Serious incident to the BOMBARDIER CL-600-2E25 (CRJ-1000) registered F-HMLD on 20 October 2021 on approach to Nantes-Atlantique (Loire-Atlantique)

Time	Around 17:50[1]
Operator	HOP!
Type of flight	Passenger commercial air transport
Persons on board	Captain (PM), co-pilot (PF), two cabin crew members, 98 passengers
Consequences and damage	None
This is a courtesy translation by the BEA of the Final Report on the Safety Investigation published in March 2023. As accurate as the translation may be, the original text in French is the work of reference.	

Note: a glossary is available in the appendix to this report.

Altimeter setting (QNH) read-back error, triggering of a MSAW on final approach

[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.

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1 HISTORY OF THE FLIGHT

Note: the following information is principally based on the QAR, statements, radio communication recordings and radar data. The data from the Cockpit Voice Recorder (CVR) was not preserved (see paragraph 2.6.1).

The crew were performing flight AF33CW from Lyon-Saint-Exupéry (Rhône) bound for Nantes-Atlantique (Loire-Atlantique).

A strong low-pressure system named Storm Aurore was present over the northern half of France.

At 17:39, in descent to the destination airport, the controller asked the crew to descend to 3,000 ft QNH one thousand and two (their first altitude below the transition level) and cleared them for an RNP 21 approach (*"descendez vers l'altitude trois mille pieds QNH mille deux autorisé à la RNP*[2] *vingt-et-un"*). The crew read back the instruction incorrectly, replying that they would descend to 3,000 ft, one thousand and twenty-one, and that they would call back once established on RNP 21 ("*vers trois mille pieds mille vingt-et-un et on vous rappelle établi pour la… sur la RNP vingt-et-un*"). The controller did not detect the read-back error.

Eight minutes later, the crew were transferred to the airport control frequency as they had passed the Final Approach Fix (FAF) on final in the RNP approach procedure for runway 21 (see *Figure 1*, point 1). The crew announced they were on final for RNP 21. The controller answered by clearing them for landing on runway 21 and by informing them of the wind (200°, 30 kt, gusting up to 40 kt). The crew asked her if there had been any windshear reports. The controller replied in the negative. The crew informed her of substantial wind variations between 3,000 and 2,000 ft.

Nearly two minutes later, at 17:49:48, when the aeroplane flew through 788 ft[3], a Minimum Safe Altitude Warning (MSAW) was triggered at the controller's position (point 2). The aeroplane entered an area where the minimum obstacle clearance altitude was 770 ft[4]. The controller informed the crew of the terrain alert, telling them to check their altitude ("*Air France trente trois Charlie Whisky euh vérifiez votre altitude, al… alerte relief*").

The PM replied at 17:50:00, asking her if this warning was for flight 33 Charlie Whisky, as they were flying through 1,200 ft one thousand and twenty-one ("*c'est pour le trente trois Charlie Whisky ? nous passons mille deux cents pieds mille vingt et un*").

Simultaneously, at 17:50:02, the PF applied a nose-up input on the stick (point 3). A few seconds later, the descent rate decreased and stabilised at slightly negative values.

At 17:50:04, the controller acknowledged the message, added that she had a terrain alert for their flight and asked the crew to check their altitude ("*reçu, j'ai une alerte relief sur votre vol, vérifiez votre altitude*"). The PM replied that they were checking it ("*eh bien on vérifie*").

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[2] Required Navigation Performance.

[3] This value was the actual altitude of the aeroplane, with the QNH of the day. The on-board altimeters indicated 1,300 ft due to the altimeter setting error.

[4] The detection logic is not linked to the penetration into the area with a minimum obstacle clearance altitude of 770 ft (see paragraph 2.3.3.1).

At 17:50:11, the controller provided the QNH value of one thousand and two (“*mille deux le QNH monsieur*”). The PM replied one thousand and twenty-one, the QNH is correct (“*mille vingt et un le QNH c’est correct*”).

At 17:50:16, the controller gave the QNH again saying it was one thousand and two, one zero zero two (“*mille deux unité zéro zéro deux*”). Simultaneously, the crew corrected the setting on their altimeters (point 4) and corrected the path.

The MSAW stopped at 17:50:36, and the aeroplane joined the normal approach slope 12 s later, 1.7 NM from the threshold.

The crew then continued the approach to runway 21 using visual references.

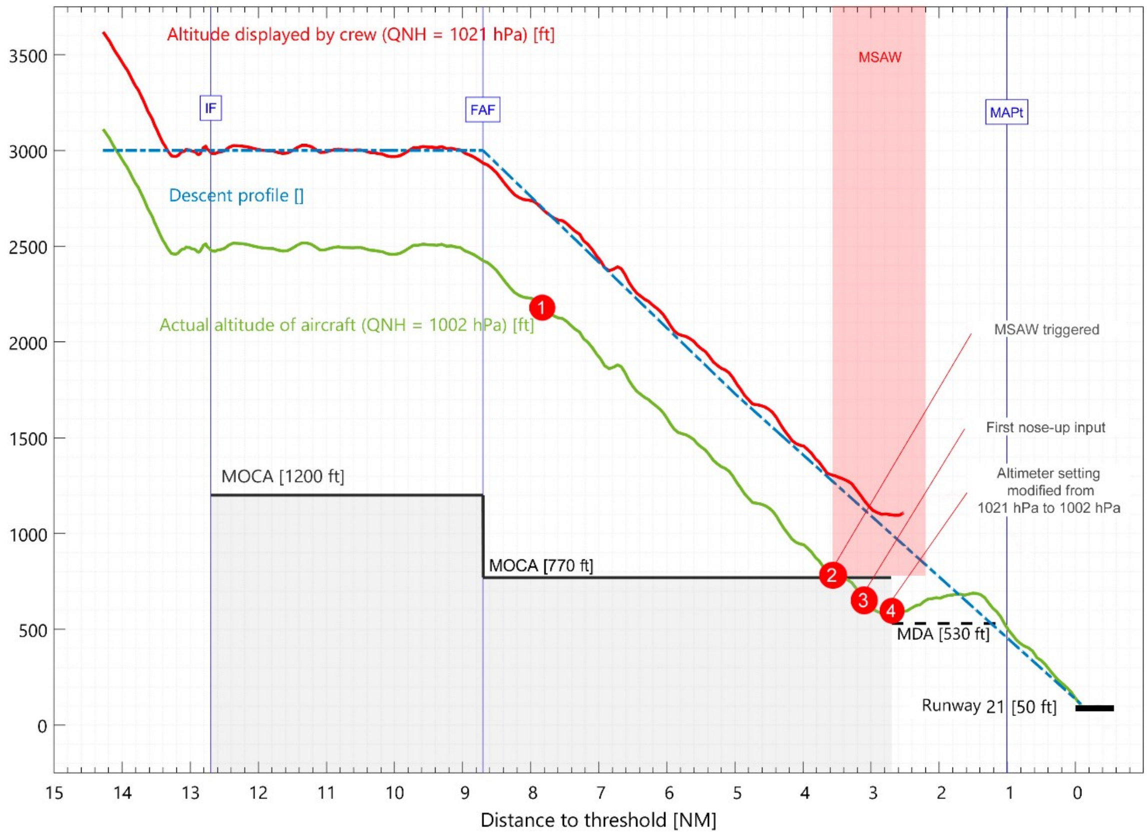

Figure 1: vertical profile of F-HMLD flight path (source: BEA)

The aeroplane landed in the rain without further incident.

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2 ADDITIONAL INFORMATION

2.1 Aerodrome information

One specific feature of the approach to runway 21 is that the aircraft is required to fly over the city of Nantes. While the terrain on the approach path is relatively flat, certain buildings such as the Brittany Tower determine the approach slope and the minimum altitudes of this approach.

For the RNP21 procedure, the aircraft intercepts the final approach slope at point FRS21, at 3,000 ft and 8.7 NM from the runway threshold. The approach slope angle is 3.1°. The final approach for the RNP21 procedure is offset by 12° from the runway axis[5].

Two Step-Down Fixes (SDF) are published on the final approach chart:

- one SDF located at 1,460 ft and 4 NM from the runway threshold: this fix is associated with the note "*Report 4NM to DTHR (MNM **1460**)*" on the approach chart used by Hop! crews;
- one SDF located at 1,020 ft and 2.7 NM from the runway threshold.

The 506 ft-high obstacle shown on the chart in the vicinity of the approach path, nearly 4 NM from the threshold, determines the area's Minimum Obstacle Clearance Altitude (MOCA) of 770 ft between the FAF and the point located 2.7 NM from the threshold. It corresponds to the Brittany Tower[6].

The Minimum Descent Altitude (MDA) is set at 530 ft for Category C aeroplanes, which includes the CRJ 1000. The missed approach point (MAPt, named "MAPTS" on the chart) is located 1 NM before the threshold of runway 21. The obstacle used to define this MDA value is an antenna of an altitude of 288 ft. It is shown on the chart, to the left of the approach path.

[5] The chart used by the crew indicates an offset value of 13°.

[6] The altitude value of Brittany Tower taken into account for the calculation of the protection areas is 522 ft. This is the value shown on the approach chart published in the AIP.

