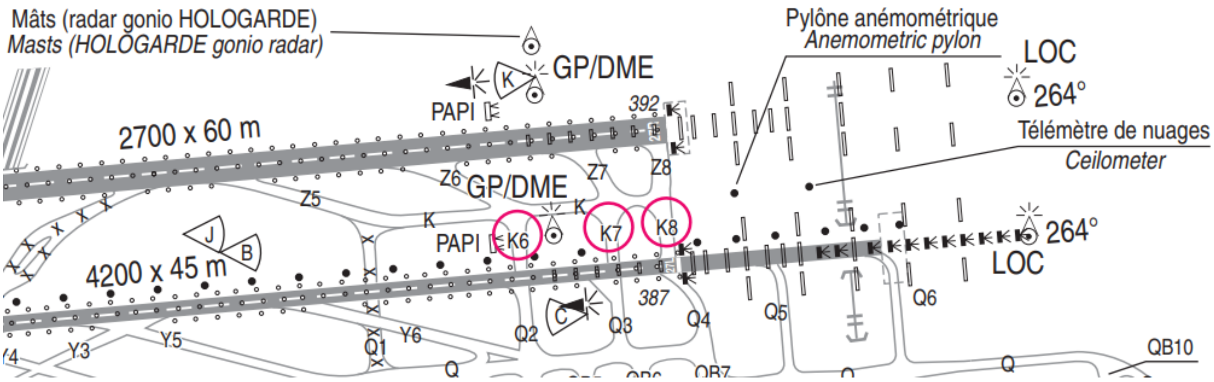


Figure 24: lights for runway 27R at CDG (source: SIA)

Recordings for CDG's lights on the day of the serious incident showed that:

- the PAPI for runway 27R was switched on with an intensity of 4/4 at 07:31;
- the lights for runway 27R and the touchdown zone (TDZ) were switched on with an intensity of 2/4 at 11:38:30, i.e. approximately three minutes before the serious incident;
- the approach lights for runway 27R were switched on with an intensity of 3/4 at 11:42:30, i.e. during the go-around of flight NSZ4311.

Regulation (EU) 2017/373 known as ATM/ANS[43], in accordance with ICAO Doc 4444 "PANS-ATM", stipulates that all aeronautical ground lights must be switched on during the aeronautical night and "*at any other time when their use, based on meteorological conditions, is considered desirable for the safety of air traffic.*" It also indicates that approach lighting should also be operated:
"a) by day when requested by an approaching aircraft;
b) when the associated runway lighting is operated."

The CDG Operating Manual (OM) stipulates that approach lights must be switched on at night or in low visibility conditions, as part of Pre-LVP or LVP (Low Visibility Procedures). The lighting intensity range must be adapted in real time at the request of crews and according to the weather conditions.

[43] AMC1 ATS.TR.150.

The corresponding weather conditions are as follows:

- Pre-LVP procedures are applied as soon as RVR < 800 m or ceiling[44] < 300 ft.
- LVP procedures are applied at one set of parallel runways at CDG as soon as RVR ≤ 600 m or ceiling ≤ 200 ft.

At the time of the serious incident, the weather conditions did not correspond to a transition to Pre-LVP or LVP operations. There was therefore no regulatory or procedural obligation to switch the runway lights on, with the exception of the obligation to simultaneously switch on the runway and approach lights.

By way of example and according to the AIR OPS[45], flying an approach similar to that of the serious incident (RNP APCH down to LNAV/VNAV minima and a DH at 360 ft) in No Approach Lighting System (NALS) conditions would require a Runway Visual Range (RVR) of more than 1,600 m. As a reminder (see paragraph 1.7.2), the RVR measured at CDG during the two approaches was more than 2,000 m.

1.10.2 Equipment, IFR procedures and approach charts

CDG airport is equipped with Performance Category III ILS for each of its eight runway ends.

The three types of PBN operations (RNP APCH down to LNAV, LNAV/VNAV and LPV minima) are published for each of the eight runway ends. The indicated minimum temperature for Baro-VNAV approaches is -20 °C.

During the period including the day of the serious incident, from 16 May to 31 May 2022, the ILS systems for runways 09L and 27R were out of service due to work to replace the ILS antennas. This was indicated by way of a NOTAM.

Concerning PBN operations for runway 27R, the final approach chart published in the Aeronautical Information Publication (AIP) by the Aeronautical Information Service (AIS) is as follows:

[44] Cloud base height

[45] AIR OPS, AMC5 CAT.OP.MPA.110 Aerodrome operating minima.

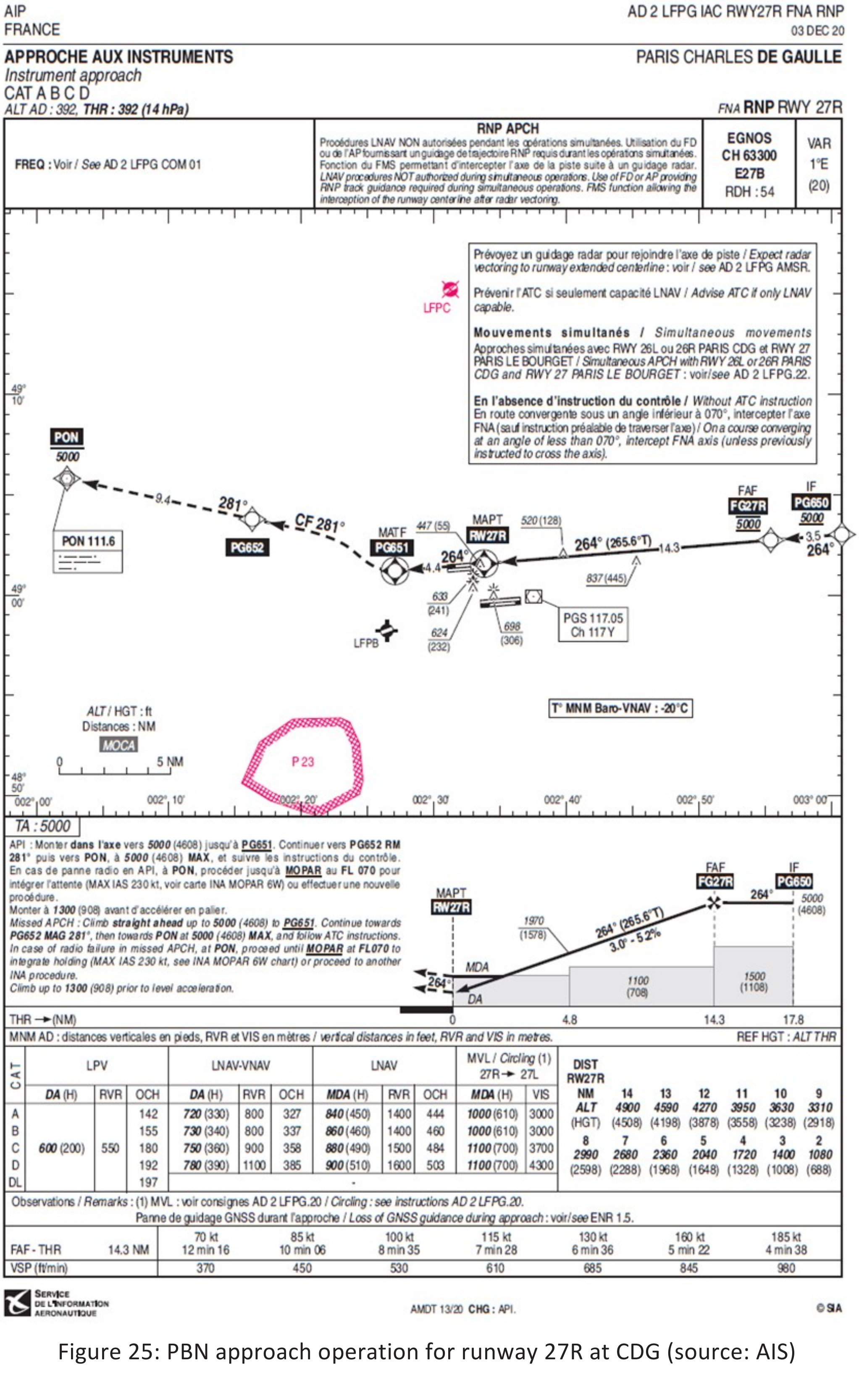
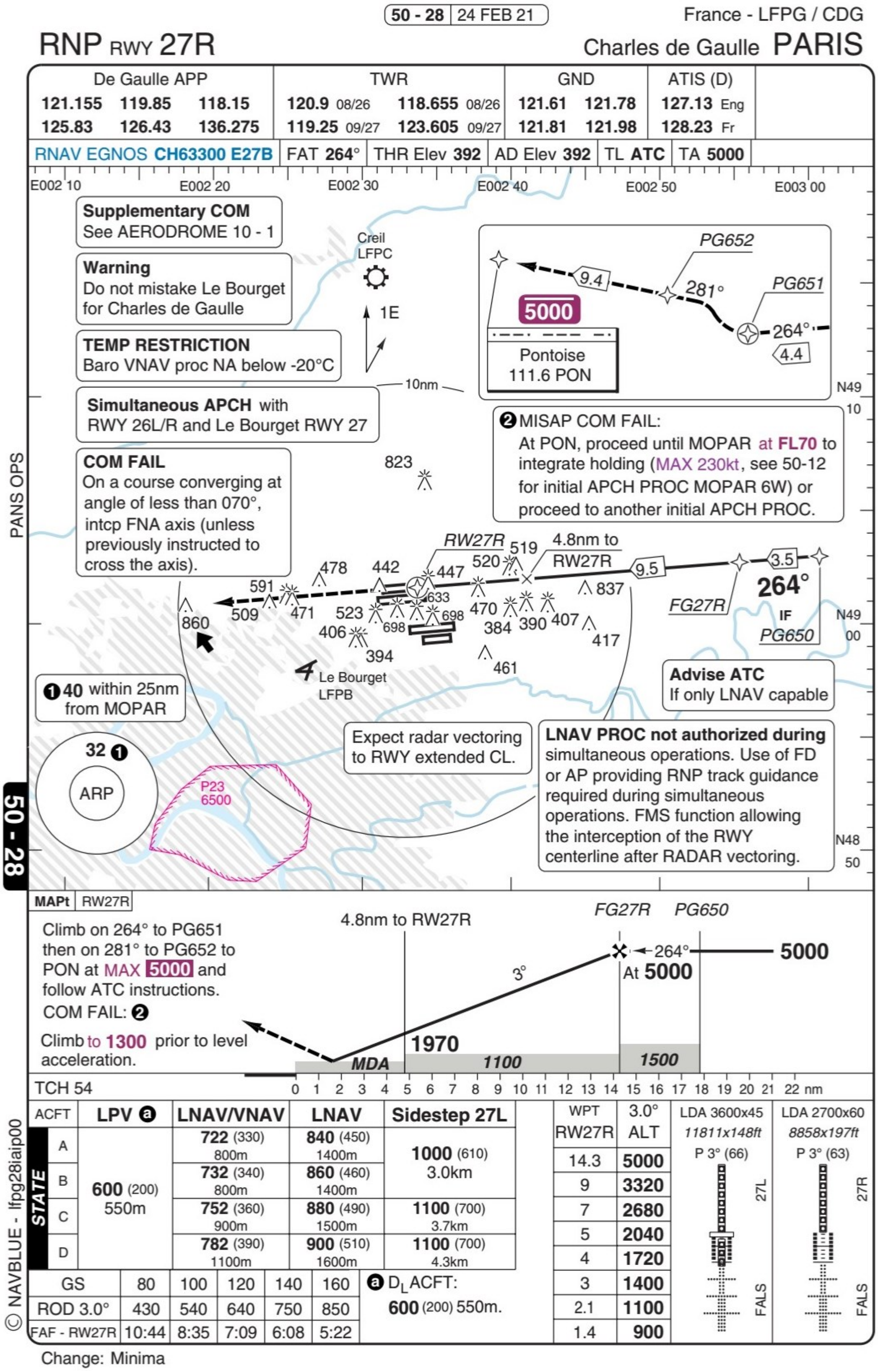


Figure 25: PBN approach operation for runway 27R at CDG (source: AIS)

The crew used the approach chart provided by NavBlue:



ACFT	LPV ⓐ	LNAV/VNAV	LNAV	Sidestep 27L
A	600 (200) 550m	722 (330) 800m	840 (450) 1400m	1000 (610) 3.0km
B		732 (340) 800m	860 (460) 1400m	
C		752 (360) 900m	880 (490) 1500m	1100 (700) 3.7km
D		782 (390) 1100m	900 (510) 1600m	1100 (700) 4.3km

GS	80	100	120	140	160
ROD 3.0°	430	540	640	750	850
FAF - RW27R	10:44	8:35	7:09	6:08	5:22

ⓐ D_L ACFT: 600 (200) 550m.

WPT RW27R	3.0° ALT
14.3	5000
9	3320
7	2680
5	2040
4	1720
3	1400
2.1	1100
1.4	900

LDA 3600x45 11811x148ft P 3° (66) 27L FALS
LDA 2700x60 8858x197ft P 3° (63) 27R FALS

© NAVBLUE - lfpg28iaip00

Change: Minima

Figure 26: approach chart used by the crew (Source: Airhub Airlines)

In particular, the following differences could be identified:

- the NavBlue chart only includes part of the AIP's altitudes/distances;
- the NavBlue altitudes/distances, Step Down Fix (SDF) and minimum safety altitudes do not include the heights indicated in the AIP.

Some of these differences, and in particular the fact that the heights of the altitude-distance pairs or the SDF are not included, are also common to other navigation data providers, such as LIDO or Jeppesen.

1.10.3 Air traffic controller systems at CDG

Various systems are available to air traffic controllers at CDG. Only those related to the serious incident are detailed here.

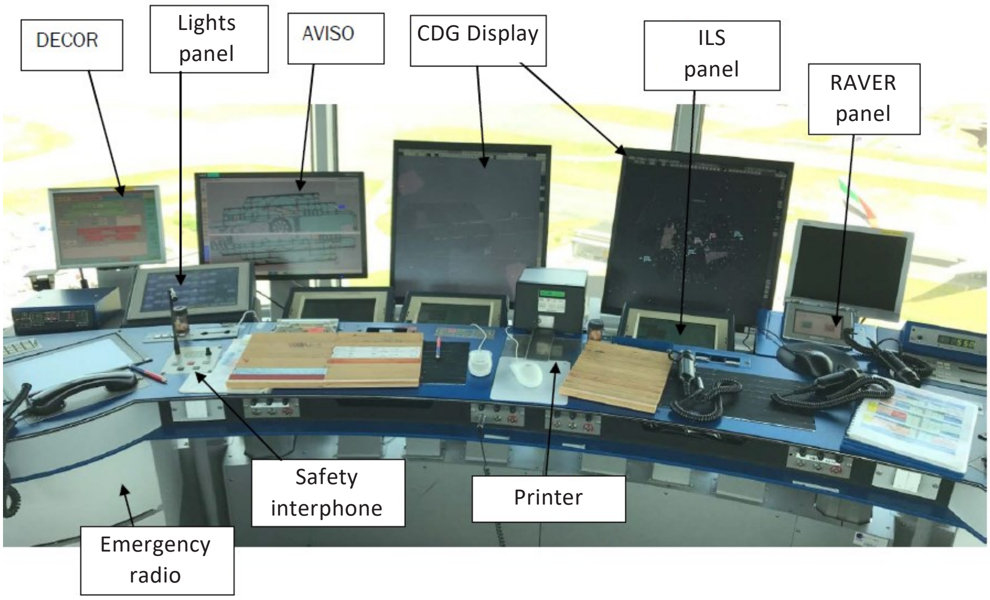


Figure 27: systems available to the TWR controller at CDG (source: CDG OM, annotated by the BEA)

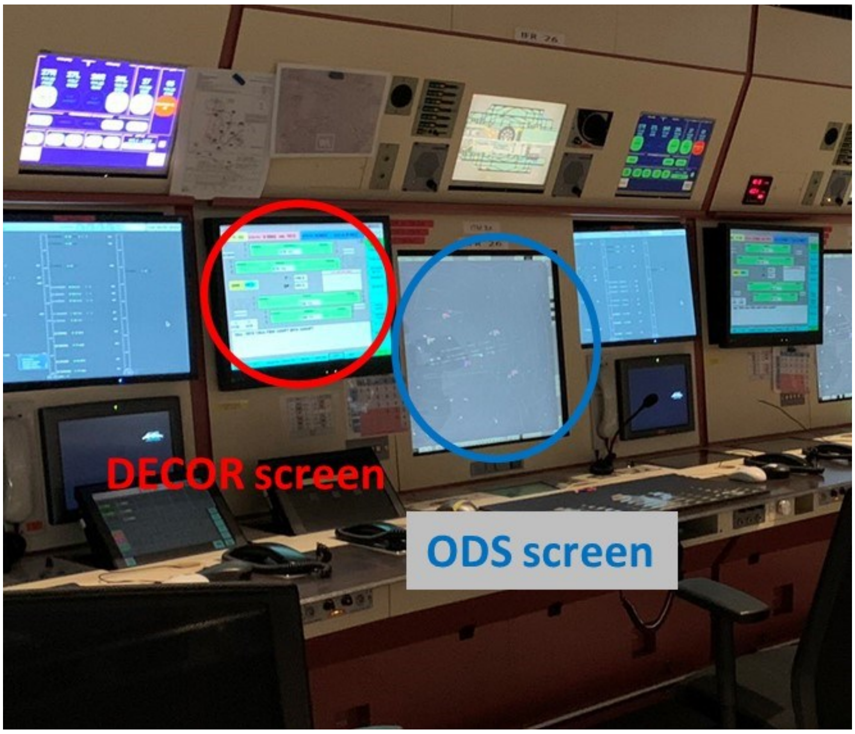


Figure 28: example of a control position in the approach room at CDG (source: BEA)

1.10.3.1 DECOR, ISATIS and BOREAL

DECOR (*Données environnement contrôle pour Orly et Roissy*, Orly and Roissy control environment data) is the general information transmission system for air navigation services at CDG and Orly, including in particular meteorological, ATIS, radionavigation means and runway occupancy information. The same interface is used for tower and approach positions. Controllers provide the QNH value based on this DECOR screen.

Meteorological information is generated automatically from Météo-France servers, it is updated at least every minute and transmitted automatically to CDG's ATM systems. This means that there can be no human error in the transcription of the QNH, either for the METAR, the ATIS, or the information contained in DECOR.

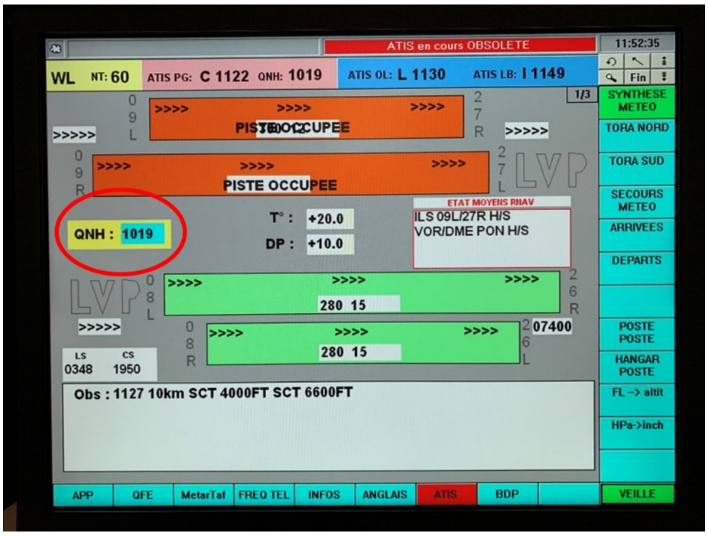


Figure 29: example of a DECOR screen display with QNH information (source: BEA)

The ATIS data entry and transmission system at CDG, ISATIS, uses meteorological information directly imported from Météo-France data. Any change of one hectopascal in the QNH must be updated in the ATIS. ATIS information is also distributed via a data-link connection (D-ATIS[46]).

BOREAL (*Balisage opérationnel avec retour d'état et d'alarme*, operational lights with status and alarm feedback) is the airport's light supervision system. It provides a real-time summary of the light status. Tower supervisors are responsible for managing the lights. They may delegate this task to the TWR controller. It is possible to control several functions of the light system, including the runway lights, the approach lights, the PAPI, etc. The brightness level can be selected for each element.

For each QFU, the light button (BAL) can be used to switch on all the available lights at once, including the approach lights, the touchdown zone lights, the runway lights and the PAPI.

1.10.3.2 Radar blip display

Safety nets

Various safety nets are available at CDG, including the following:

- Short Term Conflict Alert (STCA): this system anticipates a loss of minimum radar separation in the short term. In the event of an alert, the STCA indication appears on line 0 of the radar label for the aircraft concerned, alternating between orange and grey.
- Minimum safe altitude warning (MSAW): this system detects the risk of collision with terrain in the short term. In the event of an alert, the MSAW indication appears on line 0 of the radar label, alternating between orange and grey (see paragraph 1.10.4 for more details regarding MSAW operation).

Altitude display

The Operating Display System (ODS) implemented at CDG is a radar display system based on a system developed for en-route centres. This system does not have a function for automatically changing the altitude display from a flight level to a QNH altitude below the transition level.

Thus, by default, aircraft altitudes on the controllers' ODS screens (APP or TWR) are displayed as flight levels (FL, pressure altitude with baseline at 1013 hPa), based on data from the aeroplane's mode-C transponder. Since the mode-C transponder directly provides the flight level, this is therefore not based on the altimeter setting from the pilots' instruments.

However, the display tool has an "Alt" button, which temporarily displays, for as long as it is pressed, the QNH altitude for all aeroplanes. This QNH altitude, which is calculated using the mode C data of aeroplanes and from the QNH provided by Météo-France to the various ATM systems, is therefore distinct from the aeroplane's altimeter setting. The altitude is then preceded by an "A" on the radar label.

This button was not used by air traffic controllers during the serious incident.

[46] Digital-ATIS. In France, the following airports have a D-ATIS system: CDG, Orly, Nice, Lyon and Pau.

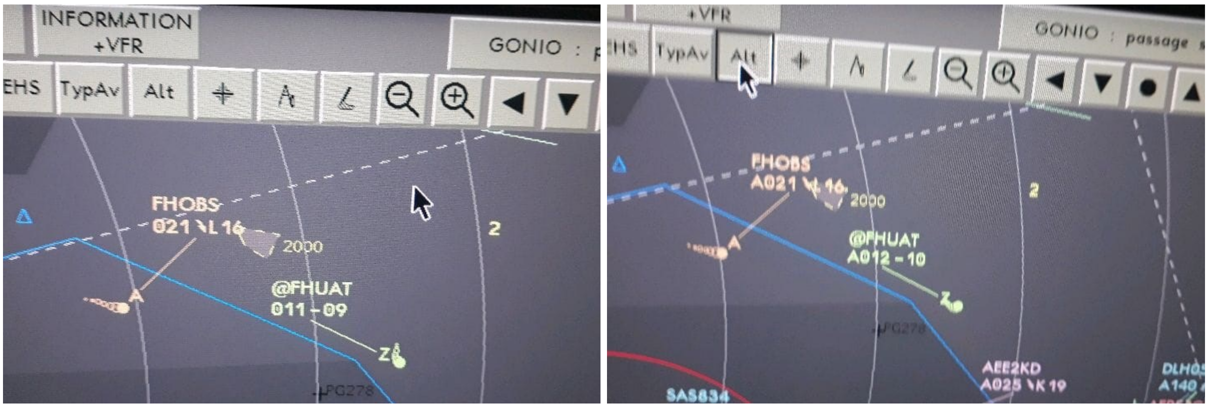


Figure 30: altitude displayed at CDG as FL (left), and as QNH altitude by pressing and holding "ALT" on the ODS (right) (source: CDG OM)

A national directive from the DSNA/DO recommends to air traffic units which are not equipped with ODS (CDG is thus excluded from this directive) that they automatically display the QNH altitude below the transition level. However, a number of air traffic control authorities still use the flight level value (1013 hPa) as the default setting today. This is the case for Nantes and Orly for example.

In the absence of a vertical profile display, it is difficult to detect an altitude deviation when not in level flight. During the first approach, the FAF's interception level at 5,000 ft was very short (approximately half a nautical mile), making it very difficult to detect the deviation. During the downwind leg for the second approach, the aeroplane remained in level flight for around seven minutes with a clearance at 5,000 ft. The radar label displayed a flight level altitude of "050" (or 051 depending on the precision) instead of the expected "053" (or 054) for a clearance at 5,000 ft with an altimeter setting of 1001 hPa.

Figure 31: radar label for flight NSZ4311 at 11:45:58, during the downwind leg for the second approach (source: DSNA)

Assuming an automatic display of the QNH below the transition level, the radar label for flight NSZ4311 would have displayed an altitude value of "A047" with a selected altitude at 5,000 ft of "@050" (see below), whereas the labels of the other flights cleared at 5,000 ft with an altimeter setting of 1001 hPa would have displayed an altitude of "050" for a selected altitude of "@050".

Enhanced surveillance mode S (EHS) information

The system can display Mode-S EHS data. Three parameters can be displayed, from left to right: the flight level (altitude or level) selected by the crew, the indicated airspeed in knots, and the instantaneous magnetic heading.

Figure 32: EHS data available to air traffic controllers (source: CDG OM)

The altimeter setting is part of the downlink information provided by Mode-S EHS through the Barometric Pressure Setting (BPS) parameter. This parameter is not processed by ATM systems at CDG (see paragraph 1.18.2).

1.10.4 Minimum Safe Altitude Warning (MSAW)

1.10.4.1 Basic principle

The Minimum Safe Altitude Warning (MSAW) is a ground-based collision avoidance system. This safety net warns air traffic controllers about an aircraft flying dangerously close to the ground and obstacles.

In France, the MSAW provides protection against hazards arising both below and in front of the aircraft, with two types of predictions. There is a certain safety margin with respect to the terrain for each of them:

- forecast hazard below the aircraft, based on the predicted altitude at the end of an extrapolation time;
- forecast hazard in front of the aircraft, based on the predicted position at the end of an extrapolation time, keeping the current altitude.

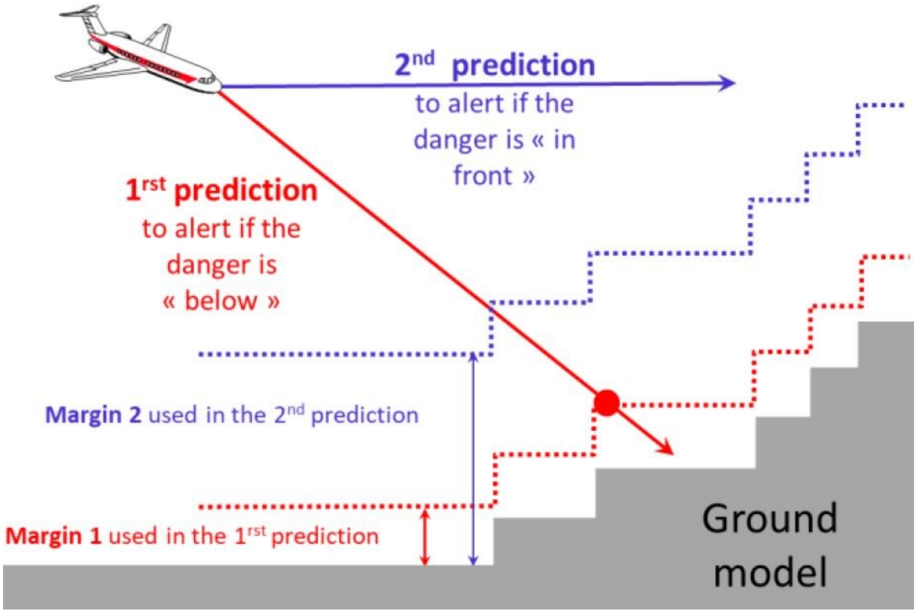


Figure 33: basic principle of MSAW (source: DSNA)

The MSAW uses the following information:

- the altitude value sent by Mode C of the aircraft's transponder (flight level information, pressure altitude at 1013 hPa), which is independent of the on-board altimeter setting. This value is corrected with the value of the QNH, which is automatically provided by Météo-France stations, and entered in air navigation services systems;
- a database of the terrain and obstacles in the vicinity of the airport.