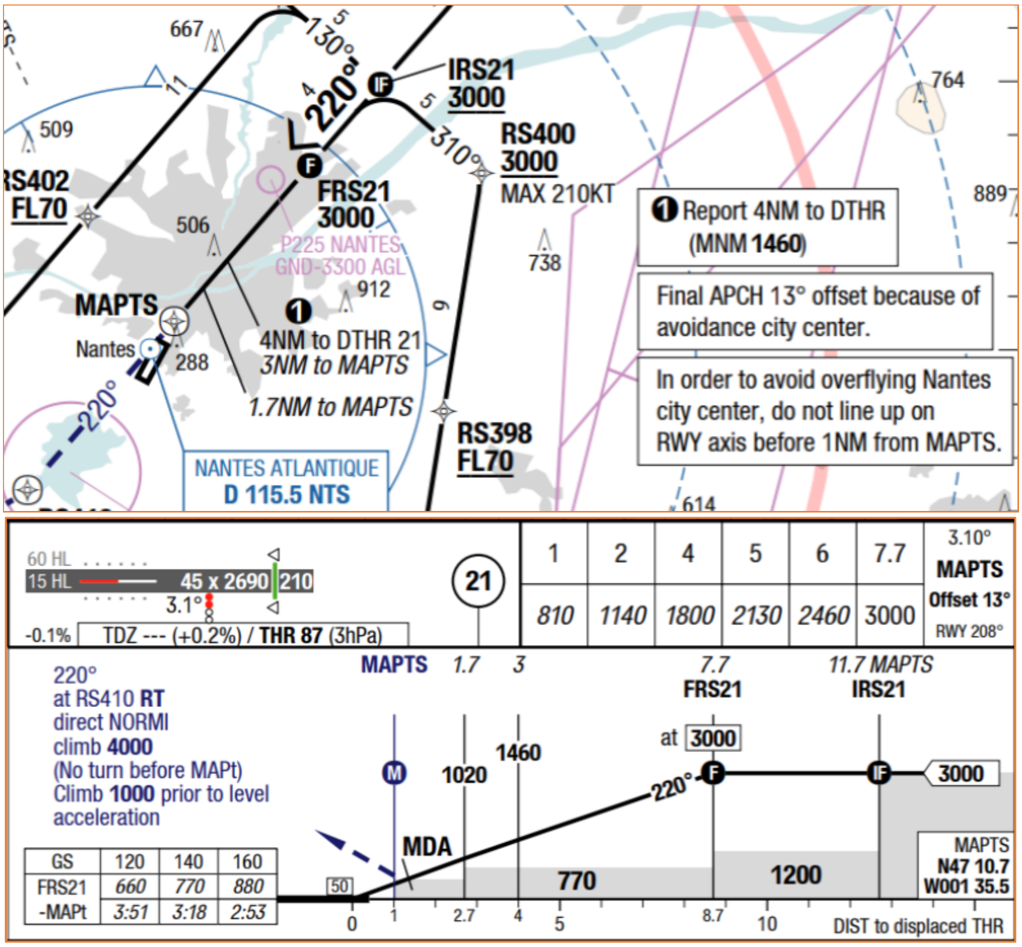


Figure 2: extracts from the approach chart used by the crew (source: Lido)

2.2 Meteorological information

Northern France was experiencing the effects of a rapid south-westerly airstream wrapping around the Storm Aurora low-pressure system, which was centred over the Channel at 18:00.

Since the beginning of the afternoon, the pressure had been falling over Nantes-Atlantique airport. The QNH was 1009 hPa at 13:00 when the crew made their first approach to Nantes and 1002 hPa at 17:30.

The crew had the up-to-date meteorological information before departing from Lyon-Saint-Exupéry. In particular, they had the Terminal Area Forecast for Nantes-Atlantique airport, which forecast an increase in wind strength and passing heavy showers at the scheduled landing time.

During the preparation for the approach, the crew noted the 17:15 ATIS information on the flight plan, which included the following elements:

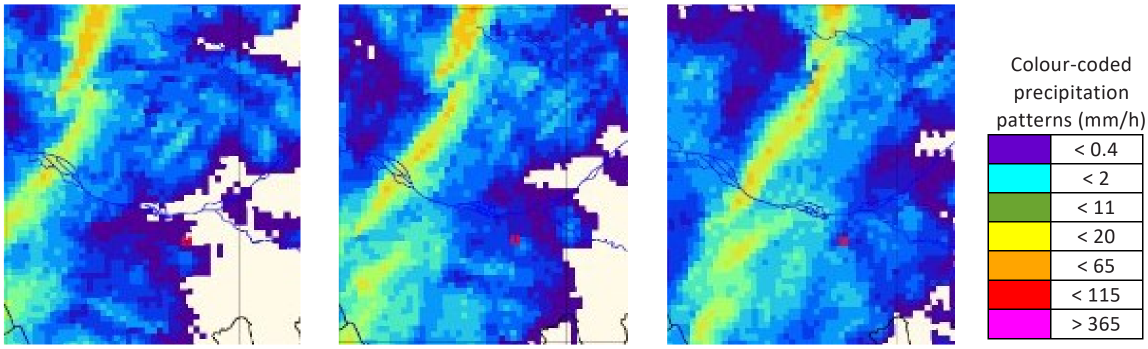
- wind from 210°, 27 kt, gusts up to 40 kt;
- visibility 10 km;
- overcast ceiling at 2,300 ft;
- QNH 1003 hPa.

During the approach, the control gave the crew the following wind information:

Time	Wind information	
17:36	200°/25kt/G40kt	Flying through level 130 in descent
17:48	200°/30kt/G40kt	Landing clearance

Table 1: wind information given to the crew during the approach

The precipitation radar images showed that, at the time of arrival of F-HMLD, a rain shower was arriving at Nantes-Atlantique airport.



17:40 17:45 17:50

Figure 3: precipitation radar images (source: Météo-France)

(the red dot corresponds to Nantes-Atlantique airport)

The crew reported that the landing was performed in the rain and that the disembarkation was stopped due to a driving rain shower.

On the day of the incident, sunset in Nantes was at 17:09. The rain shower arriving from the west made conditions darker.

The crew indicated that they had sight of the ground at the time of the MSAW and that they could see the Precision Approach Path Indicator (PAPI) when they corrected the path (see paragraph 2.4.5). The evidence gathered was unable to precisely establish the visibility conditions duringnthe approach.

2.3 Air navigation service information

2.3.1 General procedures

2.3.1.1 Air traffic control organisation

During an approach to Nantes-Atlantique airport, traffic is successively managed by the approach (APP) controller and then by the airport (LOC) controller.

The approach controller is responsible for the Terminal Manoeuvring Areas (TMA) and the Flight Information Service (FIS) at Nantes. In particular, it is in charge of regulating the final approach flow at Nantes and Saint-Nazaire, and of climbs and descents to/from the aerodromes located in the vicinity of Nantes airspaces. The area of responsibility can be divided among several controllers distributed by sector. At the time of the event, due to low traffic, only one radar controller assisted by a coordinator controller was in charge of all the TMA and FIS areas.

The LOC controller is responsible for the Control Traffic Region (CTR) zone, for part of the manoeuvring area, and when runway 21 is in use, for the non-CTR portion of the airspace encompassing the final for the approach procedures for runway 21. The LOC controller may be assisted by a control tower assistant. This was not the case at the time of the event due to the low level of traffic.

At the time of the event, both the APP and LOC controllers were in the control tower[7], next to each other.

2.3.1.2 Provision of altimeter setting information

According to implementing regulation (EU) No 923/2012, known as SERA (Standardised European Rules of the Air)[8], air traffic control must provide crews with the altimeter setting (QNH) at the first clearance to descend to an altitude below the transition level. It is not necessary to repeat the QNH afterwards when the controller knows that this information has already been given to the crew in a transmission directly addressed to them[9].

The SERA, written in English, specifies that the altimeter setting shall be transmitted by pronouncing each digit separately (requirement SERA.14035). The transposition of this rule into the French texts[10] specifies that in French, a number can be transmitted as it is said in everyday life or as a sequence of numbers (FRA.14035).

2.3.1.3 Responsibility for terrain avoidance

According to the European rules applicable to air traffic service providers (ATM/ANS IR[11]) and according to the rules of the air (requirement SERA.7001), preventing collisions between aircraft and obstacles outside the manoeuvring area does not fall within the remit of the air traffic control.

It is the pilot's responsibility to ensure that the clearances issued by the air traffic control unit do not compromise safety in this respect, 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.

2.3.1.4 Surveillance function

According to requirement ATS.TR.155 of regulation ATM/ANS IR, information derived from ATS surveillance systems should be used to the extent possible in the air traffic control service provision in order to improve capacity and efficiency as well as to enhance safety.

In particular, the Acceptable Means of Compliance (AMC) adjoining ATS.TR.155 details the various functions which include the information provided by the ATS surveillance systems being used to monitor the flight path.

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[7] If there is a high level of traffic, the approach controllers carry out their tasks from a room which is separate from the control tower cab.
[8] Version in force on the day of the Incident.
[9] (EU) 923/2012 SERA.8015 (eb) (3) and (EU) 2017/373 ATS.TR.140 (d).
[10] Amended Order of 11 December 2014 relating to the implementation of Implementing Regulation (EU) No 923/2012 (Version in force on the day of the incident).
[11] Commission implementing regulation (EU) 2017/373 of 1 March 2017 laying down common requirements for providers of air traffic management/air navigation services and other air traffic management network functions and their oversight (version in force on the day of the incident).