At CDG, this system is active over a square zone measuring 64 x 64 NM and centred on the airport, within which the terrain is modelled by squares measuring 0.5 x 0.5 NM and including the main isolated artificial obstacles.

CDG is the only site in France for which the ground collision avoidance service is provided with a 100 ft quantification step, whereas for all the other French sites equipped with a MSAW, the calculation is performed using a 25 ft quantification step.

In the event of a forecast collision with the terrain below the aircraft, an alert is triggered if the predicted trajectory with respect to the terrain, or an obstacle, where applicable, falls below a margin set at 300 ft.

The MSAW anticipates the aircraft's position for an extrapolated time that takes into account the time required to generate and transmit the alert to the controller, the time required for the controller to react to the alert, the time required to transmit the flight information, and the time required for the pilot and the aircraft to react. At Paris-Charles de Gaulle, this position prediction time is 34 s. Within the DSNA, only the time required to generate/transmit the alert according to the radar display cycle can vary, between 4 and 8 s, depending on the organisation within which the MSAW is installed.

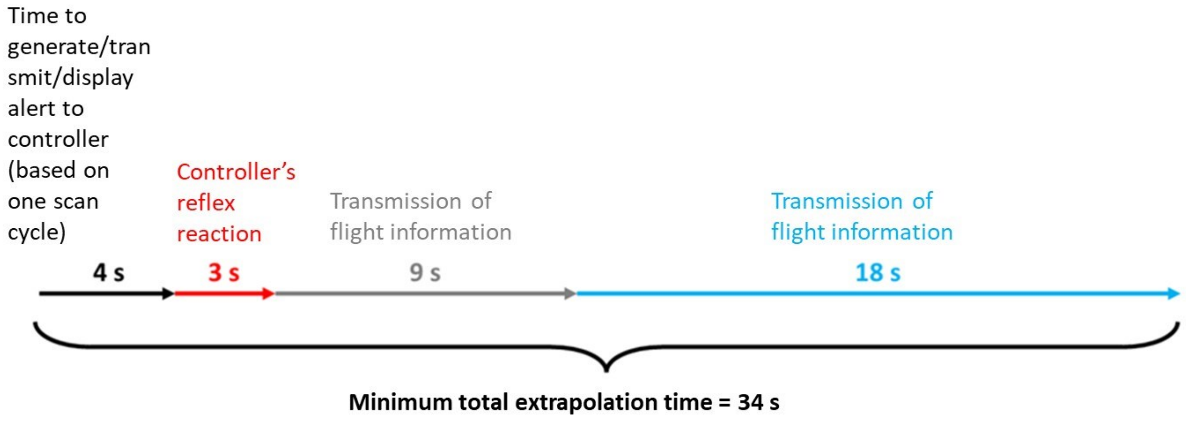


Figure 34: hypotheses for determining the extrapolation time (source: DSNA)

A MSAW alert is shown by:

- the aircraft's radar track being displayed on the controllers' screens, if it was not already displayed;
- an amber "MSAW" indication flashing in addition to the aircraft's radar label;
- an audible alert "*Beep, beep, terrain alert*".

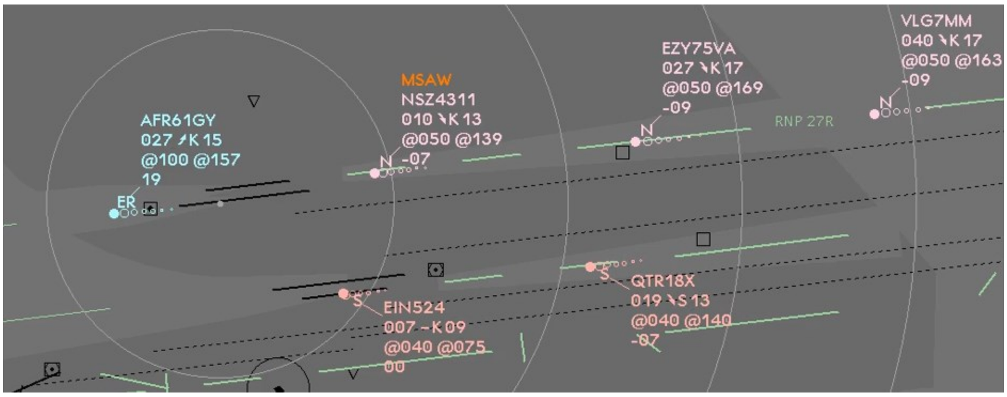


Figure 35: actual playback of the N-TWR controller's ODS radar screen when the MSAW was triggered during the first approach

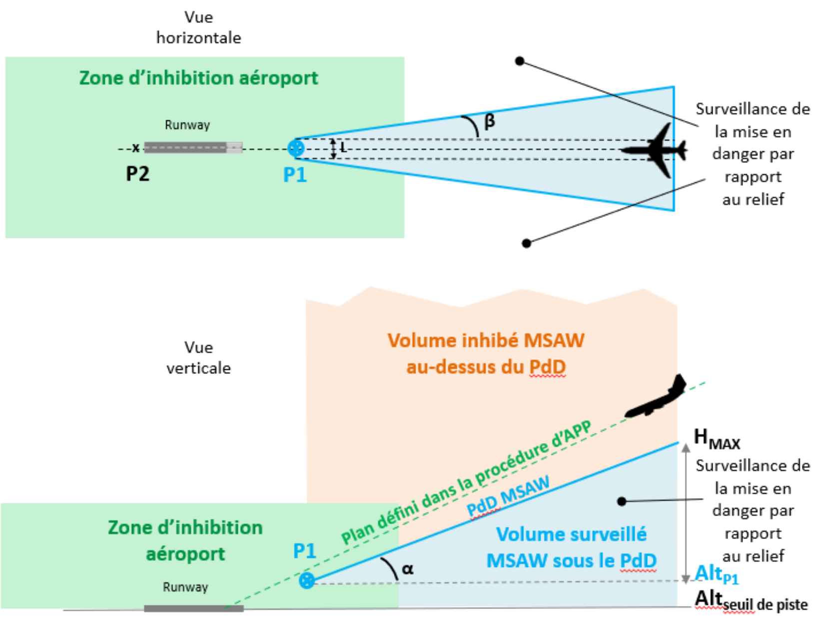
These alerts can be seen and heard on all the radar positions of the air traffic controllers. The MSAW alert is triggered immediately when the prediction conditions are met, and remains displayed as long as the activation conditions exist.

1.10.4.2 MSAW on final approach

To limit untimely alerts, a specific filter was introduced in France for final approaches, by creating a descent path threshold (PdD). In this processing volume, a MSAW alert is only triggered if the above conditions are met (34-second extrapolated path of the aeroplane entering the obstacle clearance margin of 300 ft) and if the aeroplane is below the descent path. Above this descent path, any collision prediction alert is inhibited.

On the day of the serious incident, the settings for MSAW alert zones, including the settings for the descent path filter, were configured to V6R1, a version that has been operational at CDG since 2009. In particular, the MSAW descent path volumes are determined using:

- a point at their base (P1), located at an altitude of 390 ft at CDG;
- a slope (α), which is 2.85° at CDG;
- a width (L), which is 0.09 NM at CDG;
- a maximum height (Hmax) used for filtering, which is 1,900 ft at CDG.



P1/P2	Axe du PdD MSAW
P1	Seuil du PdD MSAW
L	Largeur à la base du PdD
β	Angle de divergence du PdD

α	Pente du PdD
Alt P1	Altitude de P1
H_{MAX}	Hauteur maximale du PdD

Figure 36: MSAW monitoring on final approach (source: DSNA)

The slope α is decisive for filtering. The selected slope should suppress untimely alerts (by not triggering an alert for an aeroplane close to landing, if it is on the expected slope), while maintaining the alerts to prevent a collision with the ground. The selected point P1 should avoid untimely alerts caused by vehicles on the ground and by aircraft circulating within the airport.

1.10.4.3 MSAW system performance study

During the serious incident

Radar data from the day of the serious incident showed that three MSAW alerts were generated: two during the first approach and one during the second.

Although the aeroplane's two approaches were flown on an almost identical vertical profile, the MSAW alert was triggered during the first approach when the aeroplane had a radio-altimeter height of 239 ft RA, whereas it was 842 ft RA during the second approach.

The MSAW system performance study carried out with the DSNA/DTI services showed that, in the last five nautical miles of each approach, the 3° vertical profile followed by 9H-EMU due to the incorrect altimeter setting was almost tangent to the MSAW descent path (PdD) of 2.85°.

The uncertainty and inaccuracy of the aeroplane's altitude based on the radar, combined with the aeroplane's path (which was almost tangent to the MSAW descent path) and the altitude coding (within 100 ft), can explain the difference between the two approaches regarding the MSAW alerts generated.

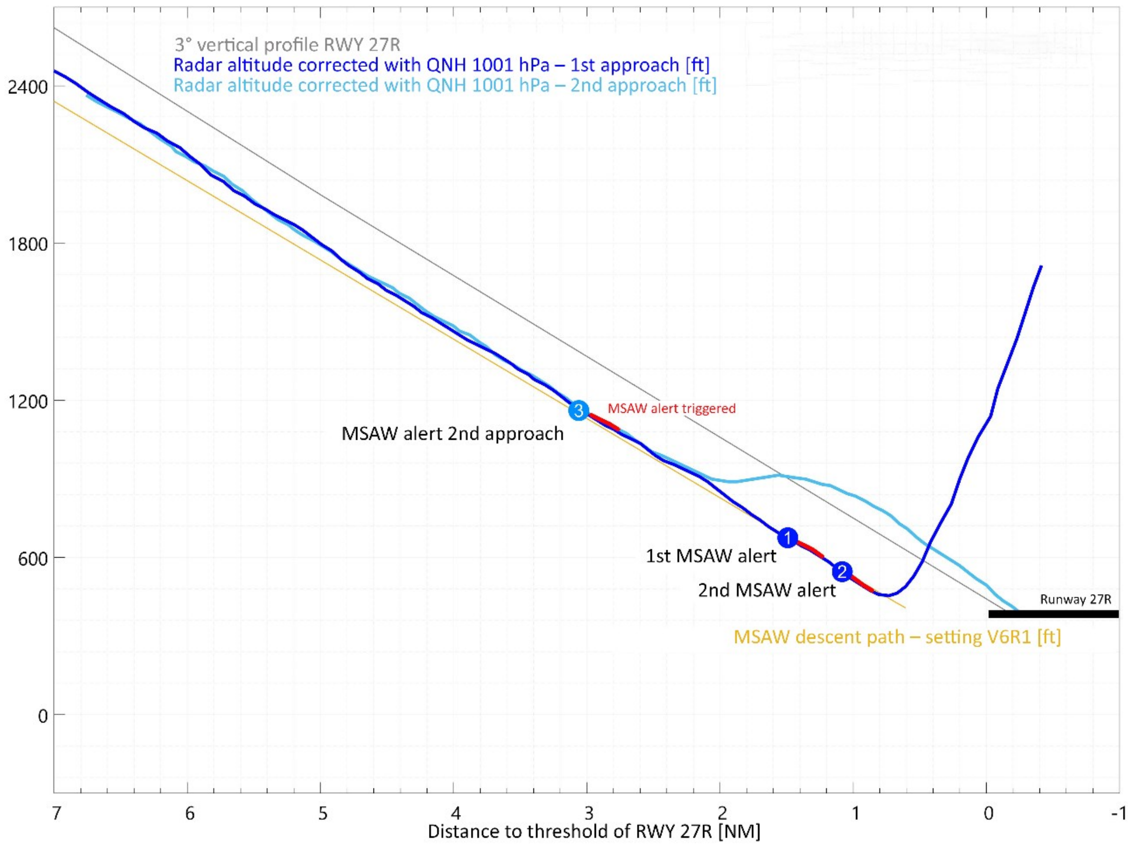


Figure 37: vertical path of 9H-EMU during the two approaches and MSAW alerts

History of MSAW versioning at CDG

In 2013, following the identification of several false MSAW alerts, as well as a MSAW alert not being generated for a situation requiring it, the CDG unit asked the DSNA/DTI to modify the MSAW settings.

This was an opportunity for the DSNA/DTI to thoroughly review the MSAW settings (and particularly the descent paths). For example, the following could be observed:

- for the south parallel runways 08 and north parallel runways 09 (arrivals facing east), only one descent path was defined for both runways of each set, whereas the runways have displaced thresholds in relation to each other. Therefore, the descent path was only correct for one runway of each set of parallel runways, and too permissive for the other;
- the descent paths were sometimes too permissive because the slope was too shallow.
- certain inhibition zones needed corrections;
- the obstacle database was not up-to-date.

In 2017, the DSNA/DTI delivered a new configuration, V7R1, to CDG. Many changes were made in this new version, including changes to the position of the departure point, to the slope and to the width of the descent path.

A succession and accumulation of technical and implementation malfunctions, lack of resources, as well as the triggering of numerous untimely alerts during the test phase of this new version (V7R1), prevented it from being brought into operational service before the day of the serious incident.

The simulations carried out by the DTI with V7R1, based on the data from the serious incident to 9H-EMU, showed that, with the descent path setting of this version, the MSAW alert of the first approach would have been triggered as soon as the 34-second projected margin with respect to the terrain was less than 300 ft, at around 11:41:01 (i.e. approximately 30 s earlier than during the serious incident with V6R1), at an altitude of approximately 1,265 ft QNH 1011 (992 ft QNH 1001, 665 ft RA), 2.6 NM from the runway threshold.

In April 2023, following the serious incident to 9H-EMU, a new version of V7R1 was brought into operational service. In September 2023, the DNSA informed the BEA that the new MSAW V7R1 configuration had been discarded and that the V6R1 configuration had been restored. This roll-back was explained by numerous untimely alerts which occurred during the summer of 2023 due to the cumulative effect of particular meteorological conditions corresponding to high temperatures combined with a low QNH and rounding errors linked to the 100 ft quantification step, which resulted in the position of aircraft seen by the MSAW system being much lower than their actual position. Since then, the DSNA has been working on a V8 configuration, which has been under evaluation with CDG since October 2023 and is scheduled to come into service in the summer of 2024.

Standardisation

There is no regulatory obligation at European level to implement MSAW-type systems to detect the risk of collision with terrain, nor are there any requirements or official standardisation criteria relating to their configuration. The elements relating to MSAW procedures and phraseology are described in paragraph 1.17.1.3.6.

However, Eurocontrol developed a three-part guide for MSAW in cooperation with several air navigation service providers, in particular with the DSNA, in order to promote its implementation and a certain degree of standardisation. The guide, which has no regulatory value, is available online.

It is also important to note that the MSAW system described in this guide does not really apply to the final approach, for which a specific function must be introduced to avoid untimely alerts on each landing. In this regard, Part III of the guide, paragraph 2.7 MSAW exclusion areas indicates that: "*MSAW is not very suitable for protecting against deviations from the expected final approach path. It is recommended to suppress MSAW functioning in the immediate vicinity of airports and to install an Approach Path Monitor (APM) to cover the final approach.*"

This is consistent with the definitions provided by Eurocontrol, which are included below:

- Minimum Safe Altitude Warning (MSAW): "*A ground-based safety net intended to warn the controller about increased risk of controlled flight into terrain accidents by generating, in a timely manner, an alert of aircraft proximity to terrain or obstacles.*"
- Approach Path Monitor (APM): "*A ground-based safety net intended to warn the controller about increased risk of controlled flight into terrain accidents by generating, in a timely manner, an alert of an unsafe aircraft flight path during final approach.*"

Approach Path Monitoring (APM)

ICAO and EASA make no reference to APM systems, which therefore have no regulatory definition and even fewer standardisation criteria.

A Guide similar to the one developed for MSAW has been made available by Eurocontrol for APM. The definition provided by Eurocontrol does not include the detection of a deviation from the final approach path, as its name might imply. The guidelines include conceptual descriptions, but do not include technical characteristics to define monitoring volumes or a single method for detection.

The lack of precise criteria in the APM definition leads to disparities in the functionalities developed in Europe. In France, the DSNA indicated that the APM functionality is to some extent provided by the MSAW, as this prevents CFIT during the final approach phase. The DSNA also indicated that it is considering the integration of an APM functionality in the literal sense of the acronym, i.e. a functionality for monitoring the aeroplane's position in relation to the theoretical approach path. Such a functionality would also detect non-stabilised approaches.

1.11 Flight recorders

The serious incident was identified a few days after it occurred and the data from the FDR and CVR flight recorders was no longer available.

Data from the non-protected Direct Access Recorder (DAR), which is similar to the FDR data, as well as audio and radar data from the air navigation services at CDG, were retrieved and synchronised with the DAR time base.

More than 500 parameters were recorded in the DAR's flight data. A number of parameters were not recorded, such as the Flight Director (FD) positions, the Vertical Deviation (V/DEV), or the Master Caution alerts.

1.12 Wreckage and impact information

Not applicable.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

Not applicable.

1.15 Survival aspects

Not applicable.

1.16 Tests and research

Not applicable.

1.17 Organizational and management information

1.17.1 Air navigation services in France

1.17.1.1 Responsibility for preventing ground collisions

According to international[47] and European[48] standards, the purpose of the air traffic control service is to ensure separation between aircraft and obstacles in the manoeuvring area. Beyond this area, it is the pilot's responsibility to ensure that the clearances issued by the air traffic control unit do not compromise safety, except when the aircraft flying under IFR is being vectored or when it receives a direct route instruction which takes the aircraft off the published ATS route.

1.17.1.2 General information on controller training

In Europe, air traffic controller training must meet the requirements of Regulation (EU) 2015/340 laying down technical requirements and administrative procedures relating to air traffic controllers' licences and certificates. This training is divided into:

- initial training, which takes place, in France, at the École Nationale de l'Aviation Civile (ENAC) and leads to the issuance of a trainee air traffic controller licence;
- unit training, which takes place in the ATS unit and leads to the issuance of an air traffic controller licence and/or a rating endorsement. The organisation of the unit training, the training courses for each unit endorsement and the processes for theoretical and practical assessments are defined in a Unit Training Plan (UTP)[49];
- continuation training, which takes place in the controller's assigned unit. It is designed to maintain the validity of the endorsements of the licence. The organisation of the continuation training, the training courses for each unit endorsement and the processes for theoretical and practical assessments are defined in a Unit Competence Scheme (UCS).

The UCS is globally covered by technical information notes issued by the DSNA, however the content itself is largely left up to each unit. The national directives are limited to the elements relating to the minimum hours in position conditions, as well as to the unit endorsement revalidation conditions. In particular, these notes stipulate a minimum duration of six days for continuation training (which may be split up and spread over the three years of validity of the unit endorsement, or aggregated in the case of early revalidation) as well as the general topics on which training must focus, i.e.:

- Standard Practices and Procedures (SPP) drawn up on the basis of local or national feedback, as necessary;
- Human Factors (HF);
- Abnormal and Emergency Situations (AES) (this topic must last a minimum of three half-days and must contain at least three practical exercises).

[47] ICAO doc 4444 PANS-ATM and ICAO doc 8168 PANS-OPS.
[48] Regulation (EU) 2017/373 "ATM/ANS" and regulation (EU) No 923/2012 "SERA".
[49] The Paris-Charles de Gaulle UTP defines eight unit endorsements (four intermediate, one final, one partial, two restricted). The four intermediate endorsements correspond to the different rating levels separating the newly assigned controller from the final ZZ endorsement.

The UCS for the Paris-Charles de Gaulle training unit describes six days of refresher training over three years. Virtually all UCSs of the DSNA control units also apply this six-day period over three years to cover controllers' continuation training, regardless of the volume of traffic, the complexity of airspaces or other factors that may have an impact on the proficiency requirements.

Abnormal and emergency situations

As regards training in Abnormal and Emergency Situations (AES), a minimum duration of 1.5 days is advised by the DSNA head office. Each control unit defines the content of this training. Indeed, the DSNA believes that these units are best able to identify abnormal and emergency situations likely to arise in their specific environment. They also have access to feedback on safety events occurring within the unit and are therefore in a position to use it and potentially incorporate it into continuation training, where applicable.

The DSNA does not publish at national level, an exhaustive list of abnormal and emergency situations, and each unit is responsible for drawing up – or not – such a list.

However, the DSNA does offer at national level, training materials on a number of identified safety topics. On the date of the serious incident, there were no such materials regarding the phraseology to be used in the event of a MSAW alert or on the importance of the QNH for barometric approaches.

In the absence of an official list of abnormal and emergency situations, there is no way of ensuring that these situations and the associated procedures are periodically reviewed. It is therefore possible that a number of emergency issues, topics or procedures will not be the subject of any regular training in a given unit, if they are not identified as relevant when the AES programme is drawn up for a given three-year cycle.

1.17.1.3 Operational tasks: regulations, procedures and training

1.17.1.3.1 RNP approaches

Regulations and procedures

ICAO texts[50] and the applicable European regulations[51] require the approach controller to indicate, on first contact with an arriving aircraft, the type of approach procedure to be expected (ILS, RNP, VOR etc.). In the event of an RNP approach, the pilot is not required to indicate the minima used (LNAV or LNAV/VNAV or LPV). Similarly, when the controller issues the clearance for an RNP approach, the associated minima are not specified.

RNP approaches were initially deployed at Paris-Charles de Gaulle so that instrument approaches could be carried out should the ILS be unavailable. They offer minima between those of a conventional, non-precision approach and those of a ILS CAT I approach, and can therefore be used as long as there is no severe deterioration in the weather conditions. They were implemented on the north parallel runways in 2016 following a safety study. They were then deployed on the south parallel runways in 2017.

[50] ICAO doc 4444 PANS-ATM and ICAO Doc 9432 Manual of Radiotelephony.

[51] Regulation (EU) No 923/2012 "SERA".

The Operating Manual (OM) of the air navigation service at Paris-Charles de Gaulle provides for the use of RNP operations as a backup in the event of a problem with the ILS. Moreover, on the date of the incident, the OM stated that training sessions for RNP final approaches were scheduled to take place every Friday afternoon on a set of parallel runways between 13:30 and 17:00 local time. However, these training sessions might be cancelled in the event of adverse weather conditions and/or if traffic is particularly heavy or complex.

The CDG OM points out the following differences between RNP approaches and ILS approaches:

- although the radar paths for RNP approaches are strictly identical to those for the ILS (identical 3° vertical profile and NTZ/NOZ[52]), the area within which the crew must have intercepted the path may be different from that associated with ILS operations;
- there is only one interception altitude for RNP approaches (5,000 ft for runway 27R at CDG). Controllers must pay particular attention to this point, as it entails specific interception constraints that are different from those of the ILS;
- a slight increase in path changes in the airspace managed by the approach controllers in relation to aircraft without the LNAV/VNAV capability;
- in the event of a missed approach followed by an RNP procedure during the second approach, the crew needs more preparation time, requiring appropriate vectoring;
- phraseology specific to RNP approaches.

There are no special indications in the OM concerning the barometric descent profile of some RNP approaches and the importance of the QNH for this type of approach in relation to a possible CFIT risk.

Apart from the characteristics listed above, the procedures for an RNP approach are identical to those for an ILS approach, in particular for TWR controllers, for whom the difference in the type of approach procedures is virtually unnoticeable.

Training

On the date of the serious incident, the DSNA had not established a coordinated programme at national level for the training aspect of the implementation of PBN. A steering committee on this topic was created in 2017 and feedback was required regarding the impact of PBN on working methods. This action did not result in any concrete follow-up measure to coordinate training activities.

Since the beginning of 2010s, the initial training of student air traffic control engineers at the ENAC has covered RNP approaches in depth, both in terms of the classification and design of these procedures and in terms of operational aspects on board and on the ground. Since the 9H-EMU event, the training of senior technicians in civil aviation studies and operations (who may work as air traffic controllers on certain aerodromes) has also included this theme. The associated risks are also addressed, in particular those linked to altimeter errors and to temperature effects.

[52] Non-transgression zone (NTZ)/Normal operating zone (NOZ)

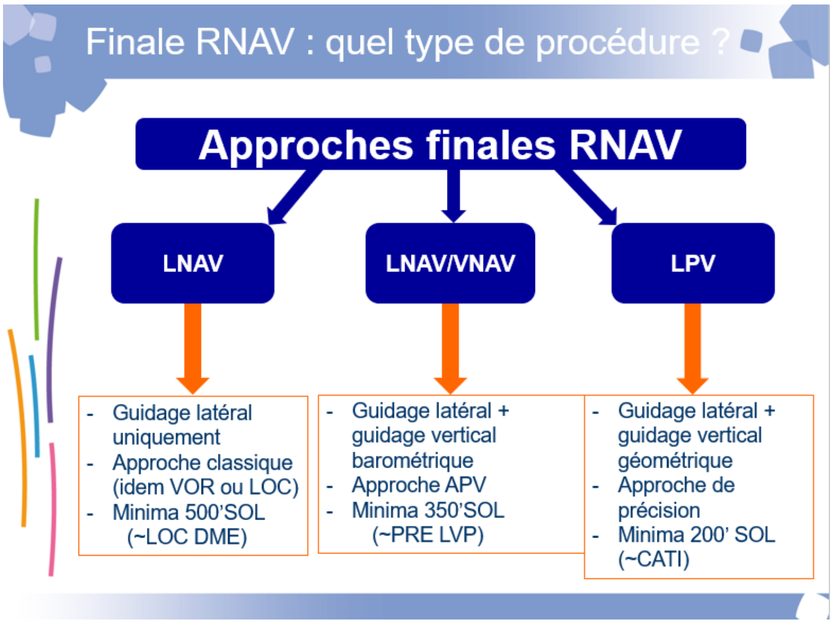
The phraseology taught is strictly based on the document entitled *Manuel de phraséologie à l'usage de la circulation aérienne générale* (Phraseology manual for general air traffic), which was drawn up in association with the ENAC. These programmes and the regulations governing them were not in force at the time of the initial training of the controllers involved in the serious incident, with the exception of the N-TWR assistant controller on duty during the first approach, who became the N-TWR controller for the second approach.