These recommendations are adopted in the operations manual of the Nantes-Atlantique approach control unit which indicates that the information which comes from the ATS surveillance systems and which is displayed on a situation display can be used to perform certain functions in the scope of air traffic control and indicates, in particular, the flight path monitoring function.

Reading the regulations and manuals shows that flight path monitoring by air traffic controllers is not a legal obligation, but can be considered a good practice.

2.3.2 Radar display

On the radar display available at the LOC and APP positions, the altitude displayed is the pressure altitude, corresponding to the standard altimeter setting (1013 hPa), in hundreds of feet. This value is provided by the radar processing system which uses the standard altitude information transmitted by the aircraft transponders. The controllers have a software pushbutton that allows them to temporarily replace the pressure altitude display with that of the altitude value corresponding to the QNH at the time[12].

The standard pressure altitude value displayed on the radar screen for F-HMLD during the intermediate approach level-off was 028[13] (2,800 ft / QNH 1021) whereas it should have been 033 (3,300 ft) if the correct QNH value had actually been used on board the aeroplane and the published flight path correctly followed.

This display based on the standard altimeter setting does not allow controllers to directly detect the path error of an aircraft using an incorrect altimeter setting.

2.3.3 Minimum Safe Altitude Warning system (MSAW)

2.3.3.1 System description

The MSAW system warns air traffic controllers about an aircraft flying dangerously close to the ground and obstacles. It is a predictive tool for preventing Controlled Flight Into Terrain (CFIT). It has a function which monitors the approach slope of aircraft.

This function uses the pressure altitude value sent by the aircraft's systems (which is independent of the on-board altimeter setting), the QNH value of the air navigation service systems, and a database of terrain and obstacles in the vicinity of the airport.

A warning occurs when the extrapolated position of the aircraft penetrates a 300 ft buffer zone above the terrain or an obstacle where applicable.

A MSAW is shown by:

- the aircraft's radar track being displayed on the controllers' screens, if it was not already displayed;
- a red MSAW indication flashing near the aircraft's radar label;
- a MSAW window being displayed with the alert characteristics;
- an aural warning ("terrain alert" message repeated twice).

[12] The QNH value used by the radar display system is provided to the air navigation services by an internal system linked to the weather station.
[13] Value verified with a radar data replay tool.

The MSAW is based on a minimum notification time, in order to allow sufficient time for the controllers and pilots to react. This time is based on the following values:

- controller's reaction time to the warning: 3 s;
- time needed for the controller to convey the warning to the crew: 10 s;
- crew's reaction time: 3 s;
- time needed to change the path: 15 s;
- radar antenna rotation time: 4 to 8 s.

In Nantes, this notification time is 34 s.

2.3.3.2 Procedure

According to Doc 4444 published by the Convention on International Civil Aviation (ICAO), Procedures for Air Navigation Services, "*In the event an MSAW is generated in respect of a controlled flight, the following action shall be taken without delay:*

> *a) if the aircraft is being provided with radar vectors, the aircraft shall be instructed to climb immediately to the applicable safe level and, if necessary to avoid terrain, be given a new radar heading;*
>
> *b) in other cases, the flight crew shall immediately be advised that a minimum safe altitude warning has been generated and be instructed to check the level of the aircraft.*"

Requirement FRA.11002 of the national supplement to the "SERA" European regulation sets out that a controller must proceed as follows in the event of a terrain alert regarding a controlled flight:

- If the aircraft is being radar vectored, the controller must, without delay, instruct the crew to immediately climb to a safe altitude and, if necessary, to change the heading;
- If the aircraft is not being radar vectored, the controller must, without delay, inform the pilot-in-command that an artificial obstacle or terrain proximity warning has been triggered and instruct him to immediately check the aircraft's flight level.

The only notable difference between the procedure described in Doc 4444 and the French text is in the notion of immediately in the check of the aircraft level.

Note: The European Aviation Safety Agency (EASA) has not described a specific procedure for a terrain proximity warning in the SERA, on the basis that the ICAO recommended procedure does not differ from generic air traffic control principles:

- an aircraft being radar vectored receives an instruction from the control to prevent the collision with the terrain or obstacles;
- in the case of an aircraft not being radar vectored, the captain, responsible for clearing the terrain and obstacles, is informed of the terrain proximity alert by asking him to check the level of the aircraft.

2.3.3.3 MSAW phraseology

The reference documents show disparities in the phraseology to be used by the controller in the event of a MSAW.

Reference Documents	Alerting phraseology
ICAO Doc 4444, 16th edition, 2006 – *Procedures for Air Navigation Services* — Air Traffic Management	<u>Low altitude warning:</u> (aircraft call sign) LOW ALTITUDE WARNING, CHECK YOUR ALTITUDE IMMEDIATELY, **QNH IS (number) [(units)]**. [THE MINIMUM FLIGHT ALTITUDE IS (altitude)]. <u>Terrain alert:</u> (aircraft call sign) TERRAIN ALERT, (suggested pilot action, if possible).
ICAO Doc 9432, 4th edition, 2007 – *Manual of Radiotelephony*	<u>MSAW:</u> FASTAIR 345, <u>LOW ALTITUDE WARNING</u>, CHECK YOUR ALTITUDE IMMEDIATELY, **QNH IS 1006**, THE MINIMUM FLIGHT ALTITUDE IS 1,450 FEET FASTAIR 345 <u>TERRAIN ALERT</u>, CLIMB TO 2,000 FEET **QNH 1006**
SERA, October 2017 and March 2022	<u>Low altitude warning:</u> *(aircraft call sign)* LOW ALTITUDE WARNING, CHECK YOUR ALTITUDE IMMEDIATELY, **QNH IS *(number)[(units)]***. [THE MINIMUM FLIGHT ALTITUDE IS *(altitude)*] <u>Terrain alert :</u> *(aircraft call sign)* TERRAIN ALERT, *(suggested pilot action, if possible)*
Amended Order of 11 December 2014 relating to the implementation of Implementing Regulation (EU) No 923/2012, as referenced by the French Air Traffic Regulation (RCA).	<u>Low altitude warning:</u> (aircraft call sign) LOW ALTITUDE WARNING, CHECK YOUR ALTITUDE IMMEDIATELY, **QNH IS (number) [(units)]**. [THE MINIMUM FLIGHT ALTITUDE IS (altitude)]. <u>Terrain alert:</u> (aircraft call sign) TERRAIN ALERT, (suggested pilot action, if possible). (Original text in French)
Manuel de phraséologie à l'usage de la circulation aérienne générale, 9ème édition, 2021 (Phraseology manual for general air traffic, 9th edition, 2021)	<u>Without radar vectoring:</u> *Conditions of use*: The controller (1) immediately informs the pilot that a terrain alert has been generated, (2) instructs the pilot to immediately check the aircraft's level or altitude, (3) **provides the QNH, if necessary**. *Controller actions*: The controller immediately informs the pilot using the phraseology "alerte relief/terrain alert" and provides the QNH. *Basic phraseology*: Rapidair <u>3</u> <u>2</u> <u>4</u> <u>5</u>, terrain alert, check your altitude immediately, **Q_N_H 1 0 1 2**. <u>With radar vectoring:</u> *Conditions of use*: The controller (1) instructs the pilot to immediately climb to a level above or equal to the minimum vectoring altitude, (2) **provides the QNH, if necessary**.

	Controller actions: He provides the QNH. *Basic phraseology*: Rapidair 3 2 4 5, terrain alert, immediately climb 5000 ft, **Q_N_H 1 0 1 4**, immediately / Rapidair 3 2 4 5, terrain alert, immediately climb 5000 ft, **Q_N_H 1 0 1 4**, and turn right immediately heading 2 7 0. (Original text in French)
Directive No. 05-25/21 pertaining to the use of MSAWs in ANS, published by the Operations Directorate of the DNSA[14] in March 2021	Without radar vectoring: AFR 32 45, terrain alert, check your altitude immediately With radar vectoring: AFR 32 45, immediately, climb 5000 ft Q_ N _H, immediately, due to terrain. (Original text in French)
Approach control centre's operations manual for Nantes-Atlantique airport, version of 13 September 2021	Without radar vectoring: AFR 3245, terrain alert, check your altitude immediately, **QNH xxxx** With radar vectoring: AFR 3245, terrain alert, immediately, climb 2000 ft **QNH xxxx**, immediately. (Original text in French)

Table 2: MSAW phraseology[15]

Thus, while most of the documents mentioned include QNH information in the message, the phraseology manual, which is the national reference for all air traffic services, does not unambiguously state the obligation to mention the QNH information. Directive No 05-25/21 published by the Operations Directorate of the DSNA in March 2021 does not include the QNH information in the message.

Also, the word "immediately", used in phraseology when immediate action is required for safety reasons, does not appear in the terrain alert messages provided in the ICAO documents, in the SERA or in the Order of 11 December 2014. However, "immediately" appears in the low altitude warning messages included in these same documents.

In France, the word "immediately" is part of the messages described in the phraseology manual, the operational directive and the operations manual mentioned, both when the aircraft is radar vectored and not radar vectored.

Furthermore, some of these documents (ICAO doc 4444 and the "SERA" European regulation) do not differentiate between radar vectored and non-radar vectored situations, but are based on a "low altitude warning" or "terrain alert" situation that is not otherwise defined.

[14] Direction des Services de la Navigation Aérienne (French air navigation service provider).
[15] In this table, the portion of text in square brackets is optional.

In the Nantes control tower, stickers have been affixed to the upper frame of the radar screen at the LOC position, reminding the controller of the phraseology to be used in the event of a MSAW, both in French and in English. This phraseology is for aircraft that are not being radar vectored. The exact wording on these stickers is as follows:

> *Alerte Relief, Vérifiez votre altitude immédiatement, QNH... (label on the right side)*
> *TERRAIN ALERT, check your altitude immediately, QNH… (label on the left side)*

Figure 4: position of stickers on radar screen at LOC position (source: SNA-O[16])

2.3.3.4 Aerodromes equipped with MSAW systems

According to the AIP dated 21 April 2022, in metropolitan France, of the 119 aerodromes with IFR approaches, 14 are equipped with MSAW systems.

2.3.4 Statements

2.3.4.1 APP controller

The radar controller on duty at the APP position reported that his shift was calm. Due to Storm Aurora, there was no VFR traffic in the area. He was at the end of his shift and did not feel particularly tired.

When F-HMLD entered his area of control, he was focused on a potential traffic conflict situation south of the TMA. This potential conflict involved four aircraft, including a Boeing 737 coming from the south bound for Nantes, a private Beechcraft B300 bound for Saint-Nazaire, a Boeing 737 departing from Nantes and heading south-east, and an Airbus A320 bound for Brest which was flying at an intermediate level in the area. The implementation of his strategy depended on the actual time of departure of the outbound traffic.

He thought that he focused on this potential conflict and may have paid less attention to F-HMLD. The path of F-HMLD, arriving from the north-east of the TMA, was not in conflict with this traffic in the south of the TMA. There was no traffic in the vicinity of the F-HMLD's path.

[16] West Air Navigation Services.

The controller cleared the crew of F-HMLD to descend to 3,000 ft with a QNH 1002 and cleared them for the RNP21 approach. The controller explained that he did not perceive that the altitude was inconsistent with the procedure intermediate approach level-off altitude as he was managing traffic in the south of the TMA. When he saw that the aeroplane was aligned with the final approach path, he transferred the crew to the LOC frequency.

He explained that he thought he was attentive to read-back problems, but his focus on the conflict resolution strategy concerning the traffic in the south of the area probably distracted him from the F-HMLD crew's read-back

2.3.4.2 LOC controller

The controller on duty at the LOC position started her shift at the beginning of the afternoon. When the event occurred, she had just returned to the position after a break.

She explained that she had very little memory of the sequence of events. She did not remember if she looked at the radar display when F-HMLD was transferred to her frequency.

She was aware of the stickers on the radar display at the LOC position. She did not remember whether she used these stickers to issue the warning message.

2.3.4.3 Service Quality subdivision

The statement of a manager of the Service Quality subdivision of the air navigation service at Nantes was also collected as part of the investigation.

She explained that before the generalisation of continuous descent approaches, controllers perhaps paid more attention to the altitude of aircraft at the intermediate approach level-off. This was especially true when several aircraft were following each other at this level. It was then easy to detect an aircraft with an altitude different to that of other aircraft.

2.3.5 Analysis of the event by the air navigation services

Following this event, the air navigation service at Nantes identified, among other things, the lack of consistency between the various reference texts setting out the phraseology to be used in the event of a terrain alert for a non-radar vectored aeroplane. This lack of consistency was brought to the attention of the Operations Division of the DSNA at national level, in order to harmonize the phraseology, and use internal communication to clarify the recommended phraseology based on the Division's recommendation.

The DSNA decided to keep the phraseology manual as is, as it considered that it complies with the SERA European regulation and the Order of 11 December 2014 relating to the implementation of Implementing Regulation (EU) No 923/2012.

2.4 Air operations information

2.4.1 Altimeter setting procedures

The altimeter setting procedure contained in the chapter relating to the prevention of collisions between aircraft and with the ground in the Hop! operations manual (Part A), stipulates that the right and left altimeters must be reset to the QNH when the crew is cleared to descend to an altitude or at the latest at the transition level. The standby altimeter is reset as the aircraft approaches FL 100.

It is specified that, when switching from the standard setting to the QNH, the consistency of the QNH communicated by the ATC must be validated using another source (ATIS, METAR, flight file, ACARS, etc.).

In the same chapter, the operations manual stipulates that, during a Non-Precision Approach (NPA) or Barometric Vertical Navigation approach (Baro-VNAV), the vertical path is affected by altimeter setting errors, and that such errors cannot be detected by cross-checking the altimeter indication with the values indicated on the approach chart (altitude-distance checks).

2.4.2 RNP LNAV non-precision approach procedures

The RNP LNAV approach is a non-precision approach without vertical guidance, where lateral guidance is based on the RNAV system using the GNSS signal.

According to the operator's procedures, on the CRJ-1000, the Baro-VNAV function is used to manage the vertical profile of the path for this type of procedure. The deviation from the vertical profile is calculated based on the horizontal position information of the FMS/GNSS and on the barometric altimeter information. The vertical path thus generated is therefore affected by altimeter errors, and in particular by setting errors[17].

The crew monitor the vertical path on final using the vertical deviation information known as a "*snowflake*"[18], which uses a symbology similar to the representation of a "Glideslope" deviation for an ILS approach. Minimum altitudes at SDFs must be called out and adhered to.

2.4.3 Stabilisation on approach principle

The Hop! operations manual indicates that stabilizing the approach counters the risk of CFIT. The stabilisation target is set at 1,000 ft Above Aerodrome Level (AAL).

Two limits are fixed at 1,000 ft and 500 ft AAL, with distinct criteria. If the stabilisation criteria are not met when flying through and after these limits, a go-around must be performed.

The criteria that allow pilots to determine whether the approach is stabilised are speed, engine power, bank angle, configuration, completion of the before landing checklist and path compliance.

[17] The operations manual refers to this topic in the paragraph on the risk of setting errors in the chapter relating to the prevention of collisions between aircraft and collisions with the ground, as mentioned above in paragraph 2.4.1.
[18] Vertical deviation from the calculated approach slope.

The general instruction regarding the path is to be on the axis and on the approach slope. However, maximum deviations are permitted and defined according to the type of approach. For non-precision approaches, it is also specified that the minimum altitudes must be observed when passing the step-down fixes (see paragraph 2.1). If this is not the case, the stabilisation criteria are not met.

Step-down fixes	Published MOCA (ft) [*corresponding height*]	Published altitude (ft)	Displayed altitude (QNH 1021) (ft)	Actual altitude (QNH 1002) (ft)
FRS21	1,200 [*1,110*]	3,000	2,934	2,424
D3 MAPTS[19]	770 [*680*]	1,460	1,457	942
D1.7 MAPTS		1,020	1,098	582

Table 3: fly-through altitudes and minimum altitudes at SDF and D3 MAPTS

2.4.4 Procedures close to the ground

2.4.4.1 MSAW procedure

The Hop! operations manual describes the MSAW procedure as follows:

> Without radar vectoring
> In the event of a warning, the ATC will warn the crew as soon as possible using the following phraseology:
> *"AF XXX TERRAIN ALERT, CHECK YOUR ALTITUDE IMMEDIATELY";*
> *"AF XXX ALERTE RELIEF, VERIFIEZ VOTRE ALTITUDE IMMEDIATEMENT".*
> With radar vectoring
> *"IMMEDIATELY, CLIMB TO XXX FT QNH, IMMEDIATELY, DUE TERRAIN"*
> *"IMMEDIATEMENT, MONTEZ XXX FT QNH, IMMEDIATEMENT, CAUSE RELIEF".*
> In all cases, pilots must apply the procedure following the GPWS PULL-UP warning.

2.4.4.2 Monitoring radio altimeter information

The radio altimeter is activated and appears on the PFDs when its value is below 2,500 ft. The Hop! operations manual procedure specifies that:

- the PM calls out radio altimeter alive;
- the crew check the Minimum Safe Altitude (MSA) and correct the path if necessary;
- if the call out is not consistent with the situation, the crew must without delay apply the procedure corresponding to the "GPWS Pull-Up" warning.

[19] The D3 MAPTS point does not meet the definition of a SDF. However, this point corresponds to the obstacle determining the MOCA value for the minimum altitude segment of 770 ft.

2.4.5 Statements

The crew on board F-HMLD started the day with a Lyon to Nantes round trip, the first take-off being scheduled for 12:00. The incident took place during the third leg[20]. The co-pilot was PF on this leg.

The co-pilot remembered that during the approach to Nantes on the first flight of the day, at about 13:15, the QNH was 1009 and the wind was already strong, 25 kt, gusting up to 40 kt[21]. During the approach briefing of the incident flight, the crew mentioned the wind threat and the possibility of windshear.

The captain explained that normally, when resetting the standby altimeter on passing FL 100, he checked the QNH value on the flight plan. During this flight, having been cleared to descend to the first altitude as they were approaching FL 100, the standby altimeter was reset at the same time as the other altimeters. He added that he did not take out the flight plan, as he usually did, in accordance with the altimeter setting procedures, because they were "shaken about" due to the aerological conditions. The altimeter values were cross-checked, and all three altimeters were verified.

In the Air Safety Report (ASR) written after the event, the crew mentioned particularly turbulent conditions with gusts of 60 kt between 3,000 and 5,000 ft.