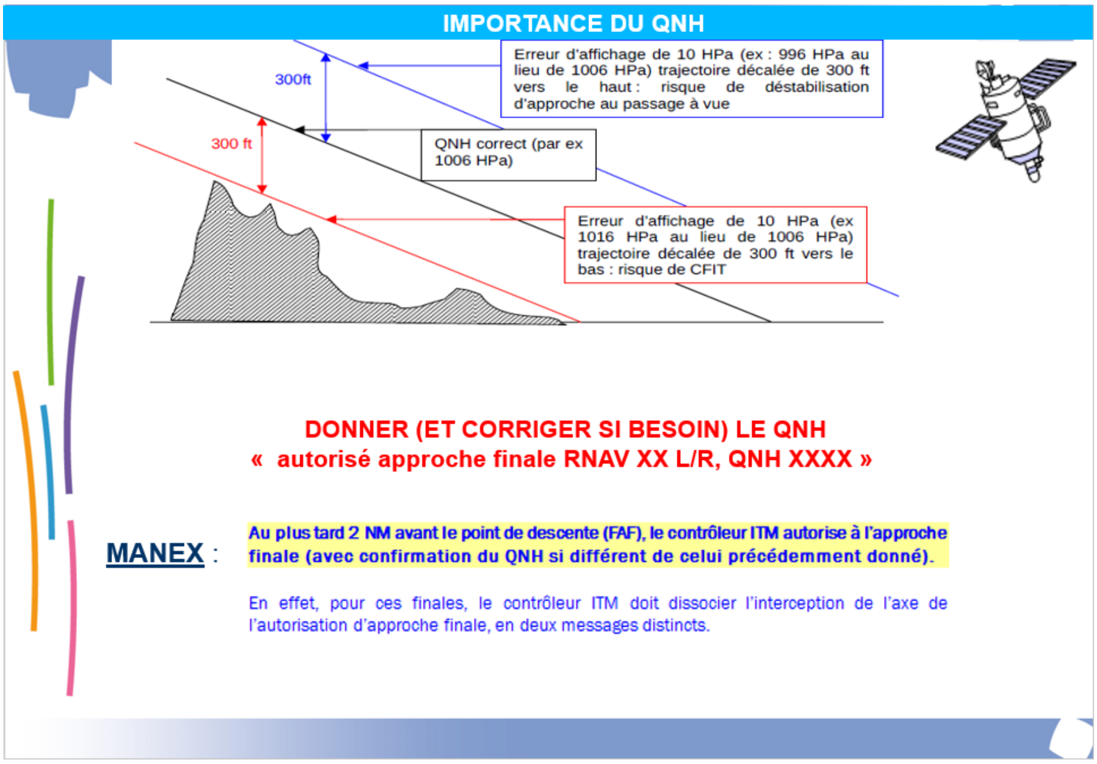
During unit training, the characteristics and procedures associated with PBN approaches to Paris-Charles de Gaulle (as well as to peripheral aerodromes) are taught in theory and applied in simulation during the so-called "pre-OJT" courses for the acquisition of successive unit endorsements. These are addressed in theory and in simulation in the course entitled "*Initiation à la Salle IFR, secteurs ARRIVEE*" (Introduction to the IFR Room, ARRIVAL sectors) and are designed to present the interactions which exist between the work of the TWR and of the IFR room, in particular the ITM sector.

As part of the continuation training in Standard Procedures and Practices (SPP), the programme for the period 2021-2024 included a section entitled "*Procédures RNAV*" (RNAV operations), which was attended by the three controllers involved in the serious incident. This training covered general aspects of the PBN and RNAV concepts as well as RNP approaches for Paris-Charles de Gaulle and the satellite aerodrome concerned. Reminders concerning the differences between LPV, LNAV/VNAV and LNAV approaches were also discussed, with a particular focus on the similarity between LPV and ILS CAT I approaches, as well as the risks associated with conducting some of these approaches with an incorrect QNH.

Moreover, in addition to training, the Control subdivisions organised regular briefings on PBN for controller teams to support the deployment of PBN on French territory. This was particularly the case at Paris-Charles de Gaulle. Attendance at these briefings was mandatory as part of the change adaptation training.

The material from the last RNAV briefing given before the serious incident was sent to the BEA and mentions the different RNP approach operations and their characteristics, as well as the importance of the QNH:


Finale RNAV : quel type de procédure ?
Approches finales RNAV
LNAV
LNAV/VNAV
LPV
- Guidage latéral uniquement
- Approche classique (idem VOR ou LOC)
- Minima 500'SOL (~LOC DME)
- Guidage latéral + guidage vertical barométrique
- Approche APV
- Minima 350'SOL (~PRE LVP)
- Guidage latéral + guidage vertical géométrique
- Approche de précision
- Minima 200' SOL (~CATI)


IMPORTANCE DU QNH
300ft
Erreur d'affichage de 10 HPa (ex : 996 HPa au lieu de 1006 HPa) trajectoire décalée de 300 ft vers le haut : risque de déstabilisation d'approche au passage à vue
300 ft
QNH correct (par ex 1006 HPa)
Erreur d'affichage de 10 HPa (ex 1016 HPa au lieu de 1006 HPa) trajectoire décalée de 300 ft vers le bas : risque de CFIT
DONNER (ET CORRIGER SI BESOIN) LE QNH
« autorisé approche finale RNAV XX L/R, QNH XXXX »
MANEX :
Au plus tard 2 NM avant le point de descente (FAF), le contrôleur ITM autorise à l'approche finale (avec confirmation du QNH si différent de celui précédemment donné).
En effet, pour ces finales, le contrôleur ITM doit dissocier l'interception de l'axe de l'autorisation d'approche finale, en deux messages distincts.

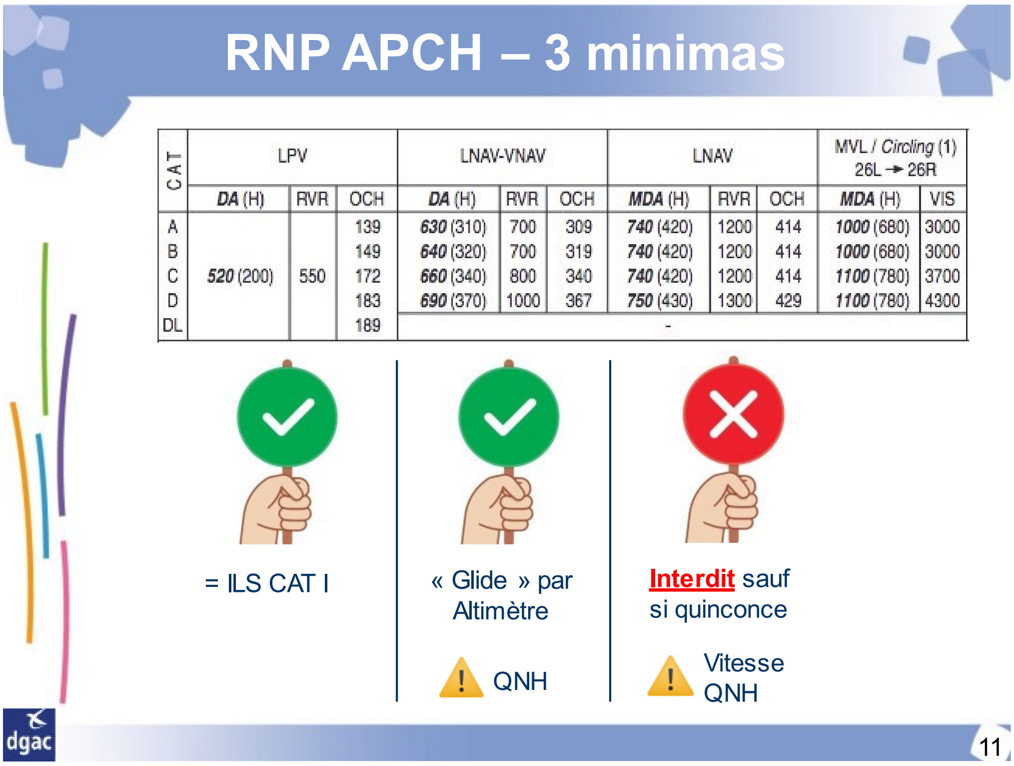


Figure 38: excerpt from training materials on RNP at CDG (source: DSNA)

During the various interviews with CDG controllers in the course of the investigation, it appeared that the danger and seriousness represented by an incorrect QNH value for RNP approaches were not necessarily perceived and understood, even though this topic was addressed in training and during briefings. The controllers were not necessarily aware that this could lead to a collision with the ground. During the interviews, it was also regularly mentioned that RNP approaches were presented as ILS approaches, with only a few differences.

1.17.1.3.2 Air-ground communication

Regulations and procedures

ICAO Annex 10-Volume II, the SERA regulation and the French Order of 11 December 2014 relating to the implementation of the SERA regulation are the texts that define the applicable phraseology requirements, including conventional phraseology expressions in English and French. These same expressions are also found in ICAO doc 4444 PANS-ATM. From these texts come manuals that indicate how to use the conventional expressions and give examples of their use.

The *Manuel de phraséologie à l'usage de la circulation aérienne générale* (Phraseology manual for general air traffic) published by the Operations Directorate (DO) of the DSNA, which was applicable at the time of the serious incident in its ninth edition of 15 May 2021, defines read-back as an action by the pilot which consists in repeating all or part of a message, so that the controller who issued this message can check that it was correctly received.

ICAO Doc 9432 Manual of Radiotelephony states that, "*Read-back requirements have been introduced in the interests of flight safety. The stringency of the read-back requirement is directly related to the possible seriousness of a misunderstanding in the transmission and receipt of ATC clearances and instructions. Strict adherence to read-back procedures ensures not only that the clearance has been received correctly but also that the clearance was transmitted as intended.*"

The Paris-Charles de Gaulle OM highlights the importance of the hear-back as part of the GND and TWR controllers' functions. It is also specified that, although the TWR assistant controllers may visually monitor the control situation as well as monitoring the TWR frequency, when their other tasks allow them to do so, this traffic monitoring does not replace that of the TWR controller, who remains solely responsible for checking the read-back and transmitting the correct version of the elements concerned.

Training

European Regulation (EU) 2015/340, in the modules for communication specified in AMC1 ATCO.D.010(a)(2)(vi) on the composition of initial training, mentions the sub-topic "Communication techniques, read-back/verification of read-back". This sub-topic is covered numerous times and applies to the various subjects presented in these regulations.

Read-back and the detection of read-back errors are aspects which are addressed and assessed both from a theoretical and practical perspective in initial training courses. This is justified both for regulatory and educational reasons relating to best practices in exercising air traffic controller functions.

During discussions with the BEA, the Instruction subdivision of the Paris-Charles de Gaulle control unit indicated that the read-back and the verification of the read-back are important topics which are addressed throughout the unit training. However, it is considered that the basic principles are taught during the training courses delivered at the ENAC and read-back/hear-back is therefore not formally presented during this training.

The skills in hear-back and detecting read-back errors are assessed in simulation and during the examinations that validate the acquisition of unit endorsements. During the interviews, it was reported that failure to detect a read-back error during a simulation session resulted in a negative assessment and systematic failure in an assessment process. However, it was also reported that no failures due to a read-back error were recorded at Paris-Charles de Gaulle during the assessment process for obtaining or revalidating a unit endorsement.

As regards refresher training, topics relating to read-back can be addressed during training courses covering human factors. As part of these training courses, the DSNA provides training materials at national level, which are implemented by the units at local level. For example, the materials for the 2009-2011, 2012-2014, 2015-2018 and 2021-2023 periods addressed issues concerning the mechanisms associated with read-back, at various levels.

Studies of air-ground communication errors

Communication between pilots and controllers is based on a communication chain: controller's clearance – pilot's read-back – controller's verification of read-back (hear-back). During normal situations, and especially when adverse factors are likely to affect communication, the confirmation/correction process is a line of defence against communication errors. Numerous studies focused on communication errors.

A study conducted under the aegis of Eurocontrol showed that the absence of an acknowledgement or a correction by the controller may be implicitly perceived by the pilot as a confirmation of the read-back[53].

As part of Eurocontrol's EVAIR Bulletin 21 published in August 2020, 13,000 Air Traffic Management (ATM) occurrence reports, collected between 2015 and 2019 during the summer periods (01 April – 30 September) and representing approximately 20 million flights, were studied. One of the main contributors to ATM occurrences was air-ground communication: spoken communication (call sign confusion, language and accent, noise and interference, etc.) and operational communication (read-back errors, phraseology, transfers, etc.), with around 1.4 occurrences reported per 10,000 flights. Hear-back errors accounted for between 0.1 and 0.2 events reported per 10,000 flights.

A study[54] was conducted by the Netherlands aerospace centre (NLR) for Eurocontrol in 2004, based on the analysis of a sample of 444 incidents[55] connected to communication problems between controller and pilot. It showed that, of all the errors identified, the most common was the read-back/hear-back error (31%). In 38% of the cases, the consequences of these read-back/hear-back errors was an altitude deviation.

The FAA also conducted several studies into communication errors between pilots and air traffic controllers. In particular, a study published in 1998 identified "*Hearback type II*" errors, which are described as situations in which "*the pilot correctly repeats the clearance that was issued; but the controller fails to notice that the clearance issued was not the intended one.*" The authors of this study analysed this type of error, observing that "*saying something different from what we intended to say is all too easy to do.*" This is why they recommended that controllers "*treat the readbacks as they would any other piece of incoming information.*" They also recommended that controllers "*actively listen to the readback and check it against the flight strip notations.*"

The DSNA also identified air-ground communication as a vector for improvement. This topic was the subject of a work request from the safety occurrence processing body (ITES) during its meeting on 07 April 2021. The experts who took part in this work reminded the participants of the main communication mechanisms, in particular the "focused listening" mechanism. In this regard, they mentioned that hear-back may be done in two "modes":

- when hear-back is the main task, listening is said to be "focused", with maximum cognitive availability. This situation is ideal, allowing any errors to be heard and corrected. This operating mode is determined by a situation in which tasks can be performed as a sequence rather than concurrently, without being interrupted or anticipating future traffic;
- when hear-back is a background task, listening is said to be "half-focused", and the controller relies on his habits and familiarity with a number of messages (frequencies, geographical points, etc.), or on the fact that, if the sound of the messages differs from what is expected, this will attract his attention.

[53] European Action Plan for Air Ground Communications Safety, Ed 1.0 May 2006

[54] Air-ground Communication Safety Study: An analysis of pilot-controller occurrences.

[55] Incidents in 2002-2003, in Europe, involving aeroplanes with a maximum take-off weight of more than 5.7 t and engaged in commercial air transport.

In this study, the DSNA detailed several factors contributing to the impairment of the ability to detect a read-back error, such as fatigue, the after-effects of the COVID-19 context, low traffic situations, and stress at the position.

Lastly, in its Safety Bulletin #68, the DSNA mentioned the correction loops that a TWR assistant or TWR coordinator controller can constitute, by being able to detect a verbal slip-up by the TWR controller. However, it was clearly specified that this corrective listening task is not identified as a priority. Similarly, it was noted that other crews listening to the radio frequency can also pick up on any errors previously missed under certain conditions.

1.17.1.3.3 Transition altitude/level

The transition altitude is defined in ICAO Doc 8168[56] “PANS-OPS” as “*the altitude at or below which the vertical position of an aircraft is controlled by reference to altitudes.*” The transition level is defined as “*the lowest flight level available for use above the transition altitude*”. This definition is transposed at European level into Regulation (EU) No 923/2012 “SERA”.

As regards the transition altitude, PANS-OPS volume 3 indicates the following: “*2.1.2.4 The height above the aerodrome of the transition altitude shall be as low as possible but normally not less than 900 m (3 000 ft).*”

The increase in traffic and the introduction of jet aeroplanes at the end of the 1950s led ICAO to draw up a policy on transition altitudes in particular, which is still in force today. At the time, there were several reasons for this principle. One of the main reasons was the lack of air navigation service facilities. Some units did not have the necessary facilities to provide en-route traffic with information on current pressure. Provisions such as the use of the standard QNH at 1013.25 hPa and a relatively low transition altitude were thus adopted all around the world, providing a common reference for vertical separation in flight.

Since then, the organisation of air navigation services and meteorological information has evolved considerably. As a consequence, many States set high transition altitudes. In the United States, the transition altitude was set at 18,000 ft from the outset. Today, a transition altitude of 10,000 ft or more is used not only in the United States and Canada, but also in Australia (10,000 ft), New Zealand (13,000 ft), Japan (14,000 ft) and the Philippines (11,000 ft).

In Europe, a wide variety of transition altitudes are used. Historically, in line with international regulations, France established low transition altitudes, generally between 3,000 ft and 6,000 ft depending on the airport.

The Single European Sky set up in the 2010s highlighted the issue and relevance of harmonising and raising the transition altitude. Various working groups, mandated by EASA and Eurocontrol to handle this topic, did not conclude that such harmonisation would bring any obvious benefits[57]. There was no change in policy regarding the transition altitude. However, it was pointed out that the ICAO requirements in this respect were obsolete. The issue of barometric approaches was not taken into account in these studies, nor subsequently in the writing of the IR-PBN regulation.

[56] Procedures for air navigation services Aircraft Operations – Volume III – Aircraft Operating Procedures. First edition, 2018.
[57] See for example Eurocontrol’s document Network Operations Team NETOPS/12 IP04 or the results of EASA’s A-NPA 2012-01 Harmonised Transition Altitude.

Eurocontrol's work on cockpit workload according to altitude and the safety study on Baro-VNAV approaches conducted in 2010 concluded that it would be preferable for the transition altitude to be raised above 10,000 ft to allow flight crews to carry out critical actions without interference from secondary tasks, that this would reduce the risk of omission or error when changing the altimeter setting, and that this would also allow more time for the crew and controllers to identify a possible incorrect altimeter setting.

1.17.1.3.4 Transmission of altimeter setting information

ICAO doc 4444 PANS-ATM, as well as Regulation (EU) 2017/373 known as "ATM/ANS" and Regulation (EU) No 923/2012, known as "SERA" (Standard European Rules of the Air), stipulate the following:
"*SERA.8015 Air traffic control clearances:*
Except when it is known that the aircraft has already received the information in a directed transmission, a QNH altimeter setting shall be included in:
i) the descent clearance, when first cleared to an altitude below the transition level;
ii) the approach clearance or the clearance to enter the traffic circuit;
iii) the taxi clearance for departing aircraft."

Therefore, the procedures applied by the DSNA and the CDG unit, by way of its OM, as regards the transmission of the altimeter setting for arriving aircraft, consist in:

1) communicating the altimeter setting via the ATIS message as previously described in paragraph 1.9.1;
2) transmitting the altimeter setting by way of radio exchanges when first cleared to an altitude below the transition level.

As the altimeter setting is systematically transmitted with this clearance, it is not repeated at part of the approach clearance or the clearance to enter the traffic circuit. Indeed, the DSNA considers that, since the QNH is given when cleared to descend below the transition level, the mention "*except* ..." in point SERA.8015 allows the requirement of ii) to be waived and the QNH not to be repeated as part of the subsequent approach clearance.

Some of the controllers questioned in the scope of the investigation said that they almost always specify the QNH when they transmit a clearance containing an altitude. These are personal habits.

The quick-reference sheet regarding RNP final approaches to CDG for the ITM position stipulates the following phraseology for the approach clearance: "*AFR023, QNH 1018, autorisé finale RNP piste 08R*" / "*ACA870, QNH 1018, cleared RNP final runway 08R*". This phraseology, which differs from the OM in that it includes the QNH in the approach clearance, is only rarely used in practice.

1.17.1.3.5 Altitude monitoring

ICAO Doc 4444 PANS-ATM on air traffic management[58] and Regulation (EU) 2017/373 known as "ATM/ANS IR[59]" indicate that "*the tolerance value used to determine that the pressure-altitude-derived level information displayed to the air traffic controller is accurate should be ±60 m (±200 ft) in RVSM airspace.*" (RVSM = Reduced Vertical Separation Minima). "*In other airspace, it should be ±90 m (±300 ft)*." This is particularly the case for approaches such as those at Paris-Charles de Gaulle.

[58] 8.5.5.1 Verification of level information
[59] AMC 1 ATS/TR.155(f) TOLERANCE VALUE FOR PRESSURE-ALTITUDE-DERIVED LEVEL INFORMATION

These regulations also specify that, "*verification of pressure-altitude-derived level information displayed to the controller shall be effected at least once by each suitably equipped ATC unit on initial contact with the aircraft concerned or, if this is not feasible, as soon as possible thereafter. The verification shall be effected by simultaneous comparison with altimeter-derived level information received from the same aircraft by radiotelephony. The pilot of the aircraft whose pressure-altitude-derived level information is within the approved tolerance value need not be advised of such verification*".

The criteria used by the air traffic controller to monitor the position of an aircraft apply to aircraft:

- holding a level;
- vacating a level;
- passing a level in climb or descent;
- reaching a level.

In such situations, the criteria will determine whether or not the aircraft occupies a given level. However, there are no criteria for monitoring a vertical profile.

If an air traffic controller detects a situation in which an aircraft is not complying with an altitude instruction with regard to the above-mentioned criteria, he must inform the pilot.

The altitude display system on the radar screens at CDG is described in paragraph 1.10.3.2.

1.17.1.3.6 MSAW

As indicated in paragraph 1.10.4, the Minimum Safe Altitude Warning (MSAW) is a terrain proximity safety net which warns the crew when an aircraft's path is such that it is likely to collide with the terrain in the short term.

Procedures, phraseologies and regulations

The investigation into the serious incident to the BOMBARDIER CL-600-2E25 (CRJ-1000) registered F-HMLD on 20 October 2021 on approach to Nantes-Atlantique (Loire-Atlantique) contained a study of documents relating to procedures, phraseologies and international regulations applicable to ground collision avoidance systems. It appeared that the MSAW was almost never defined in international texts[60], that two procedures applied depending on whether the aircraft was being radar vectored or not, and that two distinct phraseologies were possible, without it being specified in which cases they applied:

- Low altitude warning: (aircraft call sign) LOW ALTITUDE WARNING, CHECK YOUR ALTITUDE IMMEDIATELY, QNH IS (number) [(units)] [THE MINIMUM FLIGHT ALTITUDE IS (altitude)].[61]
- Terrain alert: (aircraft call sign) TERRAIN ALERT, (suggested pilot action, if possible).

[60] The MSAW is however framed by French national regulations, which indicate the types of flights eligible for warning generation as well as the measures to be applied by controllers depending on whether the aircraft is vectoring or not (FRA.11002 of the French Order of December 11, 2014 relating to the implementation of the SERA regulation).

[61] Usually, a portion of text in square brackets is optional.

This study led the BEA to issue safety recommendations to the DSNA (the answer to which has been assessed adequate and closed by the BEA), and to ICAO and EASA (which were still being processed in April 2024), concerning the need to:

- clarify in which cases these two phraseologies should be used;
- systematically mention the urgency of the situation;
- systematically remind the crew of the QNH in the message.

Training

During their initial training at ENAC, student air traffic control engineers receive approximately one hour of theoretical instruction dedicated to MSAW operating principles. This course is mainly based on the SERA regulation and uses the videos published by Eurocontrol on this topic as training material. They are then regularly faced with situations involving the activation of this alert in simulation, with six occurrences being planned in the simulation programme. Spontaneous activations may be requested by instructors for training purposes.

During unit training at CDG, the MSAW theory was addressed during the "pre-OJT" course for the unit endorsement corresponding to tower controller functions, as part of the presentation on safety nets used at Paris-Charles de Gaulle. The presentation covered the MSAW's operating principles and associated working methods. The MSAW was discussed alongside other safety nets, namely the RIMCAS (used to detect potential runway incursions), the STCA (used to prevent losses of separation) and the APW (used to prevent intrusions into certain volumes). The "safety nets" topic was part of a teaching session held one morning, which also covered VFR procedures and heliport management.

During the afternoon following the theoretical training mentioned above, a simulation was planned to illustrate the various topics covered, with this simulation being selected from a choice of three simulations. Only one of these three simulations offered a scenario including MSAW activation. This activation is simply played by the instructor, as the software system does not allow MSAW to be implemented in simulation.

With regard to continuation training within the Paris-Charles de Gaulle control unit, although the activation of a terrain proximity alert is an emergency situation, this was not covered in the previous training sessions on abnormal and emergency situations (AES). In addition, due to the limitations of the simulation system at CDG, it is not possible to practise this situation in an operational context.

According to the statements of the controllers questioned, the MSAW is rarely triggered in real situations on approach to Paris-Charles de Gaulle airport.

1.17.1.4 Safety and compliance management system

1.17.1.4.1 Regulatory framework

On the date of the serious incident, European Commission Implementing Regulation (EU) 2017/373 of 1 March 2017, known as "ATM/ANS IR", laid down common requirements for providers of air traffic management/air navigation services. This regulation contains requirements applicable to the DSNA, including requirements concerning:

- the management system (ATM/ANS.OR.B.005), which includes, in particular, internal compliance monitoring;

- the safety management system (ATS.OR.200), which may be an integral part of the management system and which includes, in particular, processes relating to safety risk management, safety assurance and safety promotion.

1.17.1.4.2 DSNA's integrated management system

The DSNA Management Manual in force on the date of the serious incident[62] described the DSNA's Integrated Management System (IMS), which covers four areas: safety, security, environment and quality. The Management Manual provided the hierarchical structure and a set of processes on which the DSNA's IMS was based. This manual did not take into account recent organisational changes underway at the time of the serious incident, in particular the recent creation of the Safety Directorate (DSEC) on 1 January 2022.

The description of the processes in the DSNA Management Manual referred in particular to the following two procedures:

- Procedure for assessing and mitigating risks (PRO-002).

This procedure describes the DSNA's organisation for managing changes to the functional system. It is supplemented by a methodology for assessing and mitigating the risks associated with changes made to the ATM system (MET-001).

- Procedure for processing findings and actions (PRO-003).

The purpose of this procedure is to identify the sources of findings managed by the DSNA, and to describe how to process and manage the actions arising from them. Findings include "established malfunctions" (reported or detected safety occurrences, deviations from regulatory requirements or internal standards).

Safety occurrence processing is covered by a dedicated methodology (MET-009) as well as a manual made available to QS/S subdivisions. A safety occurrence may be analysed locally, by the QS/S subdivision only or by the local safety committee (CLS), or even nationally by the safety occurrence processing body (ITES).

According to procedure PRO-003, deviations are detected by means of audits and inspections and by the agents themselves, who report deviations.

Procedure PRO-003 also refers to "potential malfunctions" detected through observations, i.e. situations which, although complying with regulatory requirements, should be brought to the attention of the relevant entity and/or would require implementing an improvement action.

The DSNA Management Manual made no mention of any overall safety risk management process, beyond the processing of occurrence reports and the risk studies conducted prior to a change. On the date of the serious incident, the DSNA had not developed a national risk representation model on which such a process could be based. In civil aviation, it has been common practice for a number of years to use risk representation models, which depict safety barriers in such a way that it is possible to check how reliable they are. The DSNA drew up a concise risk map in 2010, broken down into "technical" and "operational" components. The DSNA did not use this risk map in its processes related to safety management. This map was not updated based on feedback and was not used as a tool for occurrence analysis or risk studies prior to a change.

[62] *Manuel de management*, Version 10, April 2018

The DSNA Management Manual indicated that information on lessons learned was provided both locally and nationally. Initial and continuation training was mentioned as the framework for local feedback, while the use of targeted awareness-raising campaigns was carried out for feedback at national level. During the investigation, the DSNA confirmed that there was no entity with national competence responsible for identifying priorities in terms of initial and continuation training based on identified risks, in particular using feedback.