Regarding the MSAW, the co-pilot explained that the controller spoke with a low tone of voice and that she could not hear her very well. She remembered asking the captain what the controller had said. The captain mentioned that the controller did not have a firm voice during the message. He felt he had a total lack of understanding of the situation in relation to this alert. He explained that they were stable on the path and had sight of the ground, that he knew Nantes well and that he was able to locate himself in relation to the Brittany Tower, which he believed was the only obstacle.

When they corrected the QNH, they were in VMC conditions and had sight of the runway and the PAPI, approaching the MAPt. The co-pilot did not remember how the "*snowflake*" behaved when the altimeter setting was changed. The captain did not remember what PAPI colours were visible at the time of the alert[22], but he remembered that they quickly changed to two white and two red when they corrected the path.

The captain explained that they should have applied the GPWS procedure and performed a go-around. Nevertheless, he added that it did not seem reasonable to him to abort the approach, as this would have meant adopting a nose-up attitude of around 20° when they were at 500 ft with gusts of up to 70 kt, and keeping the flaps at 20° with this wind. He added that a cumulonimbus (CB) was arriving in the area and that he could see it on his ND, which was displaying the weather radar information. According to him, it was therefore more judicious to continue and land. He added that if they had been in IMC conditions, they would have applied the GPWS procedure.

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[20] Take-off scheduled for 16:00, performed at 16:50.

[21] The METAR reports at 13:00 and 13:30 indicated a variable south-westerly wind of 14 to 15 kt, with a BECMG 23015G30KT.

[22] A calculation of the aeroplane's position in relation to the PAPI colour beams showed that the aeroplane was flying in an area where all four PAPI lights were red throughout the final descent. Due to the weather conditions, however, it was not possible to determine at what distance the crew could have had sight of the PAPI.

2.4.6 Crew training

In the scope of the investigation into this incident, the training programmes and the documents used by the operator for the training were consulted.

Initial training with respect to Performance Based Navigation (PBN) operations (which incorporates the aspects relating to RNP approaches) and the annual recurrent training include a reminder of the threats posed by altimeter setting errors in Baro-VNAV operations.

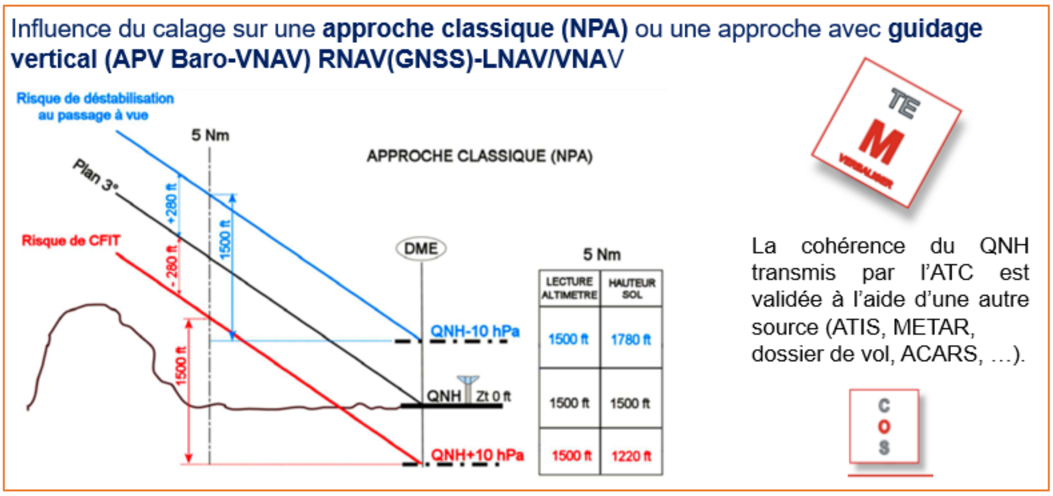

Figure 5: excerpt from the training material used in 2020-2021 by the operator for recurrent training (source: Hop!)

During the recurrent training delivered in 2020-2021, as regards NPA skills, an analysis of incidents and accidents in NPA approaches was presented. Emphasis was placed on the recent introduction of the "2D/3D operation" terminology which could lead crews to equate a non-precision approach conducted in "3D" with a precision approach. It also mentioned the most common errors, including the QNH error.

Crews were also reminded in the recurrent training that in the event of a MSAW, they are to apply the "GPWS Pull Up" procedure.

Figure 6: excerpt from the training material used in 2020-2021 by the operator for recurrent training (source: Hop!)

The captain attended the RNP recurrent training a week before the event. The co-pilot attended this training in May 2021.

2.4.7 Other events

Through its safety management system, the operator had already identified events related to altimeter setting errors. Internal safety publications for crews were issued following these events.

The last publication before the F-HMLD incident was in June 2021. It mentioned two events in which the controller provided the crew with an incorrect QNH. In both cases, the error was of -10 hPa. The crew had noted the correct QNH value of the day on listening to the ATIS message. The publication recalled the procedure (see paragraph 2.4.1) and the importance of validating the QNH information provided by the ATC by cross-checking it with another information source.

A temporary note[23] dated 6 May 2021 was added to Part A of the operations manual. It highlighted the text related to the validation of the consistency of the QNH transmitted by the ATC. The text was in red, in bold and in a box.

Passage du calage STD au calage QNH

LA COHÉRENCE DU QNH TRANSMIS PAR L'ATC EST VALIDÉE À L'AIDE D'UNE AUTRE SOURCE (ATIS, METAR, DOSSIER DE VOL, ACARS, ...).

Le PF annonce : « *LES ALTIS AU QNH* » et cale son altimètre au QNH.

Le PM cale son altimètre au QNH et annonce « QNH AFFICHÉ ».

Le PF annonce : « *A MON TOP TU DOIS LIRE XXX FT … TOP* ».

Le PM observe l'écart entre la valeur annoncée par le PF et celle indiquée sur son altimètre et répond : « *VÉRIFIÉ* » ou « ± *XX ft* » si l'écart est supérieur à 50 ft.

Figure 7: modification to text of procedure for changing altimeter setting (source: Hop!)

The modification introduced by this temporary note was incorporated into the main text of the new revision of the operations manual, published on 21 October 2021, the day after the incident.

Since the event, the operator has informed the BEA of two other cases of altimeter setting errors.

The examination of the list of altimeter setting error occurrences did not show any specificity with respect to the type of aeroplane or airport.

2.5 Generalisation of RNP approaches

Implementing regulation (EU) 2018/1048[24] requires the exclusive use of PBN from 2030. Sooner or later, this will result in air navigation services only keeping in service the radio navigation aids (ILS, VOR, DME) necessary for air navigation if there is a wide loss of the GNSS. As a result of these developments, conventional approaches are being replaced by RNP approaches.

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[23] Temporary notes are intended to communicate an operational or technical directive on a particular topic in a shorter time interval than that observed in the publication process of a complete revision of the operations manual.

[24] Commission implementing regulation of 18 July 2018 laying down airspace usage requirements and operating procedures concerning performance-based navigation ([Version in force on the day of the incident]).

In the 2020-2021 activity report, the DSNA indicated that almost all IFR runway ends not yet equipped with precision approaches had satellite approach procedures at the end of 2021.

This PBN implementation strategy has potential benefits in terms of reduced minima and better access to airports that do not have precision approach and landing capabilities. According to ICAO Resolution A37-11, it is also supposed to improve safety, because it is based on the principle of straight-in approaches, which are much safer than circling approaches. It is also consistent with a reduction of costs associated with the maintenance of ILS, VOR, DME or NDB-based navigation systems.

However, while the final purpose is to lead to a widespread use of LPV approaches (with SBAS[25] VNAV)[26] – which are not subject to the threat posed by an incorrect altimeter setting – Baro-VNAV approaches will persist during the period of transition towards this goal, and might even become predominant during this phase if the number of aircraft equipped with SBAS avionics is insufficient.

2.6 Communication

2.6.1 Read-out of communication recordings

The communication recordings provided by the air navigation services were analysed. The CVR recording was no longer available when the BEA was informed of the event.

Exchanges relevant to the understanding of the event can be found in paragraph 1. During the approach of F-HMLD, the QNH information was not transmitted to any other aircraft on the frequency.

2.6.2 *Read-back/hear-back* error

In 2004, Eurocontrol launched the *Air-Ground Communication (AGC) Safety Improvement Initiative*[27]. An action plan was drawn up to propose recommendations and solutions, based on an in-depth analysis of the causes of communication problems. The following elements are based on the information published by Eurocontrol as part of this study.

Communication between pilots and controllers is based on a communication loop which ensures effective communication. It includes the "read-back" and "hear-back" principles. 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.

[25] *Satellite-Based Augmentation System*

[26] As indicated on the EASA web page about the transition to PBN operations.

[27] *Air-Ground Communication (AGC) Safety Improvement Initiative*.