Although the concept of "observation" was defined in procedure PRO-003[63], on the date of the serious incident, none of the aforementioned procedures or methods referred to or described an approach aimed at observing the practices of controllers in position to detect any difficulties (for example in the form of deviations from procedures likely to have an impact on safety) and to understand the causes thereof. During the investigation, the DSNA specified the following:

- in the scope of a change involving the transformation of working methods, observations of controllers in position were conducted in the past to determine whether the working methods stipulated prior to the change were applied as expected;
- it recently developed (after the incident) a methodology for observing and collecting information during normal operations, and is launching a first trial at the Reims CRNA (En-route Control Centre) in 2024.

The concept of observing air traffic controllers on duty during normal operations was introduced by ICAO in 2008. Doc 9910 established the methodology for collecting and analysing data, within the more general framework of Threat and Error Management (TEM).

Various campaigns for observing controllers in position have already been conducted around the world, e.g. in the United States, Australia, Canada, Ireland, Italy, New Zealand, Saudi Arabia, South Africa, South Korea, Thailand and the United Arab Emirates. A process of this kind is similar to what has been established for years and on a large scale for airline operators with Line Operations Safety Audits (LOSA).

1.17.1.4.3 Example of CFIT risk management

The DSNA considers that an aircraft on the frequency which passes below a published minimum safe altitude is a "near-CFIT" type of occurrence. As for all safety occurrences, controllers are required to complete an Event Notification Form (FNE) for occurrences involving a risk of collision with the ground.

These occurrences may give rise to a MSAW activation, if the airport is so equipped. However, this activation is not systematically analysed by the DSNA safety management system. Thus, in the absence of an FNE, the triggering of the MSAW is not an alternative means of systematically detecting a "near-CFIT" occurrence. It should also be noted that the serious incident only came to light because the N-TWR controller completed an FNE. Without this FNE, none of the units involved would have known about the serious incident.

According to the DSNA, many MSAW activations are considered to be untimely or are not understood by controllers, who then do not systematically report them.

[63] With the meaning of an observed situation.

In the “operations” risk map developed by the DSNA in 2010, “near-CFIT” is identified as an undesirable occurrence. The MSAW is associated with it as an action plan which is already implemented. Beyond this frozen document, on the date of the serious incident, the DSNA had not developed any “near-CFIT” occurrence analysis grid and had not deployed, at a local (SNA-RP/CDG) or national level, any CFIT risk management process as expected under ATS.OR.200 or the associated acceptable means of compliance (AMC), based in particular on the analysis of safety occurrences. The DSNA was thus deprived of a global and national assessment of the CFIT risk, beyond the one-off and/or local analysis of each occurrence and of any potential enumeration of the number of “near-CFIT” occurrences recorded in its database.

During the investigation, at the request of the BEA, the DSNA transmitted a list of 89 occurrences considered as “Near-CFIT”, including 64 during the approach phase, which occurred between 2019 and 2022 (see paragraph 1.18.1.3). The analysis of these safety occurrences revealed the following weaknesses:

- weaknesses in hear-back, with several occurrences revealing failure to detect read-back errors;
- poor reliability of MSAW barrier, with numerous occurrences revealing the use of an incorrect phraseology, potentially long reaction times and even a lack of reaction from some controllers.

In addition, the DSNA did not have any methods for observing controllers in position which could update some of these weaknesses or analyse them in a different way.

Furthermore, the DSNA had not deployed any process defining how the lessons learned from this type of risk analysis could be used to establish appropriate mitigation measures, in particular at national level. For example, following the serious incident to the CRJ-1000 registered F-HMLD on 20 October 2021 on approach to Nantes-Atlantique (Loire-Altantique), the local air navigation service identified the need to strengthen MSAW training for its teams. On the other hand, no body had been (or was) tasked with studying the benefits of doing this at national level.

1.17.2 Airhub Airlines (airline operator)

1.17.2.1 Organisation

Airhub Airlines was created on 17 July 2019. It is a charter company which also provides wet leasing services. Its head office is in Malta.

The company started its operations with Airbus A320s, then with A330s/340s. On the date of the serious incident involving 9H-EMU, the fleet included nine aeroplanes: three A320s, three A330s and three A340s.

The company had 25 permanent employees and 450 flight crew members employed as independent contractors. Its operational bases are located in Vilnius (Lithuania), Amsterdam (Netherlands) and Thiès (Senegal).

1.17.2.2 Procedures

In its documentation, the air operator mentions that it complies with Standard Operating Procedures (SOP), based on those described in the Airbus FCOM (see paragraph 1.6.5.2 in particular).

The operator indicates that the SOP specific to Airhub Airlines are complementary to Airbus procedures and are intended to improve and/or clarify some specific flight phases. These procedures stipulate that any deviation from Airbus procedures is based on operational constraints identified by the air operator.

1.17.2.2.1 Operator's altimeter instructions

Altimeter setting procedures

The OM (Part A) stipulates that the altimeters are set to the QNH, this being the only barometric altitude reference for the take-off, approach and landing phases.

During the descent, if cleared to an altitude, both pilots must display the most recent QNH for the destination airport.

In RNAV operations, both pilots must update their altimeter setting to the QNH of the destination airport, at the latest at the transition level.

Altimeter setting for Baro-VNAV operations

The crew must set the altimeter setting, then check that the altitude values do not differ by more than 100 ft at the latest, at the Final Approach Fix (FAF).

The crew conduct the operation with an up-to-date local QNH altimeter setting source. No regional or remote altimeter setting source must be used.

1.17.2.2.2 Increased non-precision approach (NPA) minima

According to the operator's OM (Part B), in order to avoid passing below the published minima in the event of a go-around, the minima for NPA approaches are increased by 50 ft, except during a visual manoeuvre.

In the OM (Part A regarding approaches), the operator defines a non-precision approach (NPA) as an instrument approach with an MDH or DH greater than 250 ft and an RVR of at least 750 m. GNSS/Baro-VNAV (LNAV/VNAV) approaches therefore meet the NPA criteria and are considered as NPAs by the operator. The increase mentioned above therefore applies to RNP APCH operations down to LNAV/VNAV minima. This is the reason why the pilots of the serious incident increased the decision altitude by 50 ft.

All non-precision approaches are conducted using the Continuous Descent Final Approach (CDFA) technique.

It should be noted that according to the PANS-OPS, RNP APCH operations down to LNAV/VNAV minima are carried out in 3D and therefore do not require the application of a CDFA technique, nor is it necessary to take into account a minimum descent altitude/height (MDA/H) below which protection against obstacles is not guaranteed. LNAV/VNAV are designed with a DA/H.

1.17.2.2.3 RNP-specific briefings and procedures

Briefings prior to descent

Prior to descent, in the event of an RNP approach, crews hold two briefings: a normal briefing, common to all approaches, and a supplementary briefing, specific to RNP approaches.

Normal briefing

APPROACH BRIEFING *(Ref OM-B 2.2.16.5)*		
A/C Tech Status	Review	
NOTAM	Review relevant - affecting flight	
Weather	Review Destination and Alternate Airports	
TEM	Identify Threats / Potential Errors / Differences	
Charts *(Brief)*	Title: Airport / Chart Page / APP Type / Date App Info: FREQ / FAT ◆ / AD Elevation (Check LDG ELEV) ◆ / TA Plan View – Profile View – Minima – Lights – MSA ◆	
FMGS	**F-PLN**	STAR – APP – RWY – Missed Approach – ALT Airport ◆ Check altitude/speed constrains - MSA
	RAD-NAV	Set of confirm radio – aids ◆
	PROG	Accuracy check (HIGH GPS PRIMARY (if applicable)) ◆
	PERF	DESC: check speed ◆ APP: Config FULL or 3 Speeds - MDA(DH) GA: confirm or change THR RED / ACC Altitude
	FUEL PRED	Check fuel predictions and EXTRA fuel / time ◆ Holding (if expected)
	SEC F-PLAN	Prepare as desired (other RWY or alternate STAR) ◆
Airport	Runway Data: Length, surface, threshold, lights, exits, Weather info: Runway Conditions, braking action, expected wind Landing Performance versus runway data Tail strike awareness Use of Reverse, Auto brake selection Taxi route, Parking	
Approach Mode	Type of approach – Brief how to fly the approach Use of AP / FD / ATHR	
SUPPL PROC	Supplementary and /or non-normal procedures	
AWO / CAT II/III	Use All Weather Operations Briefing Guise (Checklist/Highlights) (CM2)	

Normal briefing: the PF to use the MCDU with his ND in PLAN view selected as main source for the briefing with the EFIS Constraint pushbutton selected. PM to crosscheck against the Aerodrome Chart and to verify the FMGS data insertion.

Note: Items with the symbol (◆) are to be cross checked with associated displays (PFD/ND/MCDU).

Figure 39: approach briefing (source: Airhub Airlines OM (Part B))

Supplementary RNAV briefing

airhub AIRLINES	LOW VISIBILITY OPERATIONS (LVO) / (RNAV) BRIEFING GUIDE	Rev 2 Eff. Date 14 OCT 2021

RNP Approaches	
GJM is approved for: RNP APCH – RNP 0.3 (This guide may be used also for VOR/NDB approaches in FINAL APP)	
CHECKLIST (Perform after Normal Briefing)	**HIGHLIGHTS**

PREPARATION
➤ A/C EQUIPMENT, STATUS, MEL, limitations
  ➤ 1 FMS, 1 GPS, 2 IRS, 1 MCDU, 1 FD, 1 PFD on PF side, 2 ND, 2 FCU channels
➤ NOTAMS, GPS PRIMARY, ground equipment
➤ WEATHER
  ➤ Check minima OAT on the applicable chart
  ➤ Apply OAT compensation for LNAV only
  ➤ Do not use remote QNH
➤ LDG MINIMA (LNAV/VNAV or LNAV) determine
➤ F-PNL A page CHECK
  ➤ 0.1-degree max diff. between CHART and MCDU vertical path
  ➤ 1.0-degree max diff. between CHART and MCDU inbound track (*)
➤ PROG page
  ➤ Insert RWY threshold for distance monitoring
➤ GO AROUND review
  ➤ Review contingency procedure for RNP GA
 	
(*) 3.0-degree max diff. for conventional radio NAVAID approach
	➤ AT 10.000 ft
	  ➤ GPS PRIMARY CHECK
	  ➤ ALTIMITERS check (max diff. 100 ft)
	➤ PRESS APPR pb when cleared for approach and TO waypoint is the final descent point
	➤ ON FINAL
	  ➤ Check that the V/DEV scale is displayed on the PFD
	  ➤ Check the blue arrow on ND at FDP
	  ➤ Monitor XTK error on ND (PM call if > 0.1 NM)
	  ➤ Monitor V/DEV error on PFD (PM call if > ½ dot)
	➤ AT MINIMUM
	IF VISUAL REFERENCES ARE SUFFICIENT (*)
	  ➤ A/P OFF
	  ➤ FD OFF
	  ➤ TRK FPA SELECT
	  ➤ RWY TRACK CHECK/SET
	IF NO VISUAL
	  ➤ GO AROUND
	*(Visual references must be the primary reference until landing)
	FAILURES
	➤ USE THE REMAINING AP/FD in case of:
	  ➤ GPS PRIMARY LOST on one ND
	  ➤ NAV ACCUR DOWNGRADE on one FMGS
	➤ DISCONTINUE THE APPROACH or proceed visually in case of:
	  ➤ GPS PRIMARY LOST on both ND
	  ➤ XTK > 0.3 NM
	  ➤ NAV FM/GPS POSITION DISAGREE on ECAM
	  ➤ NAV ACCUR DOWNGRADE on both FMGS
	  ➤ VDEV>3/4 dot (VNAV/LNAV minima)
	
	For detailed information refer to:
	FCOM/PRO/NOR/SOP/18/C/APPROACH USING FINAL APPROACH GUIDANCE

Figure 40: supplementary RNAV briefing (source: Airhub Airlines OM (Part B))

During the approach, and as mentioned in paragraph 1.6.5, specific actions, controls and precautions are stipulated. In particular, the crew must carry out altitude/distance checks on final whenever these are specified on the approach chart, in particular at the FDP.

1.17.2.3 Training

1.17.2.3.1 Operator conversion course

After being contracted at the end of 2021, the crew completed an Operator Conversion Course (OCC). This course included the following:

- theoretical training, via a number of Computer-Based Training (CBT) modules covering a variety of subjects, including PBN approaches and the risks of collision with the ground (CFIT);
- a Flight Simulation Training Device (FSTD) session lasting four hours;
- an Operator Proficiency Check (OPC) session in a simulator lasting four hours, combined with a Licence Proficiency Check (LPC);
- a “Line Check” (LC), during which the pilot is assessed in operational conditions.

Crew theoretical computer-based training in PBN/RNP approaches

The Computer-Based Training (CBT) provided by the company was developed by FLYCO TRAINING SOLUTIONS. It comprises three modules on PBN approaches, as well as one module on CFIT:

- "PERFORMANCE BASED NAVIGATION PROCEDURES" CBT MODULE (14 pages)

This module contains explanations regarding technical and regulatory terms, a history of PBN navigation, the principles of en-route and approach navigation, as well as normal and abnormal procedures related to degraded lateral navigation.

- "GENERAL RNP APPROACH PROCEDURES" CBT MODULE (11 pages)

This module covers 56 points including descriptions and procedures.
Point 34 describes the dangers associated with an incorrect QNH value and the need for effective altimeter display and control procedures. It specifically mentions that, as the calculation of the vertical profile is based on the displayed QNH value, any error would affect this calculation. It specifies that a QNH error of 10 hPa above the actual value would position the aeroplane 300 ft below the theoretical vertical profile, resulting in a risk of collision with the ground.
Lastly, it recommends using the radio-altimeter and EGPWS as a way for mitigating risks.

- "AIRBUS RNP APPROACH PROCEDURES" CBT MODULE (7 pages)

This module describes the operating procedures on Airbus aeroplanes and mentions the QNH issue at point 6: "*Pilots must have a local altimeter setting and the temperature must be within limits.*"
Point 14 mentions the need to carry out altitude/distance checks as published on the approach chart: "*PNF Cross check Altitude versus Distance to Runway Threshold using the Approach Chart and the runway entered in the Progress Page.*"

- CONTROLLED FLIGHT INTO TERRAIN (CFIT) CBT MODULE

This module warns against communication errors between controllers and crews, QNH errors and specifies that 60% of CFITs occur during non-precision approaches.
Lastly, it specifies that incorrect altimeter settings can occur in countries where the transition level is low, when the workload during the approach is high.

Simulation device sessions during the conversion course
For training and checks carried out in a simulation device, the programme includes systematically RNP approaches in 2D and 3D operations (with or without automatic guidance on the vertical profile).

1.17.2.3.2 Training and recurrent checks

Training and recurrent checks follow a three-year cycle described in Appendix 4 of the operator's Operating Manual (Part D).

These training activities and checks are carried out both in a simulation device and en route:

- in a simulation device: every six months, pilots undergo a FSTD session, followed by an OPC. Once a year, the OPC session is combined with a LPC. For checks carried out in a simulation device, the programme includes systematically conducting RNP approaches in 2D and 3D operations;
- en-route: a LC is carried out during a flight with an instructor to verify pilots' skills in operational conditions.

Assessment of both pilots did not reveal anything particular in the implementation of the programme.

1.17.2.4 Safety and compliance management system

Regulation (EU) No 965/2012, known as "AIR OPS", requires commercial air transport operators to establish a management system that includes the management of safety[64].

Airhub Airlines' safety management system is described in its Management Manual. This manual describes:

- the obligations that apply in terms of reporting safety occurrence[65];
- the methods for identifying, analysing, assessing and managing hazards and risks, as well as for recording them in a "hazard log";
- the management of the Flight Data Monitoring (FDM) programme.

The operator's "hazard log" is divided into areas of activity: flight operations, maintenance, ground handling operations, organisation, etc. For each of these areas of activity, the entries correspond to the result of a study (proactive or predictive method) or to an operating event. Each of these entries is associated with a hazard, an undesirable event, the most likely consequences, a risk level, as well as any mitigation measures and the reassessed risk level, where applicable.

On the date of the serious incident, Airhub Airlines had not formally identified any specific hazards concerning baro-VNAV approaches or the use of an incorrect altimeter setting during the approach. In addition, incorrect altimeter settings were not monitored by way of the FDM.

Note: an informal survey of commercial airline operators during the Journées Sécurité des Vols France (JSVF - flight safety days) organised by the DSAC confirmed that the detection of incorrect altimeter settings by way of the FDM was very little implemented on the date of the serious incident.

1.18 Additional information

1.18.1 Safety occurrences resulting from an incorrect altimeter setting and/or having triggered a MSAW

The occurrences presented in 1.18.1.1 were those identified by the BEA and which have been or are the subject of a safety investigation conducted by an independent investigation authority or board and involving aeroplanes with a maximum take-off weight of more than 5,700 kg and/or operated in commercial air transport.

Paragraphs 1.18.1.2 to 1.18.1.5 present a summary of the results transmitted by four authorities or organisations (DSAC, DSNA, EASA and Eurocontrol) in response to a request from the BEA to extract from their database, occurrences linked to an incorrect altimeter setting (QNH) and/or an activation of the MSAW during the approach phase.

[64] ORO.GEN.200 and the associated AMCs and GMs.

[65] Requirements under Regulation (EU) 376/2014

1.18.1.1 Accidents or incidents that were/are the subject of a safety investigation following an incorrect altimeter setting

Serious incident to the De Havilland DHC-8 registered LN-WIP on 22 December 2022 on approach to Svolvær (Norway), investigation in progress

The crew carried out a LOC/DME approach without visual references with the altimeters still mistakenly set to the standard pressure (1013 hPa) instead of the QNH (987 hPa), resulting in a descent being flown approximately 730 ft below the published vertical profile. The TAWS alert "TOO LOW TERRAIN" sounded during the descent. The crew aborted the approach and then diverted.

Serious incident to the CRJ 1000 registered F-HMLD operated by Hop! on 20 October 2021 on approach to Nantes (France)

When the crew were cleared to descend to the first altitude below the transition level and to carry out an RNP APCH down to LPV minima to runway 21, the PM incorrectly read back the QNH, indicating a QNH of 1021 instead of 1002. This error was not picked up by the approach controller or the PF. When changing the altimeter setting, the crew failed to confirm the QNH value provided by the controller with another source of information, as required by the operator's procedures. Due to this QNH error, the vertical profile during the approach was approximately 530 ft below the published vertical profile. When the MSAW alert was triggered, the TWR controller informed the crew of this alert, without initially mentioning the QNH and without including the word "immediately". The exchanges between the crew and the controller lasted almost 30 s before the crew realised their mistake and corrected the vertical profile.

Serious incident to the Boeing 787 registered A6-BMD operated by Etihad, on 6 June 2020 on approach to Abu Dhabi (United Arab Emirates)

On descent to the transition level, the crew were concentrating on managing the high energy, and incorrectly selected the QNH: when switching from the standard pressure to the QNH, the setting remained at the preset value of 1009 hPa, corresponding to the value on departure from Beijing, instead of 999 hPa. This resulted in a vertical profile being flown approximately 280 ft below the published profile. The approach controller did not provide information on the local QNH during the initial descent clearance, nor during the clearance for the RNP APCH down to LNAV/VNAV minima. When the crew noticed that the PAPI was displaying four red lights, they aborted the approach at a distance of about 1.3 NM from the threshold and at a height of about 210 ft RA whereas the indicated altitude was 570 ft. The controller did not give instructions to check the QNH or the aeroplane's altitude when the MSAW alert appeared on his radar display.

Serious incident to the Boeing 737-300 registered VH-NLK operated by Nauru Airlines on 12 June 2015 on approach to Kosrae (Federated States of Micronesia)

The crew did not carry out all the specified checks before undertaking a night NDB/DME approach without visual references. The altimeters remained set to the standard pressure instead of the QNH of 1007 hPa in force, resulting in a vertical profile being flown around 170 ft below the published vertical profile. The crew descended to the minima before going around because they had lost sight of the runway. Before aborting the approach, the crew had ignored two EGPWS "TOO LOW TERRAIN" alerts, considering that they were the result of a navigation system inaccuracy.

Serious incident to the Airbus A320 registered VH-VGT operated by Jetstar Airways, on 31 March 2014 on approach to Gold Coast (Australia)

The crew carried out an RNP approach after mistakenly entering a QNH value of 1025 hPa instead of 1018, resulting in a vertical profile being flown around 200 ft below the published vertical profile. At 159 ft RA, an EGPWS "TERRAIN" alert sounded and the approach was aborted. The investigation found that the QNH may have been confused with the cloud clover (025) or temperature (25) information in the ATIS, that there was no comparison with the QNH entered in the FMS, and that the altitude-distance cross-checks did not enable the crew to identify the error.

Serious incident to the ATR 42-500 registered OH-ATB operated by Finncomm Airlines, on 1 January 2007 on approach to Seinäjoki (Finland)

The crew did not carry out all the checks required by the operator before undertaking an NDB approach. In particular, they forgot to change the altimeter setting from the standard pressure to QNH 978 hPa. As a result, the crew were 950 ft too low during three successive approach attempts, all of which were aborted when the EGPWS was activated. Other warnings, such as the stall warning, sounded during the manoeuvres before the crew decided to divert.

Accident to the Learjet 35 registered C-GPUN operated by Canada Jet Charters, on 11 January 1995 on approach to Masset (Canada)

During a night medical flight, the crew carried out an NDB approach with an incorrect altimeter setting of 30.17 in Hg instead of 29.17 in Hg (i.e. a difference of around 34 hPa), resulting in a vertical profile being flown around 950 ft below the published vertical profile. The aeroplane collided with the surface of the water 8 NM from the airport. The two crew members and three passengers were fatally injured.

1.18.1.2 Extraction by DSAC of occurrences reported

A search was carried out in the national database[66] for the period 2020-2022. It only included mandatory and personal initiative reports of safety-related occurrences from French commercial air transport operators and the DSNA. For this search, the DSAC used regular expressions for the "narrative" attribute (free text) and certain values from the list available for the "event type" attribute. Only occurrences on approach were selected.

This search identified a total of 382 notified occurrences on approach, of which:

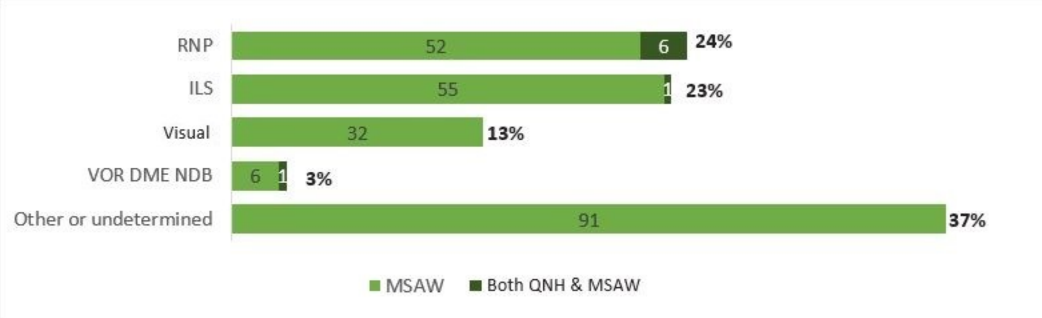
- 236 were related to the MSAW (triggering of MSAW)[67];
- 138 were related to the QNH (incorrect altimeter setting);
- 8 were related to both the MSAW and the QNH.

In the study period, only one French operator (Air France) had set up a Flight Data Monitoring (FDM) programme enabling the systematic detection of incorrect altimeter settings and thus contributing to the notification of these occurrences not covered by the pilots' personal initiative.

[66] See Regulation (EU) 376/2014, Article 6, paragraph 6.

[67] See paragraph 1.18.1.3 for the limits expressed by the DSNA concerning searches for MSAW.

Breakdown by type of approach:



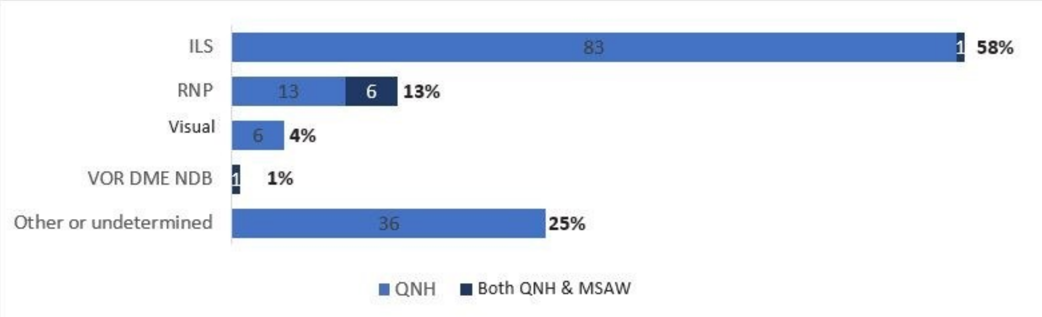


Figure 41: breakdown of occurrences, MSAW in green and QNH in blue by types of approach

Reports relating to MSAW are mainly associated with RNP (24%) and ILS (23%) approaches. The QNH errors notified are mainly associated with ILS approaches (58%); RNP approaches concern 13% of these reports relating to an incorrect altimeter setting. In both cases, the data available does not identify the type of RNP approach.

Note: in Europe, and in France in particular, the majority of IFR approaches by commercial air transport operators are carried out using the ILS and to a much lesser extent with RNP. However, whether on a local or more global scale, no organisation is responsible for counting the number of approaches carried out by type of approach. As a result, the BEA has not been able to accurately estimate the degree of exposure to the different approaches.

It should also be noted that RNP approaches account for 13% of the reports and six of the eight occurrences corresponding to the "QNH" and "MSAW" analyses. Conversely, the ILS approaches account for 58% of the reports but only one of the eight occurrences corresponding to the "QNH" and "MSAW" analyses.

Breakdown of altitudes/flight levels at which the QNH error was detected

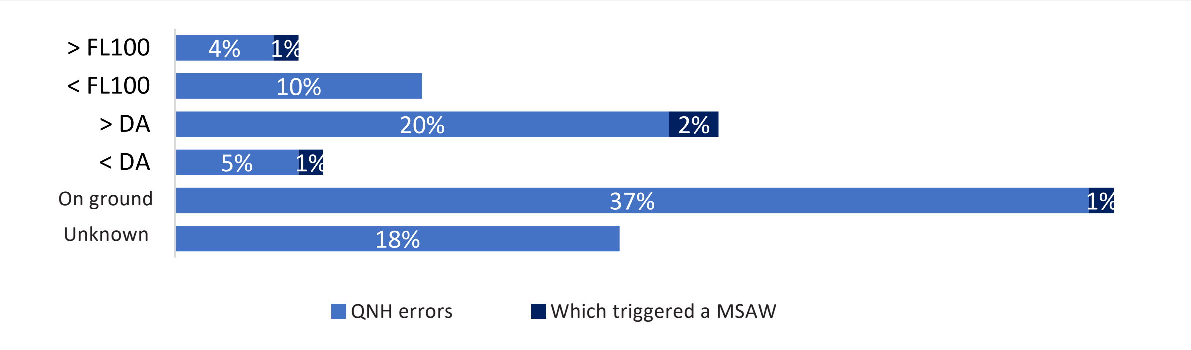


Figure 42: breakdown of altitudes/flight levels at which the QNH error was detected (source: DSAC)

It appears that a large proportion of the events relating to a QNH error are not detected during the flight phase or are detected at a height lower than the minima (respectively 38% and 6%, i.e. 44% of the approaches, bearing in mind that there are a further 18% of cases where the height at which the error was detected is unknown).

Breakdown of errors as a function of QNH values

On the following two graphs, the colour of the occurrences varies gradually:

- from dark blue to light blue when the difference between the QNH used on board and the actual QNH is negative (altitude displayed lower than the actual altitude, for a given altitude the aeroplane is therefore above the actual altitude).
- from light orange to brown when the difference between the QNH used on board and the actual QNH is positive (altitude displayed higher than the actual altitude, for a given altitude the aeroplane is therefore below the actual altitude, ground proximity).
- grey indicates an unknown true QNH value.

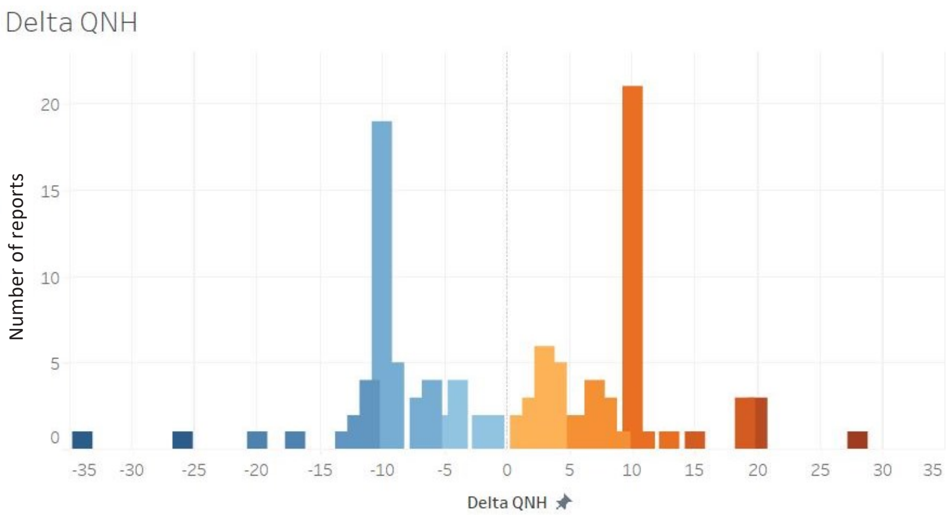


Figure 43: number of occurrence reports as a function of the value of the deviation from the actual QNH (source: DSAC)

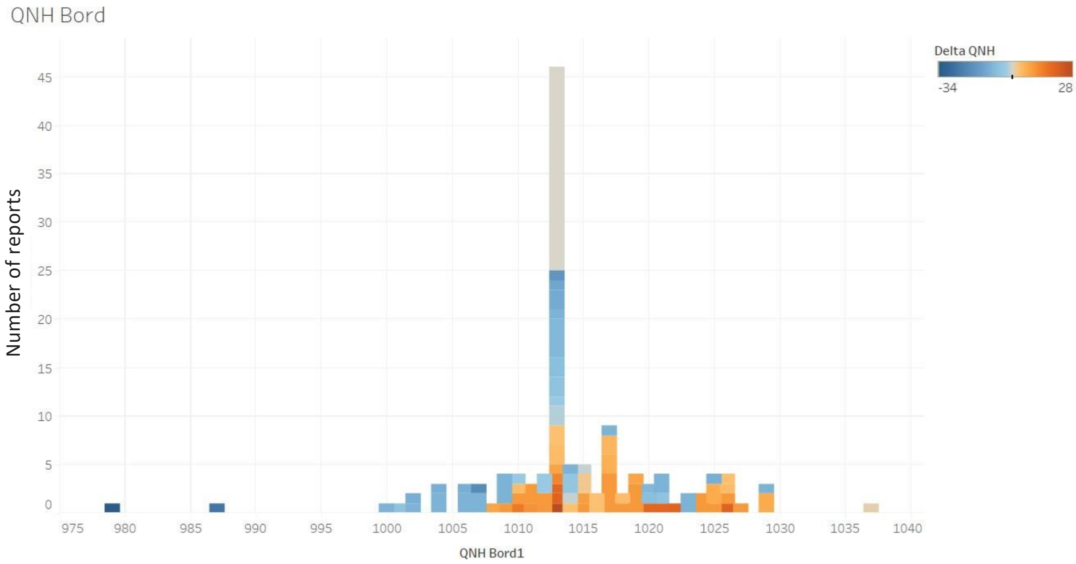


Figure 44: number of occurrence reports as a function of the value of the QNH entered (source: DSAC)

The DSAC analysis highlights the significant proportion of occurrences in which:

- the setting was plus or minus 10 hPa compared with the actual QNH (error of one digit in the tenths unit), representing 36% of the cases;
- the setting was kept at the standard value (1013 hPa), representing 36% of cases.

Cause of altimeter errors

The DSAC study also shows that most of the errors were caused by the crews (69% of QNH occurrences), with:

- the insertion of an incorrect QNH after the correct transmission and read back of the QNH (41%);
- the crew keeping the standard altimeter setting without any ATC contribution (28%).

However, on reading these reports, it can be seen that a significant proportion of the occurrences were contributed to by the ATC (27% of QNH events) with:

- erroneous read-back of the QNH by the crew, not picked up by air traffic control (14%);
- transmission of an erroneous QNH value by air traffic control (10%);
- no transmission of the QNH by air traffic control (3%).

Lastly, the incidents classified as "other or undetermined" (4%) include errors in the measurement of meteorological instruments or ATIS recording errors.

1.18.1.3 Extraction by DSNA of occurrences it had recorded

The DSNA explained to the BEA that it was unable to provide reliable extractions concerning:

- occurrences during which a MSAW alert was activated, as the activation is not recorded automatically. Furthermore, many activations are considered untimely or are not understood by the controllers, who then do not notify the DSNA although the operational instructions dedicated to the use and operation of the MSAW stipulate that they should be;

- occurrences resulting from or revealing an incorrect altimeter setting, because in the absence of a predefined coded value to retranscribe this factor, only a search for regular expressions in the text would be effective, a search that the DSNA has not been able to carry out.

Instead, the DSNA proposed to extract the occurrences coded as "near-CFIT" from its database. The DSNA uses this term to describe all IFR occurrences during which an aircraft, with or without a MSAW alert, passed or operated, without loss of control, below the published minimum altitude at the location in question. This corresponds to the crew unintentionally passing below the published minimum altitudes at the location in question The search was carried out at the beginning of 2023 and covered the period 2019-2022. Of the 89 events coded as "near-CFIT", 64 occurred during the approach phase. The characteristics presented below only concern these approach phase occurrences. The DSNA developed an ad hoc typology to reflect the cause of the occurrence. The graph below is based on this typology[68].

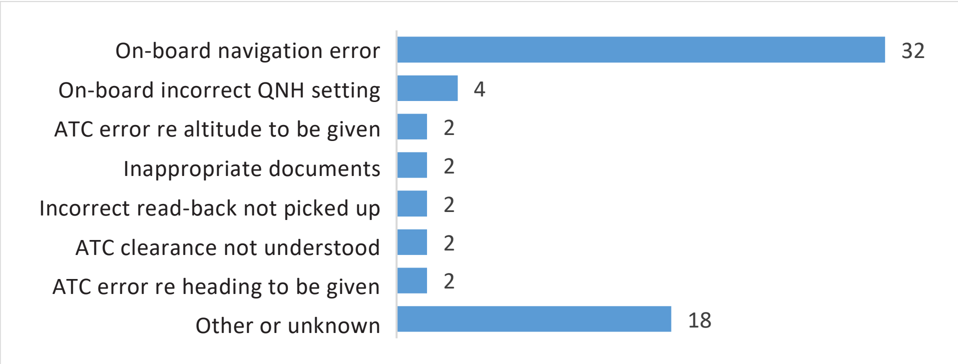


Figure 45: cause of "near-CFIT" occurrences on approach according to the DSNA ad hoc typology

At least half of these occurrences are the result of an on-board navigation error, i.e. following a different horizontal and/or vertical profile to that published and/or instructed by the controller. Four occurrences were identified as being the result of an incorrect altimeter setting, whatever its cause[69].

In two of these cases, an incorrect read back by the crew, not picked up by the controller, led to incorrect settings. In both these cases, a MSAW alert was triggered.

In just under half of the cases (30), a MSAW alert was triggered and deemed valid. Of these 30 occurrences, 19 resulted in an inappropriate controller response to the MSAW in the form of:

- absence of message (4 cases); or
- a message that did not comply with standard phraseology (15 cases).

[68] For this typology, the DSNA completed the table by assigning a single value to each occurrence. In reality, several values could characterise the same occurrence (for example: incorrect on-board QNH setting and incorrect read back not picked up).

[69] Due to the coding at the time of extraction, the serious incident which is the subject of this report was not included.

There were forty-one "near-CFIT" occurrences during ILS approaches, and sixteen during RNP approaches[70].

Extraction by CDG services of occurrences it had recorded
Using the same values as those applied by the DSNA at national level, the CDG services had recorded 15 incorrect altimeter setting occurrences between 2019 and 2022 on approach:

- seven where the crew had forgotten to change to the QNH below the transition level;
- eight concerning read-back errors that were not picked up or the insertion of an incorrect QNH after the transmission and read-back of a correct QNH value. Six of these eight cases concerned errors of 10 hPa.

1.18.1.4 Extraction by EASA of occurrences recorded in the European Central Repository

The European Central Repository[71] is the database which holds all the occurrences normally transferred from the national databases of the Member States of the European Union, these national databases being fed by the service providers (aircraft operators, PSNAs, etc.).

EASA carried out the extractions corresponding to the BEA's request at the end of 2022. The information provided by EASA was not analysed by the BEA given the difference with the DSAC and DSNA extractions. For example, only thirty-two occurrences relating to an incorrect QNH come from France over the period 2011-2021 (compared with the 146 occurrences recorded by the DSAC over the period 2020-2022). Several parameters can influence the quality of an extraction from the European Central Repository, such as the completeness of the data transfer from the national databases, the construction of the query or the language used at the time of notification for regular expression searches on free text attributes.

Note: In 2022, EASA finalised the assessment of the safety topic entitled "Approach Path Management" (Safety Issue [SI-0007]) as part of the European Programme for Civil Aviation Safety (EPAS). The report arising from this assessment does not address the possibility of using an incorrect QNH during an approach with barometric vertical guidance and its consequences. EASA explained to the BEA that, as this type of assessment requires considerable resources, it would only be updated once other safety issues, which are also priorities, had been assessed.

1.18.1.5 Extraction by Eurocontrol of occurrences notified to it

Eurocontrol administers a voluntary incident reporting system[72] independently of the regulatory provisions of Regulation (EU) No 376/2014 which are binding on organisations and States. The data comes mainly from European Air Navigation Service Providers (ANSPs) and aircraft operators, provided on a voluntary basis.

Eurocontrol carried out a search at the beginning of 2023. It covered the period from 2016 to January 2023. The term "QNH" was searched for in the text of the report. The results were analysed and an ad hoc typology was created to reflect the nature of the anomaly encountered in relation to the QNH. A total of 54 reports from all phases of flight were selected and sorted according to this typology.
According to this typology, the main anomalies relating to the QNH were:

[70] The type of RNP approach performed by the crews is unknown to the controllers (see paragraph 1.17.1.3.1).
[71] See Regulation (EU) 376/2014, Article 8, paragraph 2.
[72] Eurocontrol voluntary ATM incident reporting (EVAIR).

- selection of an incorrect value by the crew (in 20% of cases);
- a difference between the QNH value indicated in the ATIS and the one the controller transmitted to the crew (15%);
- an incorrect QNH value in the ATIS (13%);
- or the read-back by the crew of an incorrect QNH value, not picked up by the controller (11%).

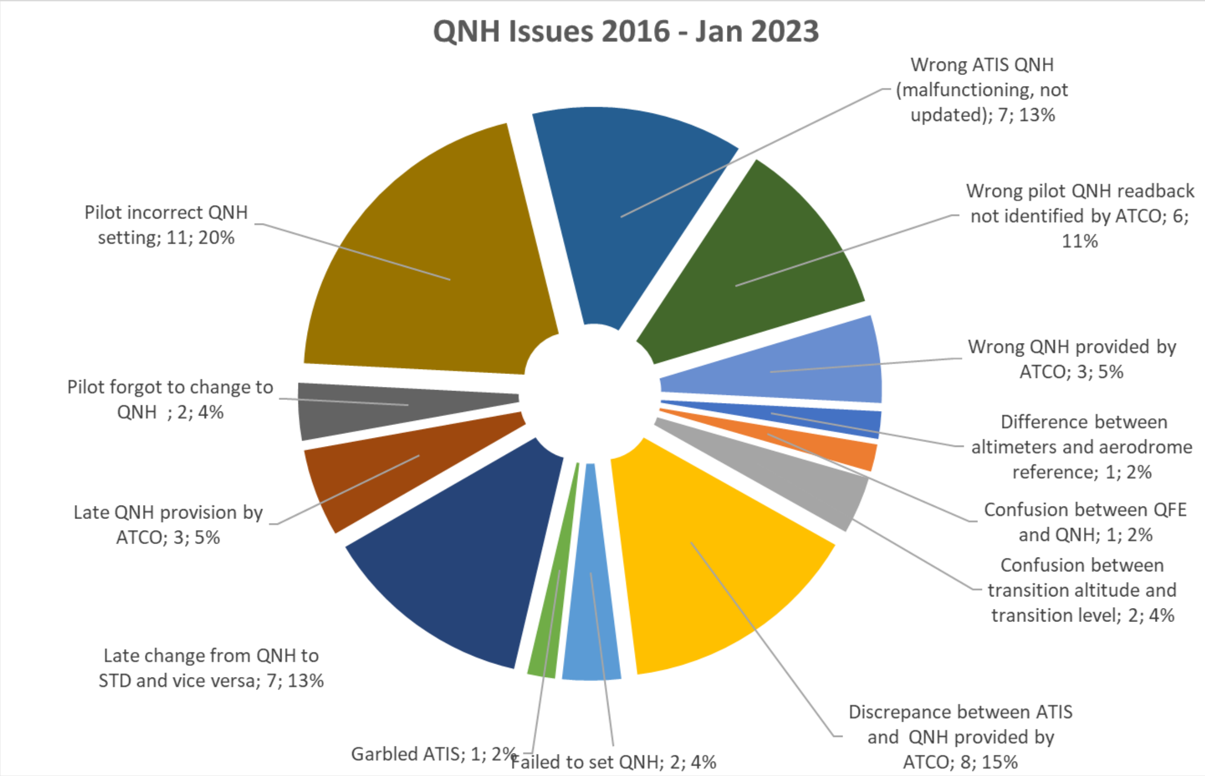


Figure 46: cause of "QNH" occurrences on approach according to Eurocontrol ad hoc typology

1.18.2 Ground systems for detecting an incorrect altimeter setting

Regulatory requirements

Some air navigation service providers, such as the NATS in the United Kingdom or the LVNL in the Netherlands, have installed a ground system which compares the altimeter setting transmitted by certain aircraft with the QNH value in force locally, in order to inform the air traffic controller of a potential incorrect altimeter reference on board an aeroplane.

Commission Implementing Regulation (EU) No 1207/2011, then Commission Implementing Regulation (EU) 2023/1770 repealing the latter and laying down requirements for the performance and the interoperability of surveillance for the Single European Sky and its amendments requires aircraft flying in European airspace with a mass greater than 5,700 kg or with a maximum cruising speed greater than 250 kt to be equipped with a transponder that transmits Enhanced Surveillance Mode S (EHS) and ADS-B protocol information. The associated certification requirements are defined in the certification specifications CS-ACNS (*Certification Specifications and Acceptable Means of Compliance for Airborne Communications, Navigation and Surveillance*). The mandatory information transmitted (Downlink Aircraft Parameter, DAP) includes the altimeter setting on board the aircraft via the Barometric Pressure Setting (BPS).

As for air navigation service providers, there is no obligation to implement a ground system that would use this BPS parameter to alert the controller in the event of an aircraft having an incorrect QNH. Nor are there any requirements for the other DAP that can be used in a more global approach by air navigation services. In 2021, ICAO published the third edition of the "*Mode S downlink aircraft parameters implementation and operations guidance document*".

Implementation in Europe and France

The data provided by Eurocontrol shows that in Europe at this time, of the forty-one Eurocontrol Member States, six have a system alerting air traffic control that an aircraft is transmitting an incorrect altimeter setting and eleven have a system enabling the aircraft altimeter setting to be displayed on air traffic controller screens.

In France, no en-route, approach or tower unit displays the BPS nor triggers an alert in the event of an incorrect altimeter setting. Likewise, no DSNA organisation in mainland France uses ADS-B data transmitted by aircraft (including the PBS) except for Ajaccio. A project is underway to obtain ADS-B coverage for en-route centres in mainland France.

Only en-route control centres receive EHS Mode S transmissions from aircraft. At Paris-Charles de Gaulle, as the control system is similar to those in the en-route centres, the EHS mode S parameters are also received. However, and for all these centres, only the selected flight level, instantaneous heading and indicated airspeed parameters transmitted by EHS mode S are available for display on the controller's screen. The altimeter setting BPS parameter is not processed by the system.

1.18.3 On-board systems for detecting an incorrect altimeter setting

1.18.3.1 Systems generating an alert for the crew

On the day of the serious incident and on board the aeroplane, the crew were solely responsible for detecting the incorrect altimeter setting. There was no on-board system to automatically detect this, nor were there any regulations requiring it.

However, several systems have been developed to alert the crew to an incorrect altimeter setting. In particular:

- **Honeywell CAM-BTA system and Airbus ALTSM step 1**

In 2010, Honeywell developed a Corrected Altitude Monitor Below Transition Altitude (CAM-BTA) function to provide an aural "Altimeter setting" alert when an inconsistency between the temperature-corrected barometric altitude and the GNSS geometric altitude is detected. This function is available through the Runway Awareness and Advisory System (RAAS) package. The function is active below 5,000 ft AAL or below the transition altitude. The aural alert is repeated once, eight seconds later if the inconsistency is still present.

This function is available through a Supplemental Type Certificate (STC) for aeroplanes equipped with a Honeywell EGPWS with software version -230-230 or higher.

Airbus took the CAM-BTA functionality and certified it in 2018 through the ALTSM Step 1 system (Altimeter setting monitor). This system is only compatible with the Honeywell MARK V EGPWS from Airbus P/N 965-1676-006 (therefore including a Honeywell -230-230 or higher software version of the EGPWS) and the MARK VA EGPWS from Airbus P/N 69000942 (-151/-251).
The MARK V EGPWS P/N 965-0976-003-206-206 on board 9H-EMU was not compatible with the

CAM-BTA and ALTSM Step 1. In order to benefit from this functionality on an A320 with an EGPWS software version before -218-218 (as is the case for 9H-EMU with a -206-206 version), it is necessary to carry out potentially major software and hardware modifications.

Honeywell concluded that, following simulations it carried out in conditions similar to the serious incident, the CAM-BTA function would have triggered an aural "Altimeter setting" alert at 1,843 ft RA, i.e. 2 minutes and 22 seconds before the recorded and corrected minimum radio-altimeter height of 6 ft during the serious incident.

It was not possible to determine how many aeroplanes were equipped with the CAM-BTA functionality. By the end of 2022, less than 200 Airbus aeroplanes were equipped with the ALTSM Step 1 functionality.

Boeing has not yet certified a similar system, but Honeywell's CAM-BTA function remains available with a STC.

- **Airbus ALTSM Step 2 system**

Airbus is currently developing an upgrade of the system, called ALTSM Step 2. This system should be compatible with all the TAWS fitted on the various aeroplane models currently manufactured by Airbus. It is intended that the ALTSM Step 2 will provide a visual alert on the PFD with the QNH value flashing in amber in addition to the aural "ALTIMETER SETTING" alert. It is also intended that the consistency between the barometric altitude and the GNSS altitude will be monitored between 600 ft RA and 6,000 ft AAL. Airbus' stated objective is to certify this function in 2024. For 9H-EMU, this would mean changing the TAWS equipment (hardware) in addition to the modifications required for ALTSM Step 1.

The following table gives the availability and forecast availability of the ALTSM on Airbus aircraft at the end of 2022:

Function	A220	A300/A310	A320 family	A330/A340	A350	A380
ALTSM (Audio only)	Not available	Under consideration	Honeywell EGPWS	Honeywell EGPWS	Not Available	Not available
ALTSM v2 (Audio + visual indication)	Under consideration	Under consideration	2024 EGPWS and T3CAS	2024 EGPWS and T3CAS (*A330 Only*)	2027 Similar function on new aircraft	Under consideration

Figure 47: availability and forecast availability of ALTSM step 1 and step 2 functions at the end of 2022 (source: Airbus, Safety first magazine November 2022)

1.18.3.2 Systems to improve crew situational awareness

Several on-board systems can increase the crew's situational awareness of the consequences of an incorrect altimeter setting. These systems are not designed to detect this type of error and are therefore not robust enough to provide an effective and sufficient barrier. However, depending on when the crew become aware of an inconsistency, it may enable them to avoid a collision with the ground, or even in some cases to identify an incorrect altimeter setting earlier.

Representation of vertical profile

The representation of the vertical profile is one of those systems which increases situational awareness and can allow the crew to indirectly detect an incorrect altimeter setting. This display is not a regulatory requirement under certification standards, even on the most recent aircraft, but many aircraft manufacturers now offer it. In the Airbus fleet, the Vertical Display (VD) is only available on the A350 and A380 (by default on both models). In the Boeing fleet, the Vertical Situation Display (VSD) is available as an option on certain versions of the Boeing 737 and by default on the Boeing 787.

On Airbus, when the radio-altimeter height is below 5,000 ft RA, the aeroplane's vertical profile, the runway and the terrain profile ahead of the aeroplane are displayed on the VD. The height of the aeroplane calculated by the radio altimeter corresponds to the difference in altitude between that of the aeroplane and that of the amber "True terrain symbol" bar. This representation is similar to that of the PFD. The altitude value displayed on the VD corresponds to that of the PFD and is therefore dependent on the altimeter setting of the FCU.

The crew can detect an inconsistency in the representation by carefully comparing the "True terrain symbol", the modelled terrain ahead of the aeroplane and the runway. In particular, in the case of an incorrect and overestimated QNH, the runway will be represented below ground level, and the "True terrain symbol" will be offset with respect to the modelled terrain. Depending on the scale used for the VD, this offset may not be easily identifiable by the crew.

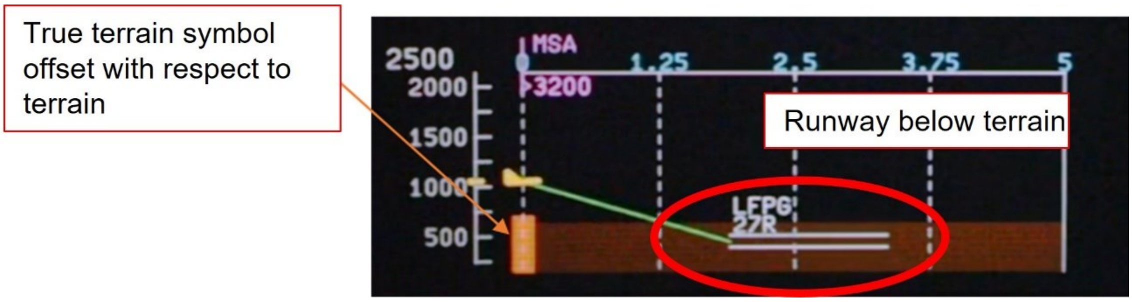


Figure 48: A350 Vertical Display in the case of an incorrect QNH (1011 hPa instead of 1001 hPa) (source: Airbus)

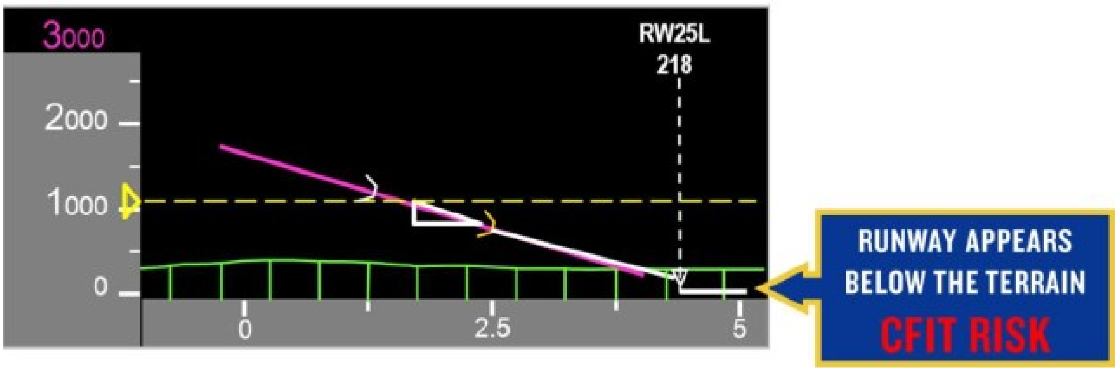


Figure 49: Boeing 737 VSD with QNH > actual QNH (source: Ryanair flight safety bulletin)

Enhanced flight vision system

An Enhanced Flight Vision System (EFVS) or a Combined Vision System (CVS) provide an image of the external environment based on data from infrared sensors, improving visibility at night or in poor weather conditions.

However, in the case of a barometric approach carried out with an incorrect QNH and when the crew does not yet have direct sight of the runway, these systems can allow the crew to become aware of an incorrect vertical profile or of the low height in relation to the terrain.

Such systems are mainly fitted to business jets.

Figure 50: Dassault Falcon Eye (source: Dassault Aviation)

1.19 Useful or effective investigation techniques

Not applicable.

2 ANALYSIS

2.1 Introduction

The crew were carrying out flight NSZ4311 from Stockholm Arlanda airport (Sweden) bound for Paris-Charles de Gaulle (CDG) airport (France) on 23 May 2022.

At CDG, the ILS for runway 27R had been out of service for several days for work and the RNP procedures were in force on this runway. The local barometric pressure adjusted to mean sea level (QNH) was 1001 hPa. There was a rain shower in progress on the final approach path, significantly degrading visibility. The lights on the landing runway had been switched on with the arrival of the rain shower but not the approach lights, an omission by the tower controller.

As the aeroplane was not equipped to carry out an RNP APCH operation down to LPV minima (approach offering satellite lateral and vertical guidance), the crew carried out an RNP APCH operation down to LNAV/VNAV minima (an approach procedure with barometric vertical guidance).

On the intermediate approach, the crew were twice given a QNH value with an error of 10 hPa by the approach air traffic controller (1011 hPa instead of 1001) which they used to set the aeroplane's altimetric systems. Now an error in the altimeter setting results in a difference between the aeroplane's actual altitude and the altitude displayed. For approaches with barometric vertical guidance, the vertical profile and the vertical guidance are affected. This meant that on using a QNH value 10 hPa higher than the actual value, the approach was carried out on a vertical profile around 280 ft below the published vertical profile without the crew being aware of this and without any external visual references.