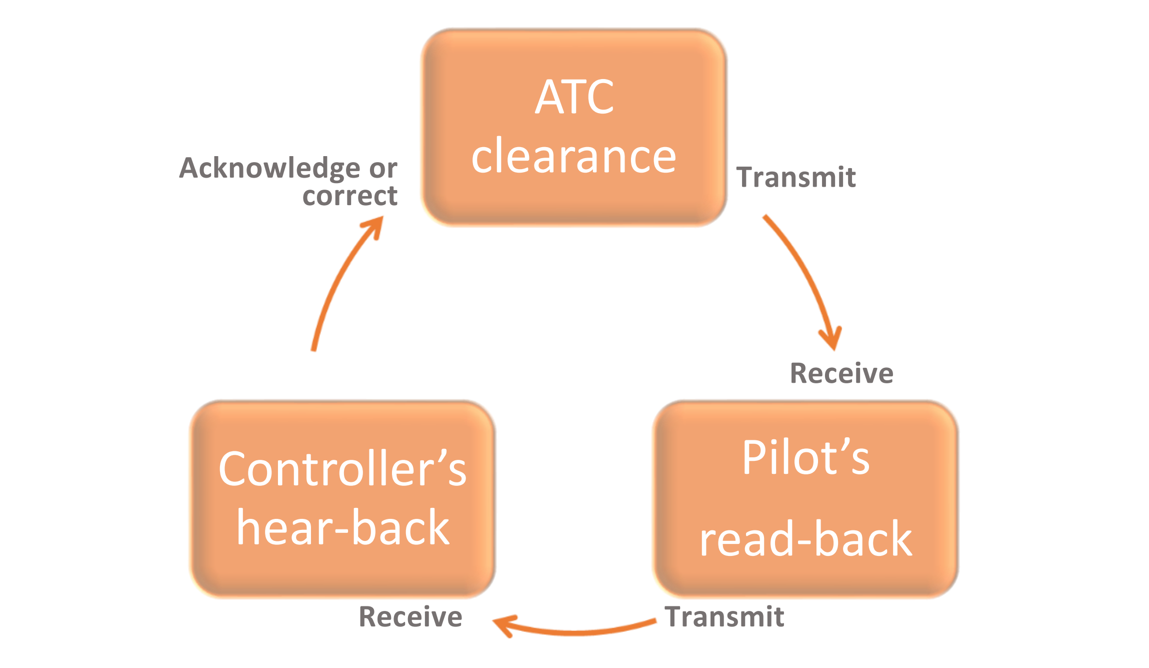

Figure 8: pilot-controller communication loop (source: BEA)

The absence of an acknowledgement or a correction by the controller is implicitly perceived by the pilot as a confirmation of the read-back.

A study[28] was conducted by the Netherlands aerospace centre (NLR) for Eurocontrol in 2004, based on the analysis of a sample of 444 incidents[29] 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 %).

The consequences of these read-back/hear-back errors result for 38 % in an altitude deviation.

The most common factors affecting read-back/hear-back errors are high workload, fatigue, distractions or interruptions.

In the serious incident investigated in this report, there was:

- a read-back error by the PM due to transposing/repeating a digit contained in the message received, which may be related to workload or distraction effects;
- a failure by the PF to detect this error, which is probably also related to similar effects;
- the absence of verification and correction of the read-back error by the controller, which was probably related to a distraction effect or to him focusing on preparing the resolution of a developing conflict involving other aircraft.

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

[29] 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.

2.6.3 Reacting to MSAW

Approximately 30 s elapsed between the triggering of the MSAW at the controller's position and the crew understanding and correcting the altimeter setting error. The event was classified as a serious incident after cross-checking this duration with the notification time calibrated on the MSAW system (set to 34 s at Nantes)[30].

When examining in detail the reason for this interval, it can be observed that:

- as a general rule, the text of the alert message to be transmitted by a controller does not give a clear indication of the situation and of the action to be taken, unlike the majority of warnings requiring a quick reaction from the crew. On the contrary, it requires the crew to analyse the situation in very stressful circumstances[31]. In comparison, the alert message provided when the aircraft is being radar vectored, gives an instruction that is appropriate to the situation and simple for the crew to understand;
- in the case of the F-HMLD event, as the QNH was not mentioned in the first alert message, the crew did not have any elements to understand the reason for the alert;
- the controller did not use the word "immediately" in the alert message;
- although the PM replied giving his altitude and QNH, the controller did not detect the QNH error at that time and repeated the alert message without further information;
- when the controller became aware of the altimeter setting error and gave the correct QNH value again, the PM repeated the QNH incorrectly, probably by reading his display.

It was probably not until the controller repeated the QNH value for the second time with insistence that the crew became aware of the error. The fact that the controller gave the QNH in a different format (pronouncing the number as a series of digits "one zero zero two" instead of "one thousand and two") during this message may also have had an influence.

The surprise effect and the additional difficulty related to the quality of the communication, expressed by the two crew members in their statements may have contributed to this delay in the crew's understanding of the situation.

These elements show that mentioning the QNH in the terrain alert is crucial and that it might help the crew understand the situation rapidly in the event of an altimeter setting error[32]. However, it is not sufficient to compensate for the additional delay resulting from the surprise effect and the crew's possible misunderstanding of the situation in relation to this alert.

2.7 EGPWS system

F-HMLD was equipped with a Honeywell Mark V EGPWS.

In the circumstances of the event, the EGPWS did not emit any warnings. This behaviour was checked and is consistent with the definitions of the alert trigger envelopes.

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[30] Nevertheless, it is important to note that the PF started to reduce the descent rate almost two seconds after the first MSAW message, i.e. 14 s after the triggering of the MSAW.

[31] A similar problem has been identified with some TCAS warnings. The serious incident that occurred in flight on 23 March 2003 to the aeroplanes registered F-GPMF and F-GHQA operated by Air France illustrates this.

[32] In other situations, mentioning the minimum flight altitude is also crucial to help the crew understand the situation.

Given that the MSAW was the safety element that stopped the sequence of the event and that a similar situation could occur at an aerodrome not equipped with a MSAW (see paragraph 2.3.3.4), a simulation was conducted on the assumption that the crew continued the approach on a path corresponding to the erroneous altimeter setting. This simulation assumed visibility conditions where the crew would not have seen the runway before reaching the MDA.

This simulation showed that an EGPWS warning would most likely have been transmitted approximately 1.6 NM from the threshold of runway 21, at a radio altitude of approximately 110 ft.

2.8 Altimeter setting error

The following analysis is based on various references covering the topic of altimeter setting errors. The main source used is the ALAR study[33] conducted by the Flight Safety Foundation.

2.8.1 Factors and prevention strategies

Altimeter errors are often the result of one or more human or operational factors. Among all the factors identified in the ALAR study, the following were observed in the incident investigated in this report:

- a high workload, in this case due to the weather conditions during the approach;
- distraction, in this case due to the fact that the crew were concerned about these weather conditions for landing and the approaching squall line from the west of the airport, on the go-around path;
- a deviation from standard procedures, in this case the fact that the ATIS QNH value written on the flight plan was not checked;
- a pilot-controller communication loop that was not effective.

The prevention strategies identified by the ALAR study, that could have been effective in the case of this event, are:

- a comprehensive and effective approach briefing, including in particular the expected QNH;
- an early awareness of the altimeter setting value, when taking into account the meteorological situation resulting from the Storm Aurore low-pressure system;
- an early awareness of the QNH value, when taking into account the METAR reports and ATIS messages for the destination airport.

The last two strategies were mentioned by the crew in their statements. They attributed the ineffectiveness of these strategies to them probably focusing on the specific aerological conditions during the approach.

2.8.2 Taking into account radio altimeter information

The ALAR study mentions the use of the radio altimeter information as a prevention tool. Integrating the radio altimeter in the instrument scan, after its activation at 2,500 ft, and calling out that the radio altimeter is alive, may reveal a critical altimeter setting error when the approach is carried out in a non-mountainous environment, by cross-checking the radio altimeter and altitude values.

[33] Approach and Landing Accident Reduction.

In the case of the F-HMLD approach, when the aircraft was in level flight on the approach intermediate segment at 3,000 ft, the radio altimeter was activated and the average radio altimeter value was 2,435 ft. The activation of the radio altimeter and the radar altitude value at this point during the approach could have alerted the crew.

Likewise, during the final approach, the radio altimeter “one thousand feet” synthetic-voice call out most likely occurred[34] when the altimeter indicated approximately 1,530 ft.

However, due to the workload during this phase of the approach, and in particular in this incident, to the weather conditions, the crew probably had few available resources to carry out these checks.

Furthermore, these checks are not clearly detailed in the standard operating procedures. In particular, the operating procedure described in paragraph 2.4.4.2, which is based on a check for consistency of the situation, does not define clear and simple criteria allowing the crew to make decisions rapidly at a time when the workload is high during the flight. For example, the procedure does not define a decision threshold and does not take into account a mountainous environment.

2.8.3 Altimeter error detection systems

2.8.3.1 On-board altimeter monitoring function

This new function has been introduced on recent aircraft, or as an optional modification on older aircraft[35]. As regards the Honeywell Mark V EGPWS, which was installed on the aeroplane on the day of the event, this is a software option which is not certified for the CRJ-1000.

This function – called *Altimeter Monitor* on the Mark V EGPWS – uses the aeroplane’s various sources of altitude information and the terrain database to provide aural and, optionally, visual messages that inform the crew, for example, of a probable erroneous altimeter setting below the transition altitude. This warning is principally based on cross-checking the pressure altitude with a “geometric” altitude value, derived from the GPS altitude.

In terms of this event, according to a study provided by Honeywell, if this function had been available, it would have triggered a warning approximately 30 s after the aeroplane passed through the transition altitude of 5,000 ft in descent. An aural message “ALTIMETER SETTING” would have been triggered and then repeated eight seconds later. As an option, an “**ALTM SETTING**” message would have been superimposed on the ND terrain display.

2.8.3.2 Ground function

In certain terminal approach control areas, the air navigation services have implemented an altimeter setting monitoring system which alerts the controller when an aircraft is flying below the transition altitude with an altimeter setting that differs from the TMA QNH. These tools are based on the altimeter setting information sent by the aircraft’s transponder when it is equipped with this function.

[34] In the absence of a CVR recording, it was not possible to verify whether the synthetic-voice call out was actually made.
[35] For example, the system has been certified as an option on the Airbus A320 and A330 since 2019.

One example is the BAT[36] system used in the London terminal approach control area (United Kingdom) which alerts the controller when an aircraft is flying below the transition altitude with an altimeter setting that differs from the TMA QNH by more than 5 hPa. On receiving the BAT alert, the controller can ask the crew to check their altimeter setting and remind them of the QNH, or can ask the crew to confirm the altimeter setting used on board.

2.9 Similar event

The BEA opened an investigation into the serious incident which occurred on 23 May 2022 on approach to Paris-Charles de Gaulle airport[37].

During this event, the controller provided incorrect QNH information. The crew were making a RNP approach with LNAV/VNAV minima, which was flown below the approach slope due to the altimeter setting error. This led to a near CFIT, with a low-height go-around approximately 1 NM before the runway without visual references.

A second approach was made under the same conditions. During this approach, the visibility conditions on final had improved and the crew acquired visual contact with the runway 2.5 NM from it, at a height of 572 ft, allowing them to correct the path.

The preliminary investigation report, published on 11 July 2022, showed that, "*During this serious incident, the MSAW was triggered on both approaches and the standard MSAW phraseology was not applied by the controllers. In particular, the crew were not instructed to check their altitude nor were they given the QNH. Initial interviews conducted as part of the investigation suggest that the emergency phraseology associated with a MSAW is not perfectly known nor understood by controllers.*"

The BEA issued several urgent recommendations, including one addressed to Paris-Charles de Gaulle air navigation services, regarding the strict use of the emergency phraseology associated with a MSAW, in particular by providing the QNH.

The analysis of the whole event is still ongoing, and the preliminary report indicates that special focus will be placed on different aspects, including the MSAW phraseology.

In response to this urgent recommendation, a temporary directive was issued by the DSNA and distributed internally to its services, as well as to all users, through an Aeronautical Information Circular (AIC)[38]. This directive states that during RNP approaches:

- when an aircraft first makes contact with the aerodrome controller, the latter shall remind the crew of the QNH value;
- in the event of a Minimum Safe Altitude Warning (MSAW), the controller shall immediately ask the aircraft in question to perform a go-around.

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[36] Barometric Pressure Setting Advisory Tool.

[37] Serious incident to the Airbus A320 registered 9H-EMU operated by AirHub on 23 May 2022 near Paris-Charles de Gaulle.

[38] AIC France A18/22.

3 CONCLUSIONS

The conclusions are solely based on the information which came to the knowledge of the BEA during the investigation. They are not intended to apportion blame or liability.

Scenario

When the crew of F-HMLD were cleared to descend to the first altitude below the transition level and to conduct the approach to runway 21, the PM incorrectly read back the QNH, indicating an altimeter setting of 1021 instead of 1002. This error was not detected by the controller or the PF.
When resetting the altimeter, the crew did not apply the procedure fully, omitting to check the consistency of the QNH provided by the controller against another source of information because of the turbulence experienced during this phase of flight, which was making it difficult for the crew to read the information written on the flight plan.

Due to this QNH error, the aircraft's path during the approach was approximately 530 ft lower than the published path. However, the procedures and information on the aircraft instruments did not allow the crew to directly identify the path error in a simple way.

The only instrument information that could have allowed the crew to detect this QNH error was the radio altimeter value, which was abnormally low compared to the procedure altitudes, taking into account the altitude of the area overflown. This check was not clearly defined by the standard operating procedures.

The altitude displayed on the radar display, which is a standard altitude, did not allow the controller to easily detect that the aeroplane was not flying the intermediate approach at the published altitude. Moreover, it was not the responsibility of the controller to carry out this check.

The final descent path checks carried out during a RNP Baro-VNAV approach do not enable the crew to detect a path error due to an altimeter setting error. This limitation inherent to RNP Baro-VNAV approaches is a well-known threat, which pilots are regularly reminded of by the operator during their recurrent training or through internal flight safety documents.

As the aircraft was approaching the missed approach point, a MSAW triggered at the LOC controller's position. The controller informed the crew of this warning, without initially reminding them of the QNH and without using the word "immediately" in the message. Exchanges between the crew and the controller lasted almost 30 s before the crew realised their mistake and corrected the vertical path.

The crew did not perform a go-around as required by the MSAW procedure described in the operations manual. As they had sight of the runway and were aware of bad weather conditions on the missed approach path, they considered it more judicious to continue the approach.

According to the stabilisation criteria, the approach was not stabilised. During the final approach, due to the inherent limitations of the Baro-VNAV function in the event of an altimeter setting error, the crew could not gain awareness of this destabilisation. The crew were only able to perceive this destabilisation on the triggering of the MSAW.

Contributing factors

The following factors may have contributed to the altimeter setting error:

- a high workload and the F-HMLD crew being excessively focused on the weather conditions associated with the ongoing storm, to the detriment of the application of the standard procedure, which included checking the consistency of the QNH value provided by the ATC against another source of information;
- the APP controller being distracted due to an imminent conflict in another sector of his area of responsibility for which he was preparing the resolution. As a consequence, the controller did not identify that the crew incorrectly read back the altimeter setting.

The following factors may have contributed to the non-detection of the erroneous final path:

- the inherent limitations of the Baro-VNAV function in the event of an altimeter setting error;
- the absence of appropriate safety measures in such situations - in particular, the "consistency check" procedure based on the radio altimeter value appears to be ineffective given the operational context at this point of the flight;
- the controller's radar display using the standard altimeter reference to indicate the aircraft altitudes.

The following factors may have contributed to the reaction time to the MSAW:

- the QNH not being mentioned when the controller conveyed the warning;
- the word "immediately" not being used in the controller's warning message;
- the surprise effect experienced by the crew.

Safety lessons

Altimeter setting error

The analysis of the event shows that most of the measures implemented to avoid the altimeter setting error are fallible. Whatever the measure considered – read-back/hear-back principle, Crew Resource Management (CRM) principles (which involve crew members cross-checking each other in the cockpit) or standard procedure principles (which clearly define the working methods to be used to resolve the threat identified) – all of these can become less effective when there are one or more disruptive factors, such as distraction or focus on another threat.

It is partly for these reasons that systems such as the EGPWS or MSAW were developed. These systems, which are often the last barrier, also have their limits. For example, in this incident, the time needed to understand and react to the MSAW was abnormally long and close to the maximum reaction time for which the MSAW system was designed.

In this context, an additional monitoring function – whether on the aircraft (such as the "Altimeter Monitor") or on the ground (such as the BAT) (see paragraph 2.8.3) – could constitute an early detection tool. Thus when the setting error implies flight at a lower altitude than that specified, it will be detected before the ground proximity becomes a significant risk factor.

The introduction of such a function seems all the more important in light of:

- the generalisation of RNP approaches, recognised as vulnerable to an altimeter setting error when vertical guidance uses the baro-VNAV function;
- the fact that the MSAW, one of the last safety barriers in this type of event, is installed at few airports in France.

Altimeter setting procedure

This serious incident illustrates how important it is to closely apply the altimeter setting procedure to ensure that the aircraft's path actually corresponds to the expected vertical profile.

Cross-checking the QNH values displayed on the different instruments can detect a display error. Checking the altitude values after having changed the altimeter setting can detect instrument errors, or even help ensure that the first cross-check was made.

These two actions do not enable an error in the QNH to be detected while the QNH value is essential for the altimeter check.

A review of the procedures of different aircraft types showed that the validation of the QNH value by cross-checking it against another source of information is not described in detail in manufacturers' procedures. This can be justified on the grounds that this validation is not directly related to the use of the aircraft and may be considered a standard practice that is taught to pilots as part of their basic training.

However, the examination of this event as well as of other cases submitted to the BEA showed that some crews apply this procedure by comparing the QNH used against the resulting instrument altitude values, without ensuring that the QNH value provided by the controller is consistent with a value provided by another information source.

The reasons for this absence of validation of the QNH value are diverse (shortcomings in pilots' initial training, incomplete application of the procedure when it is actually detailed, manufacturer's or operator's procedures not sufficiently detailed) and were not thoroughly analysed as part of this investigation.

This event illustrates how important it is to validate the QNH value by checking it against a value provided by another source of information (e.g. ATIS, ACARS messages or flight preparation documents). This should be the first step in the altimeter setting procedure.

Crew reaction to an MSAW

When the aircraft is not being radar vectored, the captain is responsible for obstacle clearance. In the event of a terrain alert generated by a TAWS[39] installed on the aircraft, the aircraft's flight manual sets out procedures to resolve this warning. In the event of a MSAW, there is no established procedure for crews.

[39] System designed to prevent controlled flight into terrain. The TAWS equipping the F-HMLD is an EGPWS.

Without a specific procedure for crews, the MSAW messages used by air traffic controllers do not enable crews to make simple decisions. On the contrary, these messages require analysis, while some information may be missing or even erroneous. However, these warnings occur in terrain proximity situations where a rapid decision is required.