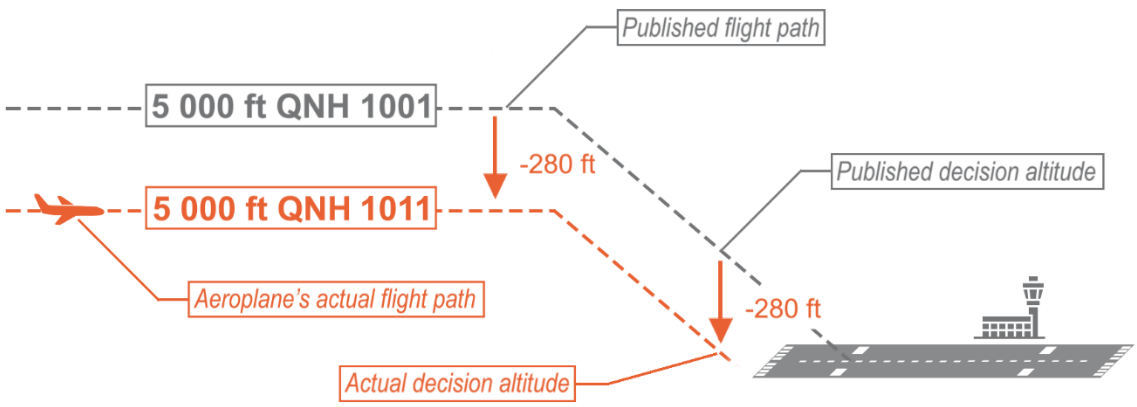


Figure 51: impact of incorrect QNH on vertical profile (source: BEA)

The design of the IFR procedures did not take into account an error in the altimeter setting, and the crews' operating procedures and those of the air traffic controllers did not prevent the use of an incorrect altimeter setting. In addition, neither the aeroplane's instruments nor the air traffic controllers' tools were designed to detect this type of error.

At a height of 239 ft RA, shortly before the aeroplane reached the indicated altitude corresponding to the decision altitude, a Minimum Safe Altitude Warning (MSAW) was triggered in the control tower. Nine seconds later, the tower air traffic controller who was in contact with the crew informed them of the situation using an incorrect and inappropriate phraseology. The crew did not hear this call and continued the descent.

A few seconds after the indicated altitude had passed the decision altitude (increased by 50 ft as per operator policy), the crew carried out a go around as they had not acquired sight of the ground. During the manoeuvre, the minimum recorded and corrected radio-altimeter height was 6 ft, i.e. about 2 m, when the aeroplane was about 0.9 NM from the runway threshold, outside the limits of Paris-Charles de Gaulle airport. As per design, there was no on-board ground proximity alert (TAWS) during the event. In their statements, the crew indicated that they had not been aware of this proximity with the ground.

During the go-around, the local QNH value was correctly given to the crew by the TWR controller. However, the copilot read back the incorrect information that was being used on board the aeroplane. This error was not picked up by the air traffic controller and the crew lined up for a second approach to runway 27R with once again, a flight path altitude that was 280 ft below the published altitude.

During this second approach, the MSAW alert triggered at a height of around 850 ft RA, much higher than during the first approach. The air traffic controller who had relieved the tower controller in position during the first approach warned the crew of the situation, and also used an incorrect and inappropriate phraseology. The crew replied that they were on the correct path and that they had sight of the runway. The approach lights were, this time, illuminated and the weather conditions had improved. The crew corrected the flight path and landed without further incident.

At the end of the flight, and according to the various statements gathered, no front-line actor had been aware of what had happened and the seriousness of the event.

The analysis covers the following points:
- communicating and entering the altimeter setting information;
- crew situational awareness;
- air traffic controller activity;
- the ground (MSAW) and on-board (TAWS) systems to prevent collisions with the ground (CFIT);
- the ground and on-board systems to detect an incorrect altimeter setting;
- insufficient consideration given to the threat of an incorrect altimeter setting;
- implementation of the IR-PBN regulation and its potential consequences.

2.2 Communicating and entering altimeter setting information

2.2.1 ATIS and preparing approach

During the preparation for the approach, the pilots, in turn, listened to the ATIS information on the radio and then compared their data. They had both noted on a piece of paper, the correct QNH value given by the ATIS, which was 1001 hPa.

The ATIS weather information at CDG is directly taken from the Météo France data which limits transcription errors. It is broadcast on a radio frequency (Voice-ATIS) and is also transmitted as digital data (Data link-ATIS). For crews on aeroplanes equipped with the Data link-ATIS[73], this avoids transcription errors being made and takes up less of their mental resources.

[73] This was not the case for 9H-EMU.

The Météo France analysis showed that in a 30-minute period, large variations in the QNH are extremely rare (see paragraph 1.7.3). It is therefore possible to consider that the QNH value obtained from the ATIS in cruise before the descent, is reliable for the approach and close to the actual value.

The crew did not preset the QNH on the aeroplane's altimetric systems on obtaining the ATIS data as the system was not designed for this and it was not required by the manufacturer's and operator's procedures. The presetting of the QNH when preparing the approach might have helped the crew to identify the large difference between the QNH provided by the ATIS and the incorrect QNH provided by the air traffic controller.

2.2.2 Transmission of QNH by air traffic control

During first approach

The intermediate approach (ITM) controller provided the crew of flight NSZ4311 with incorrect QNH information during the first altitude clearance below the transition level, namely 1011 hPa instead of 1001.

She indicated in her statement, that she usually looked at the DECOR screen which displayed the QNH before transmitting it to the crew. She did not know if she had done this during the serious incident.

This error in the tens digit and it not being corrected can probably be explained by a combination of the following factors:

- the transposition of the last two digits of the callsign of flight NSZ4311 "*four three one one*" to that of the QNH, "*one zero one one*";
- a similar musicality between "*one zero zero one*" and "*one zero one one*", with solely "*ones*" and "*zeros*";
- the last number and therefore the last sonority "one" being identical in both cases.

This last point with respect to the last number having the same sonority may be one of the factors explaining the high frequency of errors of ± 10 hPa observed in similar events (see paragraph 1.18.1.2).

Because of the nature of her work, the controller's provision of the QNH may have become a routine action, and being unaware of the fundamental role of the QNH for barometric approaches (as indicated by many controllers in their statements), the ITM controller's attention was not particularly focused on the accuracy of this information, both when it was transmitted and when listening to the read-back.

The same incorrect QNH was then transmitted in English two more times by the ITM controller:

- a second time to flight NSZ4311 during the approach clearance as the clearance included an altitude instruction and the ITM approach controller was in the habit of giving a QNH with an altitude;
- to an easyJet crew during the first altitude clearance below the transition level. However, this crew read back the correct QNH of 1001 hPa, without this being picked up.

The controller then gave the correct QNH to an Air France crew in French, using the expression, "*mille un*". This exchange could not be understood by the crew of 9H-EMU who did not speak French. Nevertheless, the next two exchanges, made in English, with two other crews before flight NSZ4311 left the frequency, did include the correct QNH given in English and could possibly have enabled the crew to detect the error.

During the transfer to the tower controller and during the landing clearance, in accordance with the operating procedures in force, no QNH information was transmitted to the crew.

During go-around and second approach

After the PM had reported the go-around on the frequency, the tower (TWR) controller did not ask the crew to carry out the published missed approach procedure, preferring to optimize the flight path as there was no conflicting traffic. He gave them several instructions in a roughly 12 s period, with five of these requiring a read-back: turn right, heading 3 6 0, climb, 5,000 ft, QNH 1 0 0 1.

The PM correctly read back four of the five items and then, probably due to a combination of anticipation bias with respect to the QNH value that was already being used and a high workload during the go-around, he incorrectly read back the 5th item, i.e. QNH "1 0 1 1", which was not picked up by the TWR controller The tower assistant controller probably did not hear the PM's message as he was coordinating the go-around by telephone.

After the exchanges concerning the go-around, no QNH information was given to the crew up to landing. Neither the approach clearance, nor the first contact with the tower controller nor the landing clearance require the QNH to be given again. This may have deprived the crew of the information they needed to detect the QNH error. The crew again carried out its approach below the published vertical profile.

Procedures and regulations

The international rules on the transmission of altimeter setting information by air traffic control services, when the aerodrome is equipped with an ATIS (which is the vast majority of cases in commercial air transport), require it to be transmitted to the crew on at least two occasions (see paragraph 1.17.1.3.4): via the ATIS and on the first altitude clearance below the transition level.

Once the altimeter setting information has been transmitted, there is no requirement to give this value again. No distinction is made in the requirements between barometric approaches and other approaches.

2.2.3 Receiving and entering QNH by crew

When the PM read back the incorrect QNH information the first time, there was a certain hesitation with respect to the QNH value, which was repeated: "*6,000 feet 1 0 1 1 ... 1 ... 0 1 1 … Red Nose 4 3 1 1*". However, he did not try to dispel any doubts he might have had by asking for explicit confirmation of the QNH value.
The PM mentioned that he tended to trust the information provided by the controller. He thought that if he himself had made a mistake, the controller would have corrected it.

The easyJet crew, who had also received the incorrect QNH information, read back the correct QNH value. The controller did not pick up this inconsistency. Neither the crew nor the controller asked for clarification although they had each announced a different QNH, this difference not having been identified.

Eurocontrol and the other organisations involved in producing a European action plan on the safety of communications (see 1.17.1.3.2) have identified that if a controller does not correct a read-back, the crew could implicitly perceive this as a confirmation of it being correct.

Furthermore, in France and generally in Europe, the transition level is relatively low, between 3,000 and 6,000 ft. As a result, the altimeter setting information, transmitted during the first clearance below the transition level, is very generally given to the crew in an approach phase with a high workload conducive to errors. Furthermore, in the event of an incorrect altimeter setting and given that the aeroplane is already relatively low, this leaves less time and fewer opportunities for pilots and controllers to identify and correct the error.

Entering, checking and confirming QNH

The operator's procedures, based on those of the manufacturer, required each pilot when changing from the standard altimeter setting to the QNH altimeter setting, to enter the QNH in the altimetric system and to cross-check the altitude value with the other pilot. There was no requirement to confirm the QNH value transmitted with the value from an external source (ATIS, METAR, flight file, ACARS, ATC confirmation etc.). Several procedures from several operators and several manufacturers were analysed during the investigation and most of them did not require confirmation of the QNH input with an external source.

The pilots of 9H-EMU indicated in their statements that they were in the habit of confirming the QNH value with their ATIS notes even if this was not required by the SOP, but that in this case they did not do it because they did not have the time, probably because of the management of the deteriorating weather situation and its impact on the workload.

2.3 Crew's situational awareness

2.3.1 Elements supporting erroneous situational awareness

Several factors already mentioned above may explain why the crew had an erroneous situational awareness in that they believed the aeroplane was on a stabilized approach on a nominal vertical profile:

- the absence of external visual references;
- the absence of a QNH preset in the aeroplane's altimetric systems when acquiring the ATIS information, the systems not being designed for this and it not being required by the procedures;
- the absence of confirmation of the QNH value received during the altitude clearance below the transition level with an external source (ATIS, METAR, QNH entered in FMS etc.), this not being required by the procedures;
- exchanges with the control during the approach which also contained incorrect QNH information and may have strengthened the crew's belief that the altimeter setting used was correct.

In addition, the comparison of the QNH value or the altitude between the two PF/PM altimeters required by the procedures is ineffective for detecting an incorrect altimeter setting common to both altimeters.

Furthermore, since the altimeter setting information for barometric approaches is used both for setting the altimetric systems and by the aeroplane systems, for generating the vertical profile and vertical guidance information (see paragraph 1.6.5), an incorrect altimeter setting does not produce an anomaly likely to draw the attention of the crew. In particular, when carrying out a stabilised approach on an incorrect vertical profile, the Flight Director (FD) bars remain centred, the Vertical DEViation indicator (V/DEV) stays at zero and the altitude-distance cross-checks provide values corresponding to those which are expected and indicated on the approach charts.

As a result, during a flight phase characterised by a high workload, with in particular a repetition of consistent altitude-distance cross-checks, the aeroplane's instruments and flight procedures did not allow the crew members to identify an anomaly. On the contrary, they reinforced the crew's erroneous situational awareness with them believing that they were on a stabilised approach on a correct vertical profile.

Furthermore, the protection envelope of the TAWS installed on board 9H-EMU is such that no alert was triggered to warn the crew of the imminent risk of a ground collision (see paragraph 2.6).

2.3.2 Information which could help pilots detect an inconsistent vertical position and difficulties associated with this

Radio-altimeter visual information

In the absence of any external visual references, the radio altimeter was the only means for the crew to identify the inconsistent vertical position of the aeroplane. The crew could have compared the height values of the radio altimeter displayed on the PFD in various forms (see paragraph 1.6.3) with the altitude of the airport and the altitude displayed, and possibly deduce that there was a vertical position anomaly. However, these various secondary parameters are intended to give the crew a better understanding of the situation in the context of CATII/CATIII operations and are not directly applicable in the context of the serious incident with a LNAV/VNAV approach.

In practice, these elements are not generally specifically monitored by pilots when approaching the minima and they were not designed to alert pilots to the incorrect vertical position of the aeroplane in a high workload situation. It is therefore not surprising that the crew did not detect or take into account these signs, because this is not required by the procedures and is not generally carried out by the crews. It would require the mobilisation of complex cognitive resources, which would be difficult to implement during the approach, a phase with a high workload when approaching the minima. What's more, this method cannot be fully generalised because it is only applicable if the terrain is relatively flat and free of obstacles before the runway.

Lastly, it should be noted that a height-distance cross-check based on information published on aeronautical charts could have helped the crew to detect an altitude inconsistency. However, no procedure provides this type of cross-check. The height information available on the approach chart published in the AIP France is generally not included on the approach charts produced by most of the chart suppliers for air operators (see 1.10.2) and this type of cross-check is generally not carried out by the pilots.

Auto callouts and inattentional deafness

The approach was carried out in a heavy rain shower with the windshield wipers set to the fastest speed, giving rise to a lot of noise in the cockpit.

The crew members indicated in their statements that they had not heard the air traffic controller's message informing them of the triggering of a ground proximity alert (MSAW) during the first approach. This information was given on flying through the decision altitude at a time when the crew's workload was particularly high. This could explain why the message was not perceived. Furthermore, the crew's erroneous situational awareness, associated with the controller's phraseology and tone (which did not allow the crew to grasp the urgency of the situation) might have been conducive to the pilots not mentally processing this information.

The pilots also indicated that they had only heard the radio-altimeter auto callouts at 2,500 ft RA and 1,000 ft RA and not those at 500 ft, 200 ft, 100 ft, 50 ft, 40 ft, 30 ft, 20 ft and 10 ft. The auto callouts might have allowed the crew to identify that the aeroplane was incorrectly positioned on the vertical profile. The tests carried out on the aeroplane's computers did not reveal any malfunction in their activation (see paragraph 1.6.4).

These callouts, emitted during each landing, are not alerts and do not normally require any action by the crew. It is therefore likely that, in the context of a high workload, a substantial proportion, if not all, of the crew members' mental resources were mobilised on tasks related to managing the approach, visually searching for the runway in conditions of reduced visibility, and then executing the go-around. It is therefore probable that the aural information transmitted via the automatic radio-altimeter callouts may have been unconsciously considered as "distractors", i.e. information that was not relevant to the task in hand. This phenomenon, also known as "inattentional deafness", mostly occurs when mental resources are overloaded (Causse, Imbert, Giraudet, et al., 2016).

It should be noted that the auto callout sequence, "FIFTY, FORTY, THIRTY, TWENTY, RETARD" occurred from the beginning of the go-around at a height of 52 ft RA, leading to a high workload for the crew. This could have contributed to the crew not perceiving these auto callouts.

During the second approach, the tower controller's message about the MSAW alert, "*I've just got a ... a terrain alert are you okay?*" was heard this time by the crew who did not understand the reason for this. Likewise, when correcting the flight path and seeing that the vertical profile was not correct on the PAPI, they did not question the reason for this difference. These elements clearly illustrate the difficulty encountered by the crew in calling into question the erroneous situational representation that they had built up.

2.4 Analysis of air traffic controller activity

2.4.1 A succession of errors

Throughout the sequence of the serious incident, errors, and communication errors in particular, were observed both on the ground and on board the aeroplane (see paragraph 1.9.2):

- the initial approach (INI) and north intermediate approach (N ITM) controllers identified and corrected several incorrect PM read-backs;
- the ITM controller gave an incorrect QNH three times;
- the N TWR controller forgot to switch on the approach lights during the final approach of NSZ4311, which was carried out in a rain shower;
- during the go-around, the tower controller (N TWR) did not identify the crew's incorrect read-back of the QNH. The TWR assistant controller was busy coordinating the go-around and did not hear the incorrect read-back;

- a conflict between an aeroplane (in contact with the S ITM controller) and flight NSZ4311 on the downwind leg in contact with the N ITM controller was not identified sufficiently early by the two controllers and led to the triggering of the Short Term Conflict Alert (STCA, see paragraph 1.10.3.2) and the use of emergency phraseology;
- during the second approach, the N ITM controller, who was managing the combined North ITM and BA (Le Bourget and others) positions, transmitted the Bourget frequency to the crew of flight NSZ4311 instead of the north tower frequency.

In a normal operation context in terms of traffic, manning of positions and weather conditions, and in the absence of any malfunction, a large number of air traffic control errors were observed over a short period of time. These various errors had consequences of varying degrees, even if some of the crew's communication errors were corrected by the air traffic control services.

The study of similar occurrences (paragraph 1.18.1.2) found that the serious incident at CDG was not an isolated case in France, and that the air traffic control services contributed to a non-negligible proportion of altimeter setting occurrences due to communication errors in particular.

In addition to these errors in normal conditions, the emergency phraseologies associated with MSAW alerts were not correctly given (see paragraph 2.5.2).

At the time of the serious incident, the risk of "near-CFIT" was identified as an undesirable occurrence in the DSNA risk map. However, the DSNA had not produced an analysis table for "near-CFIT" occurrences and had not set up a local or national CFIT risk management process - in particular based on the analysis of safety events - as would be expected in a safety and compliance management system. The DSNA thus deprived itself of an overall assessment of the CFIT risk (going beyond the selective analysis of each occurrence) and the possible quantification of "near-CFITs" recorded in its database.

Furthermore, the collection of data for the DSNA's safety management system was still essentially based on safety occurrences alone (reactive approach), and no other means or methods had been put in place at the DSNA to better apprehend weak signals, threats, errors and undesirable events that could have an impact on safety in a given operational context, and to identify good practices for maintaining safety (proactive or predictive approach). At an international level, several air navigation service providers implement, for example, on-the-job observations (see paragraph 1.17.1.4.2).

- **The introduction of methods or tools for the objective assessment of air traffic controllers' on-the-job work for the purpose of improving the safety management system is the subject of a safety recommendation addressed to the DSNA (see paragraph 5.2.6).**

2.4.2 Altitude monitoring by air traffic controllers

During the first approach, the crew only performed a short level-off of about 0.5 NM before starting the final approach. Detecting the altitude error was therefore very difficult by means of the radar display available to air traffic controllers (see paragraph 1.10.3.2) and in the absence of an Approach Path Monitoring (APM) system to warn the controller that the aeroplane was not on the correct vertical profile.

However, about seven minutes elapsed during which the aeroplane was level at 5,000 ft after the go-around, and from the downwind leg to reposition for the second approach.

The CDG radar display indicated by default, flight levels based on mode C transponder data at an altimeter setting of 1013 hPa, even below the transition level. Thus, for a clearance at 5,000 ft, the standard altitude value for flight NSZ4311 displayed to the controllers was "051" (the crew being at 5,000 ft QNH 1011), whereas it would have been "053" or "054" with QNH 1001. Theoretically, the altitude difference was therefore identifiable from the radar screen for these seven minutes.

However, controllers rarely make this type of calculation because of the cognitive resources required when there are no stimuli prompting them to check the exact altitude of the aeroplane. This is particularly the case when the altitude is correctly read back and the aeroplane is in level flight ±300 ft at the cleared altitude.

The display of a QNH altitude could make it easier to identify this difference, by allowing a direct comparison between the value displayed and the altitude cleared: for example, the displayed altitude value "A047" compared with the expected value "A050" and a selected altitude "@050". This automatic display of the QNH altitude instead of the flight levels below the transition level is recommended by the DSNA for all approaches except at CDG. This CDG exception is justified by the fact that the radar display system is a local adaptation of that of an en-route centre, handling 100% of the flights in terms of flight level.

2.5 Minimum Safe Altitude Warning (MSAW) system

2.5.1 System settings

The MSAW system can be one of the last safety barriers on the air traffic control side, for the prevention of collisions with the ground (CFIT). Like the on-board Terrain Awareness Warning System (TAWS), the setting logic for the MSAW alert is based on a compromise between relevant alerts and false alerts.

During the first approach, the MSAW alert was triggered late when the aeroplane was at a height above ground of 239 ft RA, leaving little time to prevent a possible collision with the terrain. During the second approach, carried out in almost the same way as the first and on the same incorrect descent path, the MSAW alert was triggered when the aeroplane was at a height above ground of 842 ft RA.

Studies of the MSAW system carried out with the DSNA found that the flight paths of the two approaches were almost tangent to the descent path configured in the system and used as the threshold for triggering alerts when aeroplanes pass below it on the final approach (see paragraph 1.10.4.2). These nearly tangent flight paths explain the difference in height when the MSAW was triggered for the two approaches, as it depended on when the aeroplane actually passed below this path in the radar data. The MSAW system therefore functioned according to its design.

Configuring a MSAW system is difficult; numerous parameters have to be taken into account, particularly on the final approach. However, there is no minimum operational performance specification applicable to ATM safety nets and in particular MSAW and APM (Approach Path Monitoring) nets, as there is for the TAWS, for example.

The MSAW system at CDG at the time of the incident was based on a configuration dating back to 2009. Although updates had been planned for years, technical and operational difficulties prevented its operational implementation. These updates were intended to limit false alerts and provide more relevant alerts, particularly in conditions similar to those of the serious incident. In addition, CDG is the only site in France where the MSAW system uses an altitude quantification step of 100 ft, whereas for all the other sites equipped with a MSAW system, the calculation is carried out with an altitude quantification step of 25 ft. This relatively high quantification step at CDG can lead to precious seconds being lost before a MSAW alert is triggered.

2.5.2 Controller procedures and training

Procedures

When the MSAW alert was triggered during the first approach, the tower controller took around nine seconds to react and inform the crew of the alert. At the DSNA, the triggering of the MSAW is based on an extrapolation of the aeroplane's flight path. The extrapolation time assumes that the controller transmits the MSAW information to the crew within three seconds of the alert being triggered. The hypothetical reaction time of the pilots and the aeroplane is 18 s.

In this serious incident, the controller's reaction time of nine seconds between the alert being triggered and the start of his message left very little time for the crew to react. The aeroplane was at a height of 239 ft RA when the MSAW was triggered, 122 ft RA at the beginning of the air traffic controller's message and 50 ft RA at the end of the message.

Regarding the phraseology used, during the first approach, the tower controller's message was, "*Red Nose 4 3 1 1 I just had a ground proximity alert are you okay do you see the runway?*" while on the second approach, the tower controller who was the tower assistant controller during the first approach formulated the following message, "*Red Nose 4 3 1 1 I've just got a ... a terrain alert are you okay?*" It is possible that the tower controller on the second approach was influenced by the message from the tower controller on the first approach.

In the CDG Operating Manual procedures, when the aeroplane is not being radar vectored, the phraseology to be used is as follows: "[Red Nose 4 3 1 1] *Terrain alert check your altitude immediately QNH* [1 0 0 1]".

The two messages transmitted by the two controllers were therefore incorrect and inappropriate because they:

- did not convey the urgency of the situation with the absence of the term *immediately*. In addition, the intonation of the controllers' voices did not convey the urgent character of the situation. This may have contributed to the message not being perceived by the crew;
- did not allow the crew to understand what was expected of them, "are you okay?" having little meaning for a pilot. This may have contributed to the fact that the crew did not understand either the reason for or the meaning of the message during the second approach;
- did not include the crucial information about the QNH value, which could have enabled the crew to realise that the altimeter setting was incorrect.

It is all the more important that the message in response to a MSAW alert is clear and without ambiguity as most crew members are not acquainted with the MSAW system nor the associated phraseology, nor with what is expected of them in this case, as most air operators do not provide any information or procedure associated with this system.

The investigation into the serious incident to the BOMBARDIER CL-600- (CRJ-1000) registered F-HMLD on 20 October 2021 on the approach to Nantes-Atlantique has already highlighted the need, in different international texts, for clarification of the phraseology to be used in the context of a MSAW alert, with the urgency of the situation and the QNH systematically being mentioned. Several safety recommendations were made and were still being processed by ICAO and EASA in April 2024 (see paragraph 1.17.1.3.6).

Training

DSNA controllers become acquainted with the MSAW system during their initial training at ENAC, in particular during simulator sessions. When a controller is assigned to a unit that has the system, he completes his training on the MSAW system during unit training when he arrives, and then in continuation training. Training in DSNA units is managed locally by each training unit and the procedures may therefore differ from one unit to another.

At CDG, on the arrival of a controller, the Unit Competence Scheme (see paragraph 1.17.1.3.6) includes theoretical training on safety nets, including the MSAW system, plus a simulator session in which the scenario is chosen from a catalogue of three simulations. Only one of these three scenarios includes the triggering of a MSAW alert. The alert is simply played by the instructor, as the software system does not allow the MSAW to be implemented in simulation.

As far as continuation training is concerned, the unit refresher training programme includes a theoretical part on safety nets, including the MSAW system. No practical training concerning the MSAW is provided for.

Thus, a qualified CDG controller may well never have reviewed in practice, the expected reaction to a MSAW alert since his initial training at ENAC.

Furthermore, various CDG controllers indicated in their statements that a MSAW alert at CDG was rare and that most of the time, if an alert was triggered, it involved an aeroplane on the frequency with Le Bourget, Pontoise or another unit, and that no action was therefore expected on their part.

This lack of experience and practical training in how to respond to a MSAW alert contributed to a delayed reaction and the use of an incorrect and inappropriate phraseology during the serious incident.

The study of various similar occurrences in France found that the use of an incorrect and inappropriate MSAW phraseology was not an isolated case, and that a lack of reaction of air traffic controllers was observed a number of times.

- **The training and recurrent training of air traffic controllers to ensure they have full command of the MSAW alert emergency procedure is the subject of a safety recommendation addressed to the DSNA (see paragraph 5.2.5).**

2.6 Terrain Awareness and Warning System (TAWS)

A TAWS alert is one of the last barriers to avoid a collision with the ground. It is therefore an essential element of air safety. As seen in paragraph 1.6.7, no TAWS alert was triggered during the serious incident, although the minimum recorded and corrected radio-altimeter height was 6 ft when the aeroplane was about 0.9 NM from the runway threshold. The system nevertheless functioned correctly and in accordance with its design.

The aeroplane was configured for landing and in a standard rate of descent, so no TAWS basic and reactive mode alerts or warnings were triggered. Furthermore, the GLIDE SLOPE alert is not available for barometric approaches. Lastly, since the predictive Premature Descent Alert (PDA) mode includes an inhibition zone before the runway to avoid untimely alerts on each landing, and as the EGPWS software version was an old version and did not use GNSS positioning, no alert was generated, despite the aeroplane's low height.

Honeywell's conclusions following the simulations carried out, indicated that in the circumstances of the serious incident, i.e. an approach on a standard 3° slope 280 ft blow the published vertical profile due to an incorrect altimeter setting of 10 hPa, an EGPWS equipped with a more recent software version and using GNSS positioning, would have generated a "TOO LOW TERRAIN" caution alert at a height above ground of approximately 200 ft RA, i.e. approximately 15 s before the lowest point at 6 ft RA.