Some operators analysed this threat and defined a procedure for their crews in their operations manual. For example, Hop! asks its crews to equate a MSAW with a TAWS warning, and in particular, with the "EGPWS Pull-Up" warning.

4 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.

4.1 Alignment of procedures and phraseology to be used in the event of a terrain alert

The standard expressions defined by SERA and by the Order of 11 December 2014 relating to the implementation of European Regulation (EU) No 923/2012 establish that in the event of a low altitude warning, the message includes the principle of emergency introduced by the expression "immediately", and the QNH information. In the event of a terrain alert, the standard expression does not include these elements. The notion of a "terrain alert" is not defined, and the investigation could not determine why the QNH information and the expression "immediately" are not used in this context.

The phraseology defined in the operations manuals and directives used by the French air navigation services differs according to whether the aircraft which triggered the MSAW is being radar vectored or not. This differentiation is consistent with the national regulatory text regarding procedures, but is not consistent with the national texts regarding phraseology.

It would seem that the variations in phraseology identified in the operational documents and reference manuals used by the French air navigation services, are the result of the inconsistencies observed between procedures and phraseology, and between regulations and operating procedures. The BEA did not obtain a clear explanation about these inconsistencies.

This variability in phraseology in the operational documents (operational directives, operations manual) regarding a MSAW is not likely to facilitate air traffic controllers having accurate and unambiguous knowledge of the message to be used in the event of an MSAW.

It was observed that an imprecise alert message was given in this event and in the event involving the Airbus A320 registered 9H-EMU operated by AirHub on 23 May 2022 on approach to Paris-Charles de Gaulle airport (see paragraph 2.9). In both cases, the controllers did not remind the crew of the QNH value, nor did they stress the urgency of the situation by using the word "immediately".

Consequently, the BEA recommends that:

- ***whereas the QNH information is crucial for the crew of an aircraft to be able to actually check their altitude;***
- ***whereas using the word "immediately" is important to make the crew aware of the urgency of the situation;***
- ***whereas the variability in the various DSNA documents as regards the provision of these two pieces of information;***

the DSNA, without waiting for the other actions expected from EASA and ICAO, ensure that all documents relating to phraseology and MSAW procedures are updated so that:

- ***the urgency of the situation is systematically mentioned;***
- ***the crew is systematically reminded of the QNH in the controller's message in the event of a MSAW. [Recommendation FRAN 2023-007]***

In ICAO Doc 4444 (Procedures for Air Navigation Services), as well as in French regulatory texts, the procedure to be applied in the event of a MSAW differs according to whether the aircraft which triggered the warning is being radar vectored or not.

In ICAO Doc 4444 and Doc 9432 (Manual of Radiotelephony), as well as in European and French regulatory texts, the phraseology to be used in the event of a MSAW differs according to whether it is a low altitude warning or a terrain alert. These notions are not otherwise defined in these texts.

The phraseology defined in the operations manuals and directives used by the French air navigation services differs according to whether the aircraft which triggered the MSAW is being radar vectored or not. This differentiation is consistent with the national regulatory text regarding procedures, but is not consistent with the national texts regarding phraseology.

It would seem that the variations in phraseology identified in the operational documents and reference manuals used by the French air navigation services, are the result of the inconsistencies observed between procedures and phraseology, and between regulations and operating procedures.

The BEA questioned the authorities behind the drafting of these texts and did not obtain clear explanations.

This variability in phraseology in the operational documents (operational directives, operations manual) and reference manuals regarding a MSAW is not likely to facilitate air traffic controllers having accurate and unambiguous knowledge of the message to be used in the event of an MSAW.

It was observed that an imprecise alert message was given in this event and in the event involving the Airbus A320 registered 9H-EMU operated by AirHub on 23 May 2022 on approach to Paris-Charles de Gaulle airport (see paragraph 2.9).

This is contrary to what is stated by ICAO in the foreword to Doc 9432, namely "*ICAO phraseologies are developed to provide efficient, clear, concise and unambiguous communications.*"

Consequently, the BEA recommends that:

- *whereas the low altitude warning and terrain alert notions used by ICAO Doc 4444 and ICAO Doc 9432, the SERA European regulation and the French order of 11 December 2014 relating to the implementation of Implementing Regulation (EU) No. 923/2012 to define the phraseology to be used in the event of a MSAW, are not defined in these documents;*
- *whereas the procedures to be applied by controllers in the event of a MSAW as described in ICAO Doc 4444 and in the national supplement FRA.11002 to the SERA are based on whether the aircraft is being radar vectored and not being radar vectored;*
- *whereas the QNH information is crucial for the crew of an aircraft to be able to actually check their altitude;*
- *whereas using the word "immediately" is important to make the crew aware of the urgency of the situation;*

EASA, without waiting for the ICAO documents to be updated, develop Guidance Material (GM) designed to clarify in the SERA regulation, the phraseology to be used by controllers to inform crews of a MSAW and ensure that the SERA is updated so that the urgency of the situation is systematically mentioned and the crew is systematically reminded of the QNH in the controller's message in the event of a MSAW. [Recommendation FRAN 2023-008]

EASA initiate international actions in conjunction with ICAO to also resolve inconsistencies and ambiguities in Doc 4444 and Doc 9432, so that they systematically specify that the urgency of the situation and the QNH information is mentioned, and move towards simple and unified phraseology, if possible. [Recommendation FRAN 2023-009]

ICAO ensure that the inconsistencies between MSAW procedures and phraseology contained in Doc 4444 and Doc 9432 are removed, and ensure that these documents are updated so that the urgency of the situation is systematically mentioned and the crew is systematically reminded of the QNH in the controller's message in the event of a MSAW. [Recommendation FRAN 2023-010]

This report was presented for official consultation to the following organisations: the Canadian safety investigation authority (BST) and its technical adviser Bombardier, the United States safety investigation authority (NTSB) and its technical adviser Honeywell and the BEA's technical advisers, namely the DSNA, DSAC, HOP!, EASA and ICAO.

The BEA investigations are conducted with the sole objective of improving aviation safety and are not intended to apportion blame or liabilities.

APPENDIX 1 GLOSSARY

Abbreviation	English version	French/Dutch version
AAL	Above Aerodrome (Airport) Level	
ACARS	Aircraft Communication Addressing and Reporting System	
AGC	Air Ground Communication	
AIC	Aeronautical Information Circular	
AIP	Aeronautical Information Publication	
ALAR	Approach and Landing Accident Reduction	
AMC	Acceptable Means of Compliance	
ANS	Air Navigation Service	
ANS-W	West Air Navigation Service	
APP	Approach control centre or approach control or service	
ASR	Air Safety Report	
ATC	Air Traffic Control	
ATIS	Automatic Terminal Information Service	
BAT	Barometric pressure setting Advisory Tool	
CB	Cumulonimbus	
CFIT	Controlled Flight Into Terrain	
CRM	Crew Resource Management	
CTR	Control Traffic Region	
CVR	Cockpit Voice Recorder	
DME	Distance Measuring Equipment	
DSAC	French civil aviation safety directorate	Direction de la Sécurité de l'Aviation Civile
DSNA	French air navigation service provider	Direction des Services de la Navigation Aérienne
EASA	European Aviation Safety Agency	
EGPWS	Enhanced Ground Proximity Warning System	
FAF	Final Approach Fix	
FIS	Flight Information Service	
FL	Flight Level	
FMS	Flight Management System	

Abbreviation	English version	French/Dutch version
ft	Feet	
GM	Guidance Material	
GNSS	Global Navigation Satellite System	
GPWS	Ground Proximity Warning System	
ICAO	International Civil Aviation Organization	
IFR	Instrument Flight Rules	
ILS	Instrument Landing System	
IMC	Instrument Meteorological Conditions	
kt	Knots	
LNAV	Lateral Navigation	
LOC	Local control	
LPV	Localizer Performance with Vertical guidance	
MAPT	Missed Approach Point	
MDA	Minimum Descent Altitude	
METAR	Aerodrome routine meteorological report	
MNM	Minimum	
MOCA	Minimum Obstacle Clearance Altitude	
MSA	Minimum Safe Altitude	
MSAW	Minimum Safe Altitude Warning	
ND	Navigation Display	
NDB	Non Directional Beacon	
NLR	Netherlands aerospace centre	Nationaal Lucht- en Ruimtevaartlaboratorium
NM	Nautical Mile	
NPA	Non-Precision Approach	
NTSB	National Transportation Safety Board	
PAPI	Precision Approach Path Indicator	
PBN	Performance Based Navigation	
PF	Pilot Flying	
PFD	Primary Flight Display	
PM	Pilot Monitoring	
QAR	Quick Access Recorder	
QNH	Altimeter setting to obtain aerodrome elevation above	

Abbreviation	English version	French/Dutch version
	sea level	
RNP	Required Navigation Performance	
SBAS	Satellite-Based Augmentation System	
SDF	Step Down Fix	
SERA	Standardised European Rules of the Air	
TCAS	Traffic Collision Avoidance System	
TMA	Terminal Manoeuvring Area	
TSB	Transportation Safety Board of Canada	
UTC	Universal Time Coordinated	
VFR	Visual Flight Rules	
VMC	Visual Meteorological Conditions	
VNAV	Vertical Navigation	
VOR	VHF Omnidirectional Range	