Although aircraft and TAWS manufacturers have encouraged operators to update the TAWS on their aeroplanes to more recent standards and to use GNSS positioning, Airbus and Boeing estimate that there are still around 1,600 aeroplanes in service equipped with EGPWS that would not generate an alert in the circumstances of this serious incident. It should be noted that international regulations do not require TAWS standards or versions to be updated. For aeroplanes such as 9H-EMU, updating the TAWS to a more recent standard can require operations and/or modifications that could generate significant costs.

With respect to the applicable certification standards for TAWS, the review of the latest requirements applicable to these systems also found that the Minimum Operational Performance Specifications (MOPS) for the triggering of a premature descent alert do not currently take into account an approach on a standard 3° slope 280 ft below the published vertical profile, which is an offset that corresponds to an altimeter setting error of 10 hPa, one of the most common.

- **The revision of the Minimum Operational Performance Specifications (MOPS) applicable to TAWS systems for Premature Descent Alerts (PDA) is the subject of a safety recommendation addressed to EASA (see paragraph 5.2.4).**

2.7 Ground and on-board systems detecting an incorrect altimeter setting

Ground systems

Ground systems which detect incorrect altimeter settings exist (see paragraph 1.18.2) and are implemented in certain countries such as the United Kingdom and the Netherlands.

In Europe, commercial air transport operators are required to equip their aeroplanes with Enhanced Surveillance mode S (EHS) capabilities. The EHS information contains the altimeter setting information used by the crew. It is therefore possible to compare the aeroplane's altimeter setting with the actual QNH value, and depending on this, to issue an alert to the air traffic controller so that he can warn the crew.

However, for this type of system, there are no implementation, procedure or phraseology requirements for air navigation service providers.

- **The implementation within air traffic control units of a ground system for detecting an incorrect altimeter setting and the associated phraseology for air traffic controllers, is the subject of a safety recommendation addressed to EASA (see paragraph 5.2.3).**

In France, no en-route, approach or tower unit displays aeroplane altimeter setting information or sends an alert to the air traffic controller in the event of a difference with the actual QNH. The en-route centres receive EHS mode S transmissions from the aircraft and, at Paris-Charles de Gaulle, as the control system is similar to those in the en-route centres, the EHS mode S parameters are also received. For all these centres, only the selected flight level, instantaneous heading and indicated airspeed parameters transmitted are available for display on the controller's screen. The aeroplane altimeter setting is however not processed by the system.

On-board systems

On-board systems for detecting incorrect altimeter settings have been available for several years (see paragraph 1.18.3). These systems are currently only marginally deployed in the commercial aeroplane fleet. They work by comparing the barometric altitude with other parameters such as the GNSS altitude, the radio-altimeter value and the terrain database to alert the crew in the event of an inconsistent altimeter setting.

A simulation in conditions similar to those of the serious incident carried out for the investigation found that the ALTSM step1 system developed by Airbus and whose design is based on Honeywell's CAM-BTA function, would have triggered an aural "Altimeter setting" alert at around 1,843 ft RA, i.e. 2 minutes and 22 seconds before the minimum radio-altimeter height reached during the serious incident.

2.8 Insufficient consideration given to the threat of an incorrect altimeter setting for satellite approaches with barometric vertical guidance

The incident involving 9H-EMU illustrates how an accident involving a modern aeroplane, operated by a European operator, on approach to one of the world's largest airports, in 2022, could have occurred solely due to an incorrect altimeter setting.

From practically the beginning of aviation, the aeronautical community has known of the CFIT risk due to the threat of an incorrect altimeter setting, for barometric approaches . The predominant use of non-precision approach procedures and the virtual absence of ground collision avoidance systems until the 1970s gave rise to a high CFIT risk, due in part to incorrect altimeter settings, which was tolerated in view of the overall safety requirements at the time.

The significant development of commercial air transport over the following decades greatly increased societal expectations both in terms of safety and weather-related airport accessibility. ILS installations, offering lateral and vertical guidance that is not affected by incorrect altimeter settings (although the decision altitude at the minima is still affected), along with improved weather-related accessibility due to lower approach minima, thus became widely used, making this an equipment standard worldwide even to this present day.

The development, from the 1990s onwards, of Baro-VNAV functions (offering conventional or satellite-based lateral guidance, and barometric vertical guidance based on the altimeter setting) made it possible to carry out descents, then approaches, and in the 2000s final approaches using Performance Based Navigation (PBN) down to minima close to those of Category I precision approaches.

Baro-VNAV approaches have thus played a major role in improving safety, and continue to do so, by providing vertical guidance on non-precision approaches and on runways without radio navigation equipment. They effectively reduce the CFIT risk.

However, the Baro-VNAV function was not designed to be an autonomous approach and landing system, unlike precision approach systems such as the ILS, or approaches using GNSS positioning enhancement systems (GBAS or SBAS, see paragraph 1.8.1.2.3). The vertical guidance of a Baro-VNAV approach is based solely on the aeroplane's internal data, in particular the barometric altitude, which depends on the altimeter setting. However, the latter potentially relies on multiple human inputs that are prone to error (by the meteorological services, air traffic controllers and pilots).

The approach procedures that use the Baro-VNAV function in order to have the lowest minima are the RNP APCH operations down to LNAV/VNAV minima type PBN procedures. With these procedures, it is possible to have a decision height as low as 250 ft, close to the minima for a Category I ILS approach at 200 ft. However, one of the most frequent incorrect altimeter settings in hPa is with an error of 10 hPa. This offsets the altitude and therefore the vertical profile by 280 ft to the theoretical vertical profile, which could ultimately lead to a collision with the ground before the decision altitude has been displayed to the crew.

It should also be noted that in the design of the procedures, the method of calculating decision heights for RNP APCH down to LNAV/VNAV minima, notably based on obstacle clearance margins in the ICAO PANS-OPS, was revised in 2004 to increase airport accessibility, and results in lower decision altitudes. The threats inherent in the Baro-VNAV function, such as an incorrect altimeter setting, were not taken into account when this revision was introduced, and the reduction in minima for these approaches did not give rise to a safety study by ICAO.

The CFIT risk linked to the threat of an incorrect altimeter setting for barometric approaches, and in particular Baro-VNAV approaches, although known for decades, was not sufficiently taken into account by the entire international aviation community. In the light of this serious incident and the many similar occurrences of incorrect altimeter settings, it can be considered that the hypothesis that current training, procedures and systems are sufficient to limit this risk is not true. In fact, neither the design of these IFR procedures, nor their execution by crews, nor the air traffic controllers' procedures, nor the on-board or ground systems are sufficiently robust to systematically deal with this threat.

This risk was probably not sufficiently taken into account by the aviation community as a whole in the various risk analyses, because the majority of approaches in commercial air transport have for several decades been carried out using ILS precision approaches and their vertical profiles are not affected by incorrect altimeter settings, thus masking these errors and their consequences.

It should also be noted that the risk analyses concerning Baro-VNAV approaches carried out in the United States may differ significantly from those in other parts of the world, particularly Europe, where the organisation of airspace can be different. In the United States, for example, altimeter settings are in in Hg, the transition level is at FL180 and the mother tongue for air traffic controllers is English. Comparisons may therefore be inappropriate, and discussions at international level must take these differences into account.

Given the increasing use of satellite approaches with barometric vertical guidance, the threat of an incorrect altimeter setting, although known about for decades, has become preponderant again and the associated risk for commercial air transport unacceptable in view of today's global safety requirements, which are much higher than in the last century.

- **The overall reassessment of the CFIT risk and the associated mitigation measures, in connection with the threat of an incorrect altimeter setting for Baro-VNAV approach operations, is the subject of a safety recommendation addressed to ICAO (see paragraph 5.2).**

2.9 Assessment of the impact on safety due to the changes brought about by the IR-PBN regulation

The Commission implementing regulation (EU) 2018/1048 of 18 July 2018 laying down airspace usage requirements and operating procedures concerning performance-based navigation, known as “IR-PBN” requires in particular that:

- member states shall publish RNP APCH operations down to LNAV, LNAV/VNAV or LPV minima for all instrument runway ends by 25 January 2024;
- air navigation service providers exclusively use PBN up to CAT I precision approach operations by 6 June 2030, and therefore no longer use conventional navigation procedures, including ILS, from that date except for contingency measures (in the event of the GNSS signal not being available, for example).

ICAO had asked States to accelerate the deployment of PBN, but never required or promoted the exclusive use of PBN. The introduction of this exclusive use provision in IR-PBN regulation (EU) 2018/1048 was made at the very end of the regulatory process, and did not give rise to a specific assessment of its impact on safety before the regulation was adopted. In particular, there was no assessment of the impact of the transition from commercial air operations under IFR predominantly conducted using the ILS to commercial air operations conducted solely using PBN approaches (excluding CATII/III operations), and no definition of criteria for adjusting this provision if the development of Baro-VNAV alternatives (such as LPV or GBAS) has not progressed as expected by 2030. One of the assumptions, also an objective, was that operators would modernise their fleets and equip themselves with the capability to carry out RNP APCH operations down to LPV minima, the only PBN procedure offering a level of safety and accessibility comparable to ILS CAT I precision approaches.

As seen in paragraph 1.8.4, the development of LPV capabilities is still in its infancy in commercial air transport. For example, at the end of 2022, less than 500 Airbus aeroplanes out of a fleet of over 10,000 were equipped to perform RNP APCH operations down to LPV minima, and at the time of writing this report, no Boeing aeroplane had been certified to perform these operations. Depending on the aeroplane type, the cost of retrofitting to obtain this capability could be significant. Lastly, there is no planned requirement to impose this capability in the years to come.

GBAS approach operations are excluded from the scope of the IR-PBN regulation and will therefore still be permitted after 6 June 2030. However, the rate at which aircraft are equipped to perform this type of approach, although higher than the rate at which aircraft are equipped for LPV, remains low at present, and above all, only a few aerodromes in Europe have the infrastructure required to perform GBAS approaches, so very few GLS (GBAS landing system) procedures are published.

The findings of this investigation suggest that, in the absence of a clear change of direction in Europe between now and 2030, there will be a substantial decline in the level of safety on approach, due to the transfer of a sizeable proportion of the approaches currently flown using ILS to Baro-VNAV approaches with a lower level of safety, in the absence of sufficient deployment of the LPV capability. In PBN, LPV is the only option that enables CAT I precision approaches to be flown with a safety level equivalent to that of ILS or GLS approaches, where the vertical profile is not affected by an incorrect altimeter setting.

A change in the European Commission's policy on the exclusive use of PBN, for example in the form of an amendment to the IR-PBN regulation, or the introduction of much stronger incentives to improve on-board equipment now seem necessary to maintain the level of safety of approach operations in Europe, even if corrective measures are taken in connection with the points discussed above.

- **The reassessment of the risks associated with the changes brought about by the IR-PBN, and in particular those linked to the use of an incorrect altimeter setting during a barometric approach is the subject of a safety recommendation addressed to the European Commission (see paragraph 5.2.2).**

3 CONCLUSIONS

3.1 Findings

Context of serious incident flight

- The aeroplane did not have any technical fault in connection with the serious incident.
- The crew held the necessary licenses and ratings to accomplish the flight.
- The air traffic controllers held the necessary ratings to carry out their duties.
- The Cockpit Voice Recorder (CVR) was not preserved following the serious incident.
- The weather situation at Paris-Charles de Gaulle at the time of the serious incident was one of low-pressure conditions with the presence of convective clouds with strong vertical development (cumulonimbus) and passing rain showers.
- The crew indicated that they had flown in IMC without external visual references down to the minima during the first approach.
- The tower controller had switched on the runway lights. He had, however, forgotten to switch on the approach lights for the first approach.
- The aeroplane's call sign was NSZ4311.
- The local QNH in force was 1001 hPa. This QNH was automatically transmitted from the Météo France office to the CDG ATM systems (ATIS, MSAW, radar screen, etc.).
- The ILS of runway 27R at CDG had been out of service for several days for work to replace the ILS antennas, and PBN approaches replaced ILS approaches.
- The aeroplane was not equipped to carry out PBN RNP APCH operations down to LPV minima. The crew carried out a barometric PBN RNP APCH down to LNAV/VNAV minima.
- The operator's procedures required 50 ft to be added to the decision altitude for all approaches that were not precision approaches, which included RNP APCH operations down to LNAV/VNAV minima.

Barometric approaches and incorrect altimeter settings

- Non-precision approaches (NPA based on VOR, NDB, LOC, LNAV etc.) and approaches with barometric vertical guidance (APV Baro-VNAV or RNP APCH down to LNAV/VNAV minima) are called "barometric approaches" because the aeroplane's vertical profile relies on the altimeter setting used.
- An incorrect altimeter setting for barometric approaches results in the actual altitude and consequently the actual vertical profile being offset to the published vertical profile designed to avoid terrain and obstacles.
- Close to sea level, an error of 10 hPa in the altimeter setting, one of the most frequent errors, results in an altitude offset of around 280 ft or 85 m.
- RNP APCH operations down to LNAV/VNAV minima are the barometric approaches with the lowest minima. The decision height can descend to a minimum of 250 ft.
- A study by Météo France has shown that over 30 minutes, the QNH varies by only 0 or 1 hPa in 99.77% of cases.

Sequence of serious incident flight

Initial and intermediate approach

- Prior to the descent, the crew carried out a briefing for the RNP APCH operation down to LNAV/VNAV minima after consulting ATIS Q mentioning a QNH of 1001 hPa.
- During the first altitude clearance below the transition level, the intermediate approach air traffic controller (ITM) mistakenly gave the crew of flight NSZ4311 a QNH of 1011 hPa instead of 1001 hPa.

- The crew read back this incorrect QNH and then used it as a reference for setting the aeroplane's altimetric systems. They did not confirm the value of the QNH with another source of information such as the ATIS, the METAR or the QNH entered in the FMS for example. No operating procedure required the crew to carry out this confirmation.
- The aeroplane did not have a system to detect and alert the crew in the event of an incorrect altimeter setting. Certification requirements, including the most recent ones, do not impose such systems on board aeroplanes.
- The altimeter setting, via the Barometric Pressure Setting (BPS), is part of the data transmitted through Enhanced Surveillance mode S (EHS) or ADS-B capabilities. This parameter is therefore automatically transmitted by almost all aeroplanes operating in commercial air transport in Europe. By comparing the BPS with the local QNH, air traffic control services could detect an incorrect altimeter setting.
- The air traffic control services at CDG did not have a system to detect and alert the controller in the event of an incorrect altimeter setting. No approach or tower in France has such a system. European regulations do not require air navigation service providers to have such systems.
- With an incorrect altimeter setting of +10 hPa, the aeroplane flew all of the approach around 280 ft below the published vertical profile, without either the crew or the air traffic controllers noticing it.
- Approximately two minutes after the first incorrect QNH had been transmitted to the crew, the ITM controller once again gave them the incorrect QNH of 1011 hPa instead of 1001 hPa during another descent clearance.
- The incorrect QNH of 1011 hPa was again read back by the crew.

First final approach

- During the first radio contact with the tower controller for the north parallel runways (N-TWR), the latter cleared the crew to land. In accordance with operating procedures, the QNH information was not transmitted.
- International regulations on radio communications require the QNH to be provided in the ATIS message (when it exists) and in the first altitude clearance below the transition level. No further reminder of the QNH is required once it has been provided previously, regardless of the type of approach procedure carried out, even for barometric approach operations.
- The crew carried out the altitude-distance cross-checks for each point on the approach chart, in accordance with procedures, without noticing any particular anomaly: in the event of an incorrect altimeter setting, the altitude-distance cross-checks cannot detect this type of inconsistency.
- The instruments available to the crew did not enable them to identify the incorrect altimeter setting or the incorrect vertical profile. On the contrary, they rather reinforced the crew's belief that they were on the correct vertical profile.
- For the crew, the approach was stabilised in terms of altitude, axis, airspeed, vertical speed and configuration. It was carried out in FINAL APP mode with the autopilot engaged.
- The crew carried out the final approach with a high workload, no external visual references, without the approach lights switched on and in a rain shower requiring the windshield wipers to be set to the highest speed position.

Near-collision with ground and go-around

- At a Radio Altimeter (RA) height of 239 ft and 1.5 NM from the threshold of runway 27R, a Terrain Awareness Warning System (MSAW) alert was triggered for flight NSZ4311 on the air traffic control systems.
- Approximately nine seconds later at 122 ft RA, the N TWR controller reacted to the MSAW alert with an incorrect and inappropriate phraseology, without mentioning the urgency of the situation or the QNH. In the design of the MSAW system, an air traffic controller is expected to react to an alert within three seconds. The crew indicated in their statement that they had not heard this message.
- Several similar events at CDG and other French airports showed that the emergency phraseology in the event of a MSAW alert was not systematically used. The investigation revealed that the MSAW procedure was not systematically reviewed in practical refresher training for DSNA controllers.
- At 52 ft RA, six seconds after passing the decision altitude displayed to the crew and the actual altitude was around 280 ft below the displayed one, the captain initiated a go-around. The crew indicated in their statements that they initiated a go-around at the minima as they had not acquired external visual references.
- During the manoeuvre, the minimum recorded and corrected radio-altimeter height was 6 ft, i.e. about 2 m, when the aeroplane was about 0.9 NM from the runway threshold, outside the limits of Paris-Charles de Gaulle airport.
- No on-board ground proximity alert or warning was recorded during the approach by the aeroplane's TAWS system. The TAWS had functioned correctly and in accordance with its design.
- The certification requirements, including the most recent ones, do not impose a TAWS alert in the conditions of the serious incident, i.e. a standard vertical profile around 280 ft below the published vertical profile.

Go-around and second approach

- In response to the crew's go-around message, the N TWR controller provided radar vectoring instructions containing five items to be read back, including the correct QNH value of 1001 hPa. The crew read back four of the five items correctly, but read back the incorrect QNH value of 1011 hPa without this being picked up by the N TWR controller.
- The N TWR controller was relieved by the N TWR assistant and another TWR assistant took up the position.
- No QNH information was subsequently transmitted to the crew for the rest of the flight.
- The crew were cleared to carry out a second RNP approach to runway 27R. The altimeter setting had not been changed and the vertical profile was again around 280 ft below the published vertical profile. This time, the approach lights were switched on.
- A new MSAW alert was triggered during the approach. Although the second approach was carried out in an almost identical manner to the first, the MSAW alert was triggered at a higher height above ground level, at 842 ft RA, 3.1 NM from the runway threshold.
- Approximately four seconds later, the N TWR controller (who was previously the N TWR Assistant) reacted to the MSAW alert with an incorrect and inappropriate phraseology which included neither the urgency of the situation nor the QNH.
- The crew reported that they had sight of the runway, corrected the flight path and landed without further incident.

3.2 Contributing factors

9H-EMU's near collision with the ground was due to a barometric approach being carried out with an incorrect altimeter setting (QNH) of +10 hPa, in a rain shower and with no external visual references.

Barometric approaches are particularly affected by the altimeter setting as it has an impact on the altitude adopted by the aeroplane and consequently the descent profile and vertical position along the flight path, including at minima.

The approach was thus carried out on a vertical profile around 280 ft below the published vertical profile, up to a minimum recorded and corrected radio-altimeter height of 6 ft, i.e. approximately 2 m, when the aircraft was about 0.9 NM from the runway threshold, without the crew being aware of this.

The following factors contributed to two barometric approaches being flown with an incorrect altimeter setting:

- human error in the exchanges communicating the QNH, the probability of which can never be reduced to zero;
- operating procedures for crews and air traffic controllers that are not very robust, or even ineffective against this threat;
- on-board and ground systems that are not very robust, or even ineffective against this threat.

The following factors contributed to the aeroplane descending to a near collision with the ground (near-CFIT):

- the approach lights not being illuminated;
- the absence of an on-board ground proximity warning, even though the TAWS system was operating in accordance with its design;
- the late triggering of the Minimum Safe Altitude Warning (MSAW) system, even though the system was operating in accordance with its design;
- a late and inadequate reaction by the air traffic controller to the triggering of this MSAW alert. The insufficient training of controllers with respect to the actions to be taken in response to this alert contributed to this inappropriate reaction.

The CFIT risk linked to an incorrect altimeter setting during a barometric approach has been known about for decades. However, the widespread use of ILS approaches probably helped to mask this threat and its consequences for a long time. More recently, satellite approaches with barometric vertical guidance have been promoted to increase the level of safety where previously only non-precision approaches existed. However, the increased use of these satellite approaches with barometric vertical guidance, in particular as a replacement for ILS approaches, has not led the aviation community to question the impact on safety levels, even though overall safety requirements are increasingly stringent.

3.3 Safety lessons

These safety lessons are especially aimed at air operators and air navigation service providers regarding the risk of Controlled Flight Into Terrain (CFIT) linked to the threat of an incorrect altimeter setting. These lessons, which are mainly operational, are not the subject of safety recommendations by the BEA in view of the measures taken by the stakeholders involved in the serious incident (see paragraph 4), and the fact that the BEA has given priority to longer-term recommendations with respect to systems which are more robust to error.

Aircraft manufacturers and air operators

At the time of the serious incident, the crew's operating procedures did not particularly emphasise the importance of the altimeter setting and the CFIT risk in the event of an incorrect setting. The many similar occurrences also show that this serious incident was not an isolated case and that crews make relatively frequent approaches with an incorrect altimeter setting without realising it. Most of these occurrences were on ILS approaches, which are not affected by an incorrect QNH (except for the decision altitude), and did not give rise to any significant incidents. Conversely, several significant incidents, even serious incidents or accidents, have occurred on barometric approaches.

Following the incident involving 9H-EMU and in the course of the investigation, the aircraft manufacturer and the air operator modified their procedures to correct the various points raised by the investigation. However, these modifications are for the most part, also applicable to other operators and other aeroplanes built by other manufacturers.

In order to limit incorrect altimeter settings, the crew procedures of air operators regarding barometric approaches could be changed as follows:

- include a reminder of the importance of the altimeter setting and the safety risks in the event of an incorrect setting common to the altimeters;
- prevent the input of an incorrect altimeter setting common to the altimeters, for example by:
    - presetting the QNH on the main altimeters or on the standby instrument, when preparing the approach after receiving ATIS information in particular,
    - confirming the altimeter setting with an external source (e.g. ATIS, METAR, FMS, confirmation from air traffic control etc.) when changing the barometric reference on approach;
- reduce the crew's workload on final approach as much as possible, in particular by limiting altitude-distance cross-checks to the most appropriate points (for example the Final Approach Fix (FAF) and the Step Down Fix (SDF)).

To supplement this, the introduction by air operators, of a systemic query for cases of incorrect altimeter settings as part of their flight data analysis programme would make it possible to take better account of this threat.

As for on-board measures, if air operators were to update their aircraft's TAWS to the most recent standards, this would provide greater protection against the CFIT risk. In addition, the use of GNSS positioning for TAWS would offer more effective protection envelopes in terms of safety.

Air navigation service provider

At the time of the serious incident, the operating procedures for air traffic controllers, in accordance with international regulations, required the control services to provide the altimeter setting to a crew in descent two times only. In general, it was provided via the ATIS, and then in the first altitude clearance below the transition level.

During the incident involving 9H-EMU, no altimeter setting information was given to the crew after the exchanges concerning the go-around, and up to the aeroplane landing, in compliance with operating procedures and regulations. The second approach was therefore carried out once more with an incorrect altimeter setting.

Current international regulatory requirements for the transmission of altimeter settings do not contain any specific procedures for the altimeter setting being transmitted one more time in the case of barometric approaches.

The many similar occurrences show that this serious incident was not an isolated case and that it is relatively common for crews to carry out approaches with an incorrect altimeter setting without realising it.

Following the incident, the DSNA made nationwide changes to operating procedures for air traffic controllers, with the requirement to give the altimeter setting a third time, during the first contact with the tower controller for barometric approaches (see paragraph 4.2).

In order to limit incorrect altimeter settings, the operating procedures for air traffic controllers of air navigation service providers could, for barometric approaches, include the altimeter setting being given to crews a third time, in addition to that already provided by the ATIS and in the first altitude clearance below the transition level. This new transmission could, for example, be made on first contact with the tower.

4 SAFETY MEASURES TAKEN SINCE THE SERIOUS INCIDENT

4.1 Airhub Airlines

Following the serious incident and during the investigation, the operator rapidly:

- issued a bulletin addressed to its pilots about the serious incident to remind them:
    - of the references of the procedures using the FINAL APP mode,
    - of the importance of the QNH for RNP approaches and the need to confirm its value during descent,
    - to monitor auto-callouts and to keep the radio altimeter in the instrument scan.
- implemented a flight data analysis procedure to subsequently identify incorrect altimeter setting events;
- updated all its approach operations so that pilots, at transition level at the latest, are required to confirm the QNH with the latest ATIS or METAR.

4.2 DSNA

Following the serious incident and during the investigation, the DSNA rapidly:

- issued a reminder to all tower and approach air traffic controllers of the importance of the QNH and its correct read-back, particularly for barometric approaches;
- published a provisional national directive requiring the tower controller to give the QNH on first contact during RNP approaches. The CDG unit also now requires that the QNH be transmitted at the RNP approach clearance;
- published a provisional national directive requiring the systematic execution of a go-around in the event of a MSAW alert during an RNP approach.

Subsequently, and still during the investigation, the DSNA:

- carried out an internal communication campaign about the serious incident, in particular through a safety video available at the end of 2022 providing an illustration of the different types of RNP operations and the consequences of a barometric setting error;
- introduced a compulsory additional training module on RNP approaches for tower and approach air traffic controllers at the end of 2022;
- implemented an action plan covering the following topics:
    - *training*, including reflection on the definition of a national strategy for the initial and continuation training of air traffic controllers regarding PBN and RNP;
    - *working methods*, including:
        - the permanent introduction of the provision of the QNH on first contact with the tower controller for all approaches except ILS and RNP/LPV (when it is possible to distinguish only LPV minima on an LPV procedure). The possibility of extending this principle to all instrument approach operations is given with a view to harmonising operations if this is deemed necessary. This was accompanied by a dedicated national feedback;
        - a return to "standard" MSAW phraseology as defined by SERA and ICAO documents;
        - the suppression of the systematic go-around, with an update of MSAW operational directives so that the phraseology manual (also updated) becomes the sole procedure reference;
    - *tools*, including a study of the use of ground-based systems to detect an incorrect altimeter setting and a study of Approach Path Monitoring (APM) systems;

- *safety monitoring*, including:
  - specific monitoring of the CFIT risk,
  - the study of a radar data analysis programme to assess the feasibility of measuring and quantifying situations where there are discrepancies between the on-board QNH via BPS and the ground QNH in order to determine the associated risks,
  - participation in the EASA Data4Safety programme;
- *risk analysis*, including the introduction of a risk management system based on a safety barriers model;

- reviewed the settings of the MSAW systems at the various French airports. At CDG, the DSNA is working on a V8 configuration, which has been under assessment since October 2023 and is scheduled to come into service in the summer of 2024. At CDG too, the MSAW has been integrated into the simulation software system for training;
- participated in various international meetings, in particular to push for international standardisation of the various safety measures in connection with the threat of incorrect altimeter settings for Baro-VNAV approaches.

4.3 Airbus

Following the serious incident and during the investigation, Airbus:

- updated at the end of 2022, the descent operating procedures in the FCOM, applicable to all the fleets, to highlight the threat of an incorrect altimeter setting during barometric approaches and to ask the crew to check the QNH value provided by the control with that used for the preparation of the approach (see appendix 3);
- updated at the end of 2022, in the applicable FCOMs, the operating procedures for approaches using the FINAL APP mode, so that an altitude-distance cross-check is no longer required for all the points indicated on the approach charts but solely at the FAF and SDF (see appendix 3), in order to reduce the crew's workload;
- published in November 2022, an article in the Safety First magazine entitled "*Use the Correct BARO Setting for Approach*";
- updated at the end of 2023, the descent preparation operating procedures in the FCOM, applicable to all the fleets, to include presetting the QNH when acquiring the ATIS information, either directly in the EFIS when technically possible or on the backup instrument (see appendix 3);
- updated at the end of 2023, the briefing aids in the FCTM, applicable to all the fleets, to include the threat of an incorrect altimeter setting during barometric approaches (see appendix 3);
- updated at the end of 2023, the aids for carrying out approach operating procedures in the FCTM, applicable to all the fleets, with the creation of a new paragraph on the importance of the altimeter setting, on the importance of the comparison of this value with that used during the preparation of the approach, and a mention that unexpected radio altimeter behaviour may be the sign of an incorrect altimeter setting (see appendix 3).

Furthermore, Airbus has indicated that it is continuing to work on the certification of ALTSM Step 2 (see paragraph 1.18.3.1) and to study the possibility of developing a function similar to ALTSM, available as a retrofit on all fleets.

4.4 DSAC

Following the serious incident and during the investigation, the DSAC:

- initiated an "Altimetry" working group comprising 32 organisations, including French and European air operators, Airbus, the DSNA and a representative of the French Aeronautical Federation (FFA), with the aim of exploring the various possible avenues for making aviation more robust to incorrect altimeter settings. The BEA took part in the first two meetings of the working group to share its analysis. A summary of the work is available in the DGAC 2022 Air Safety Report (rapport de la sécurité aérienne 2022 de la DGAC);
- published DGAC Safety leaflet 2023/02 on the risks associated with incorrect altimeter settings, particularly during APV Baro-VNAV and non-precision approach operations;
- participated in the initiation of the Météo France study on variations in QNH over 30 minutes (see paragraph 1.7.3 and appendix 2);
- carried out a study of similar events at the request of the BEA (see paragraph 1.18.1.2).

4.5 Other measures taken by various organisations

Following the serious incident and during the investigation, several organisations issued safety information and recommendations in connection with the altimeter setting issue.

EASA published in March 2023, a Safety Information Bulletin *SIB No 2023-03 "Incorrect Barometric Altimeter Setting"* which recalled the dangers of an incorrect altimeter setting and addressed several recommendations to air operators and air navigation service providers. The SIB was accompanied by more ample information on its Air Operations community page, "*Incorrect barometric altimeter setting"* which, in particular, provides guidance on the use of FDM to deal with incorrect barometric pressure settings.

In November 2023, EASA also officially initiated the first systemic study of the Data4Safety programme with the aim of analysing incorrect altimeter settings in detail.
EASA also informed the BEA during the investigation that it would update *Safety Issue* SI-0007 "*Approach Path Management"*, taking into account the possibility of using an incorrect QNH during an approach with barometric vertical guidance and the resulting consequences.

Lastly, the European Commission and EASA indicated to the BEA during the consultation period for the draft final report that the impact of the IR-PBN regulation and its Art.5 on restrictions regarding conventional approaches, and in particular the restrictions regarding ILS CAT I approaches after 5 June 2030, will be assessed in 2024. This impact assessment could conclude with proposals to amend Art.5 of the IR-PBN in 2025, once the corresponding rulemaking task has been included in the EPAS (European Plan for Aviation Safety).

The ICAO European and North Atlantic (EUR/NAT) Office published in July 2023, EUR OPS Bulletin No 2023_001 *"Risks related to altimeter setting errors during APV Baro-VNAV and non-precision approach operations"* which, after recalling the risks associated with an incorrect altimeter setting and how the various approach procedures are affected, proposes several recommendations addressed to air operators, air navigation service providers, meteorological offices and ICAO panels.

The UK Civil Aviation Authority published in April 2023, Safety Notice SN-2023/003: *"Risk of Controlled Flight into Terrain during 3D BARO-VNAV and 2D Approaches (Altimeter Setting Procedures)".* A video and a Podcast on the subject were also made available.

The Malta civil aviation authority, the authority of the air operator in the serious incident, also published in March 2023, Safety Notice SIAN No 06/22: “*Importance of correct QNH setting with respect to the risk of Controlled Flight Into Terrain (CFIT)*”.

Eurocontrol updated several of its *Skybrary* pages in connection with the topic of an incorrect altimeter setting and made a skyclip video on the subject.

In October 2023, the EUROCONTROL Network Manager navigation and operational safety teams, in collaboration with relevant aviation industry entities, with the participation of the BEA, jointly held a workshop on how to maintain or improve the safety level of PBN-based final approach operations with (barometric) vertical guidance.

The International Federation of Air Line Pilots’ Associations (IFALPA) published a Safety Bulletin on the subject.

5 SAFETY RECOMMENDATIONS

Note: in accordance with the provisions of Article 17.3 of Regulation No 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation, a safety recommendation in no case creates a presumption of fault or liability in an accident, serious incident or incident. The recipients of safety recommendations shall report to the safety investigation authority which issued them, on the measures taken or being studied for their implementation, as provided for in Article 18 of the aforementioned regulation.

5.1 Safety recommendations from preliminary report

Based on the initial findings of the investigation, the BEA issued six safety recommendations in the preliminary report published on 11 July 2022. They covered two main areas.

Air Traffic Control risk awareness and operational procedures

The BEA recommends:

- *Whereas in the short time span of this event, an incorrect QNH was provided to two flight crews by one controller,*
- *Whereas in the short time span of this event, two controllers did not notice the read-back of an incorrect QNH,*
- *Whereas the MSAW system, when available, can be considered as one of the last barriers to avoid CFIT,*
- *Whereas the MSAW phraseology was not used, and the QNH information was not repeated,*

that Paris-Charles de Gaulle Air Traffic Services:

- *Ensure without delay, that controllers are aware of the importance of the QNH for approaches using the baro-VNAV function, with respect to the risk CFIT [Recommendation FRAN-2022-005]*
- *Ensure without delay, that controllers are aware of the importance of checking that the information read back by flight crews is correct [Recommendation FRAN-2022-006]*
- *Ensure without delay, that controllers strictly use the standard phraseology in case of a MSAW, and provide the QNH information [Recommendation FRAN-2022-007]*
- *Implement without delay a procedure for controllers to mitigate the risk of an incorrect QNH being used by flight crews during approaches using the baro-VNAV function, possibly by repeating the QNH at an appropriate time during the approach [Recommendation FRAN-2022-008].*

Flight crew risk awareness and operational procedures

The BEA recommends:

- *Whereas there was a difference of 10 hPa between the QNH provided by the ATIS and the controller during the approach, which is higher than what might be expected from atmospheric pressure fluctuations, and was not noticed by the crew,*
- *Whereas the operational documentation of the airline does not highlight the importance of the QNH for approaches using the baro-VNAV function, with respect to the risk of CFIT,*
- *Whereas the airline operational procedures regarding approaches using the baro-VNAV function are not robust against altimeter QNH setting errors affecting both altimeters,*

that Airhub Airlines:

- *Ensure without delay, that the flight crews are made aware of the importance of the QNH setting for approaches using the baro-VNAV function, with respect to the risk of CFIT [Recommendation FRAN-2022-009]*

- *Implement without delay, a procedure to mitigate the risks of an incorrect QNH setting affecting both altimeters during approaches using the baro-VNAV function, possibly by crosschecking the QNH with another source of information, in particular with the ATIS information when available or by asking the controller for confirmation of the QNH [Recommendation FRAN-2022-010].*

All of the responses given to these recommendations by the addressees were classified as "adequate" by the BEA in view of the measures taken (see paragraph 4).

5.2 New safety recommendations

5.2.1 Overall reassessment of the CFIT risk and the associated mitigation measures, in connection with the threat of an incorrect altimeter setting for Baro-VNAV approach operations

The CFIT risk due to the threat of an incorrect altimeter setting for barometric approaches has been known about since practically the beginning of aviation. The predominant use of non-precision approach operations and the virtual absence of ground collision avoidance systems until the 1970s gave rise to a high CFIT risk, due in part to incorrect altimeter settings, which was tolerated in view of the overall safety requirements at the time.

The significant development of commercial air transport over the following decades greatly increased societal expectations both in terms of safety and weather-related airport accessibility. ILS installations, offering lateral and vertical guidance that is not affected by incorrect altimeter settings, as well as improved accessibility due to lower approach minima, thus became widely used, becoming an equipment standard worldwide even to this present day.

The development, from the 1990s onwards, of Baro-VNAV functions (offering conventional or satellite-based lateral guidance, and barometric vertical guidance based on the altimeter setting) made it possible to carry out descents, then approaches, and in the 2000s final approaches using Performance Based Navigation (PBN) down to minima close to those of Category I precision approaches.

Baro-VNAV approaches have thus played a major role in improving safety, and continue to do so, by providing vertical guidance on non-precision approaches and on runways without radio navigation equipment. They reduce the CFIT risk.

However, the Baro-VNAV function was not designed to be an autonomous approach and landing system, unlike precision approach systems such as the ILS, or approaches using GNSS positioning augmentation systems (GBAS ou SBAS). The vertical guidance of a Baro-VNAV approach is based solely on the aeroplane’s internal data, in particular the barometric altitude, which depends on the altimeter setting. However, the latter potentially relies on multiple human inputs that are prone to error (by the meteorological services, air traffic controllers and pilots).

The approach operations that use the Baro-VNAV function in order to have the lowest minima are the RNP APCH down to LNAV/VNAV minima type PBN operations. With these operations, it is possible to have a decision height as low as 250 ft, close to the minima for a Category I ILS approach at 200 ft. However, one of the most frequent incorrect altimeter settings in hectopascal is with an error of 10 hPa. This offsets the altitude and therefore the vertical profile by 280 ft to the theoretical vertical profile, which could ultimately lead to a collision with the ground before the indicated decision altitude has been reached by the crew.

It should also be noted that in the design of the operations, the method of calculating decision heights for RNP APCH down to LNAV/VNAV minima, notably based on obstacle clearance margins in the ICAO PANS-OPS, was revised in 2004 to increase airport accessibility, and results in lower decision altitudes. The threats inherent in the Baro-VNAV function, such as an incorrect altimeter setting, were not taken into account when this revision was introduced, and the reduction in minima for these approaches did not give rise to a safety study by ICAO.

The various risk analyses carried out on Baro-VNAV approaches by different international institutions have not sufficiently taken into account the threat that an incorrect altimeter setting represents for the CFIT risk, whether in the design of these IFR procedures, in their implementation by crews, in air traffic controllers' procedures or in on-board or ground systems. It should also be noted that the risk analyses regarding Baro-VNAV approaches carried out in the United States concerned a context and airspace organisation that greatly differ from those in other parts of the world and Europe in particular. In the United States, for example, altimeter settings are in in Hg, the transition level is at FL180, and the mother tongue for air traffic controllers is English. Comparisons may therefore be inappropriate, and discussions at international level must take these differences into account.

In a context of the increasing use of satellite approaches with barometric vertical guidance, the threat of an incorrect altimeter setting, although known about for decades, has become preponderant again. This risk was probably not sufficiently taken into account by the aviation community as a whole because the majority of approaches in commercial air transport have for several decades been carried out using ILS precision approaches and their vertical profiles are not affected by incorrect altimeter settings, thus masking most of these errors and their consequences.

In the light of this serious incident and the many similar occurrences of incorrect altimeter settings, it can be considered that the hypothesis that current training, procedures and systems are sufficient to limit the CFIT risk when a Baro-VNAV approach is being carried out with an incorrect altimeter setting is not true and that this risk is incompatible with the overall safety level expected today in commercial air transport.

The various measures taken by different aviation stakeholders during the investigation aimed to improve safety. However, these measures are either actions taken by certain organisations that have not been generalised, or reminders of good practice or recommendations that do not lead to systemic changes or only have short-term effects.

Therefore, the BEA recommends that:

- ***whereas the threat represented by a barometric approach flown with an incorrect altimeter setting giving rise to a CFIT risk in particular;***
- ***whereas the large number of similar occurrences of approaches carried out with an incorrect altimeter setting;***
- ***whereas the design of barometric approach operations and the associated minima do not take into account the possibility of an incorrect altimeter setting;***
- ***whereas the standard operating procedures of crews and air traffic controllers are not sufficiently robust to systematically prevent and detect an altimeter setting error;***
- ***whereas ground and on-board systems for detecting an incorrect altimeter setting are currently only marginally deployed;***

- ***whereas the current limited availability on board aeroplanes, of LPV capabilities, which are not vulnerable to incorrect altimeter settings, and which could be difficult and costly to retrofit;***
- ***whereas CFIT prevention barriers, both procedural and system-based, are neither always present nor always effective;***
- ***whereas ICAO EUR OPS bulletin No 2023_001*** **"Risks related to altimeter setting errors during APV Baro-VNAV and non-precision approach operations"** ***contains recommendations that should be maintained, extended or formalised;***

ICAO, in collaboration with the manufacturers, authorities and operators, carry out an overall reassessment of the CFIT risk and the associated mitigation measures, in connection with the threat of an incorrect altimeter setting for Baro-VNAV approach operations. These measures could consist of updating the standards and recommended practices and associated documents and defining incentives, or even stipulations, to ensure the development of new safety barriers or the improvement of existing ones.
[Recommendation FRAN-2024-006].

5.2.2 Maintaining the safety level of approach operations in Europe in 2030

Commission Implementing Regulation (EU) 2018/1048 of 18 July 2018 laying down airspace usage requirements and operating procedures concerning performance-based navigation, known as the "IR-PBN" regulation, requires that European air navigation service providers exclusively use PBN up to CAT I precision approach operations by 30 June 2030. Consequently, approach operations using conventional navigation systems such as the ILS, will no longer be proposed from that date onwards except as an emergency measure.

GBAS approach operations are excluded from the scope of the IR-PBN regulation and will therefore still be permitted after 6 June 2030. However, not only is the percentage of aircraft equipped to perform this type of approach, although higher than the percentage of aircraft equipped for LPV, still low at present, but only a few aerodromes in Europe have the infrastructure required to perform GBAS approaches (CDG is not one of them), so very few GLS (GBAS landing system) procedures are published.

The introduction of the requirement to exclusively use PBN in IR-PBN regulation 2018/1048 was made at the very end of the regulatory process, and did not give rise to a specific assessment of its impact on safety before the regulation was adopted. In particular, there was no assessment of the impact of the transition from commercial air operations under IFR predominantly conducted using the ILS to commercial air operations conducted solely using PBN type approaches (excluding CAT II/III operations), and no definition of criteria for adjusting this provision if the development of LPV capabilities has not progressed as expected by 2030. One of the assumptions, also an objective, was that air operators would modernise their fleets and equip themselves for RNP APCH operations down to LPV minima, the only PBN procedure offering a level of safety and accessibility comparable to CAT I precision approaches.

The investigation found that the development of LPV capabilities is still in its infancy in commercial air transport. For example, at the end of 2022, less than 500 Airbus aeroplanes out of a fleet of over 10,000 were equipped to perform RNP APCH operations down to LPV minima and at the time of writing this report, no Boeing aeroplane had been certified to perform these operations. Depending on the aeroplane type and the serial number, the retrofit to obtain this capability seems to be prohibitive. Lastly, there is no planned requirement to impose this capability in the years to come.

In the absence of the LPV capability, aircraft air operators will privilege Baro-VNAV approaches in a context where the exclusive use of PBN is imposed.

The investigation found numerous weaknesses in the aviation system, both in terms of the threat posed by the use of an incorrect altimeter setting, which particularly affects a Baro-VNAV approach and also in terms of the CFIT risk which can be a consequence of this.

The findings of this investigation suggest that, in the absence of a clear change of direction in Europe between now and 2030, there will be a substantial decline in the level of safety on approach. The European Commission and EASA indicated during the consultation period for the final report that the impact of Art.5 of the IR-PBN regulation restricting the use of conventional approaches will be assessed in 2024 and may lead to proposals for amendments to the IR-PBN regulation.

Therefore, the BEA recommends that:

- ***whereas in Europe the current level of safety for final approaches in scheduled commercial air transport is mainly based on precision approaches using ILS;***
- ***whereas by 2030, with the implementation of the IR-PBN regulation, in Europe the level of safety for final approaches will be mainly based on RNP approaches;***
- ***whereas of the three RNP approach minima, only RNP APCH operations down to LPV minima have a level of safety similar to the ILS in terms of vulnerability to incorrect altimeter settings;***
- ***whereas the current availability of on-board LPV capabilities is limited and that manufacturers indicate that retrofitting could be difficult and costly;***
- ***whereas by 2030, with the implementation of the IR-PBN regulation, operators with no LPV capabilities will carry out barometric RNP APCH operations down to LNAV or LNAV/VNAV minima that are vulnerable to incorrect altimeter settings;***
- ***whereas the weaknesses of the aviation system with regard to the threat posed by the use of an incorrect altimeter setting, as highlighted by this serious incident and by many other similar occurrences;***
- ***whereas there has been no assessment of the impact of the transition from commercial air operations predominantly conducted using ILS-based IFR approaches to commercial air operations conducted solely using RNP approaches during the IR-PBN regulation process;***
- ***whereas the other measures planned or in progress, including those resulting from the other recommendations issued by the BEA as part of this investigation to minimise the risk associated with an incorrect altimeter setting, do not make it possible to achieve a level of safety equivalent to that of ILS, GLS, or RNP APCH approaches down to LPV minima;***

the European Commission, in collaboration with EASA, analyse and reassess the risks associated with the changes induced by the IR-PBN regulation 2018/1048 and in particular those linked to the use of an incorrect altimeter setting during a barometric approach, and take appropriate measures to maintain the targeted level of safety of final approach operations in Europe in 2030.
[Recommendation FRAN-2024-007].

5.2.3 Ground system for detecting an incorrect altimeter setting

At the time of the 9H-EMU serious incident, there was no ground system to enable air traffic controllers to detect an incorrect altimeter setting at CDG. Some air navigation service providers, such as the NATS in the United Kingdom or the LVNL in the Netherlands, have installed a ground system which compares the altimeter setting transmitted by aircraft via EHS or ADS-B downlink data with the QNH value in force locally, in order to inform the air traffic controller of a potential incorrect altimeter reference on board the aeroplane. The data provided by Eurocontrol shows that of the forty-one Eurocontrol Member States, six have a system alerting air traffic control that an aircraft is transmitting an incorrect altimeter setting and eleven have a system enabling the aircraft altimeter setting to be displayed on air traffic controller screens. However, no comparable system is currently in place in France. Furthermore, there are no standards for these systems, nor any standard operating procedures or phraseology.

Commission Implementing Regulation (EU) No 1207/2011, then Commission Implementing Regulation (EU) 2023/1770 repealing the latter and laying down requirements for the performance and the interoperability of surveillance for the Single European Sky and its amendments requires aircraft flying in European airspace with a mass greater than 5,700 kg or with a maximum cruising speed greater than 250 kt to be equipped with a secondary transponder that transmits Enhanced Surveillance mode S (EHS) and ADS-B protocol information. The mandatory information to be transmitted includes the altimeter setting on board the aircraft via the Barometric Pressure Setting (BPS).

Commercial air transport operators have complied with this requirement and the BPS information is available for use by the approach units and control towers. In the absence of a requirement to impose its use on the ground, the majority of air navigation service providers have not made this investment.

The investigation found that crews frequently perform approaches with an incorrect altimeter setting without being aware of it, and that this serious incident is not an isolated case. A large proportion of these similar occurrences took place during ILS approaches where the vertical profile is not affected by an incorrect altimeter setting and did not give rise to significant incidents. Conversely, several significant incidents, even serious incidents or accidents occurred during barometric approaches.

Therefore, the BEA recommends that:

- ***whereas the threat represented by a barometric approach flown with an incorrect altimeter setting giving rise to a CFIT risk in particular;***
- ***whereas the large number of similar occurrences of approaches carried out with an incorrect altimeter setting;***
- ***whereas the standard operating procedures of crews and air traffic controllers are not sufficiently robust to systematically prevent an approach being carried out with an incorrect altimeter setting;***
- ***whereas on-board systems for detecting an incorrect altimeter setting are currently only marginally deployed;***
- ***whereas ground systems for detecting an incorrect altimeter setting are currently only marginally deployed and they are an effective means of preventing the risk of an approach being carried out with an incorrect altimeter setting;***

- ***whereas the BPS information is included in the aircraft downlink data, a function made compulsory for the near-majority of aircraft operated in commercial air transport;***
- ***whereas there is no obligation for the air navigation services to use this data;***
- ***whereas the ATM safety nets need clear, standardised procedures and phraseologies;***

EASA require that air traffic control units can systematically detect an incorrect altimeter setting, in particular in the towers and approach units and define the associated phraseology for the air traffic controllers.
[Recommendation FRAN-2024-008].

5.2.4 On-board Terrain Awareness Warning System (TAWS)

A TAWS alert is one of the last barriers to prevent CFIT-type accidents and has proved its worth in this respect. However, the system must both warn crews of the CFIT risk and not generate false alerts that could result in crews losing confidence in the system.

In the light of lessons learned and accidents, Minimum Operational Performance Standards (MOPS) were introduced and required for certification. These standards are only applicable during the individual certification of the aeroplane, and operationally, there is no requirement to update the TAWS, which can therefore remain in a version applicable when the aeroplane was manufactured, without taking into account the various existing upgrades.

In this serious incident, in accordance with its design, the TAWS on 9H-EMU did not generate an alert even though the minimum recorded and corrected radio-altimeter height was 6 ft and the aeroplane was about 0.9 NM from the runway threshold. In fact, as the aeroplane was configured for landing and in a standard rate of descent, no TAWS basic and reactive alert or warning were triggered. What is more, the GLIDE SLOPE alert is not available for barometric approaches. Lastly, since the predictive Premature Descent Alert (PDA) mode includes an inhibition zone before the runway to avoid untimely alerts on each landing, no alert was generated, despite the aeroplane's low height, because the EGPWS software version was an old version and did not use GNSS positioning.

The investigation estimated that around 1,600 Airbus and Boeing aeroplanes in service at the time of publication of this report, are flying with a TAWS software version that will not trigger an alert in the conditions of the serious incident.

In addition, the investigation found that a nominal vertical profile on a 3° slope, offset by around 280 ft, representing an incorrect altimeter setting of 10 hPa which is one of the most frequent errors, is not covered by the MOPS currently in force.

Therefore, the BEA recommends that:

- ***whereas the importance of the TAWS in preventing CFIT;***
- ***whereas, in compliance with its design, the TAWS equipping the aeroplane involved in the serious incident did not generate a CFIT alert;***
- ***whereas it was estimated that at the time of publication of the report, around 1,600 Airbus and Boeing aeroplanes in service, are flying with a TAWS that will not trigger an alert in the conditions of the serious incident;***
- ***whereas a nominal vertical profile on a 3° slope, offset by around 280 ft to the published vertical profile, representing an incorrect altimeter setting of 10 hPa which is one of the most frequent errors, is not covered by the certification requirements currently in force via the MOPS applicable to TAWS;***

- ***whereas the revision of the standardisation requirements is a necessary step in order to be able to impose standards in operation at a later date;***

EASA, in coordination with the FAA and RTCA, study the revision of the Minimum Operational Performance Specifications (MOPS) applicable to TAWS for Premature Descent Alerts (PDA), in order to take into account at least a standard 3° vertical profile offset by around 280 ft to the published vertical profile, representing an error of 10 hPa on a barometric approach.
[Recommendation FRAN-2024-009].

5.2.5 MSAW training

During the serious incident and on both approaches, two different tower controllers used an incorrect and inappropriate phraseology in response to the triggering of the MSAW alert. The phraseology used did not convey the urgency of the situation, did not allow the crew to understand what was expected of them, and did not include the crucial information of the QNH value which could have enabled the crew to realise that they had an incorrect altimeter setting.

In addition, the air traffic controller's reaction time to the alert during the first approach left the crew very little time to react.

The investigation found that a CDG controller may well never have reviewed in practice, the expected reaction to a MSAW alert since his initial training at the ENAC.

The study of various similar occurrences found in France, that the MSAW emergency phraseology was only partially correctly used, that the use of an incorrect and inappropriate MSAW phraseology was not an isolated case, and that a lack of reaction was observed a certain number of times.

At the time of the preliminary report, the BEA issued a recommendation regarding the MSAW phraseology. In its response, the DSNA focused on the procedures to be used when such an alert is triggered, accompanied by feedback and reminders. However, no overall national action was taken in terms of the continuation training of air traffic controllers to ensure on a permanent and continuous basis, that emergency phraseology is immediately used in the event of a MSAW alert.

Therefore, the BEA recommends that:

- ***whereas the importance of the MSAW in preventing CFIT;***
- ***whereas the importance of the reaction time and the phraseology to be used in response to a MSAW alert;***
- ***whereas the number of similar occurrences in France involving the use of incorrect MSAW phraseology;***
- ***whereas at national level, the continuation training of air traffic controllers is insufficient and does not guarantee that they will be able to immediately use the expected phraseology in the event of a MSAW alert;***

the DSNA ensure that, at national level, the continuation training of air traffic controllers guarantees that they master the emergency procedure relating to a MSAW alert.
[Recommendation FRAN-2024-010].

5.2.6 DSNA safety management system

The incident involving 9H-EMU highlighted a succession of errors during normal operations, by different controllers, at different positions, in a short space of time.

The DSAC's study of similar events found that in France, air traffic control contributes to about a quarter of the events linked to incorrect altimeter settings.

In addition to these errors in normal conditions, the emergency phraseologies associated with MSAW alerts were not correctly used during the serious incident.

At the time of the incident involving 9H-EMU, the risk of "near-CFIT" was identified as an undesirable occurrence in the DSNA risk map. However, the DSNA had not developed an analysis table for "near-CFIT" occurrences and had not set up a local or national CFIT risk management process - in particular based on the analysis of safety events - as would be expected in a safety and compliance management system. The DSNA thus deprived itself of an overall assessment of the CFIT risk (going beyond the selective analysis of each occurrence) and the possible quantification of "near-CFITs" recorded in its database.

Furthermore, the collection of data for the DSNA's safety management system was still essentially based on safety occurrences alone (reactive approach), and no other means or methods had been put in place at the DSNA to better apprehend weak signals, threats, errors and undesirable events that could have an impact on safety in a given operational context, and to identify good practices for maintaining safety (proactive or predictive approach).

Since the serious incident, the DSNA has accelerated the implementation of a risk management system based on a safety barriers model and has reinforced the consideration it gives to the CFIT risk. The DSNA is also working on the implementation of an observation process at air traffic controller positions.

Therefore, the BEA recommends that:

- ***whereas the various control errors identified during the investigation;***
- ***whereas the DSNA management system is based solely on the analysis of safety occurrences and does not identify weak signals, threats, errors and occurrences during normal air traffic controller operations;***
- ***whereas the DSNA has initiated a process to modify its risk analysis and management methods;***

the DSNA introduce methods or tools for the objective assessment of air traffic controllers' on-the-job work for the purpose of improving the safety management system.
[Recommendation FRAN-2024-011].

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