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Bureau d'Enquêtes et d'Analyses
pour la sécurité de l'aviation civile

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RAPPORT D'ENQUETE DE SECURITE

Accident to the Embraer– EMB-500 registered 9H-FAM on 8 February 2021 at Paris-Le Bourget

Time	Around 10:00[1]
Operator	Luxwing
Type of flight	Passenger commercial air transport
Persons on board	Captain (PM), co-pilot (PF), one passenger
Consequences and damage	Aeroplane destroyed

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

Stall on short final in icing conditions, hard landing, rupture of main landing gear and nose gear, fire, runway veer-off

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

1 ORGANISATION OF THE INVESTIGATION

In accordance with Annex 13 to the Convention on International Civil Aviation and European Regulation (EU) No 996/2010 concerning the investigation and prevention of accidents and incidents in civil aviation, the investigation authorities of the following countries were informed and appointed accredited representatives:

- Brazil (CENIPA) as state of manufacture of the aircraft;
- Malta (BAAI) as state of registration of the aircraft.

Brazil and Malta also appointed specialists from the manufacturer (Embraer) and the operator (Luxwing) as technical advisers.

After the consultation phase of the draft final report, on CENIPA's request, the observations made by Brazil were appended to this report (see Appendix 1).

2 HISTORY OF THE FLIGHT

Note: the following information is principally based on the Cockpit Voice Recorder (CVR) and Flight Data Recorder (FDR) data, statements and radio-communication recordings.

The crew, composed of a captain and a co-pilot, carried out a passenger commercial air transport flight from Venice (Italy) bound for Le Bourget (France). They took off from Venice at 08:17 with one passenger on board. The co-pilot was the PF for this leg.

During the flight, the crew discussed the weather conditions forecast at their destination and mentioned the possibility of snow and the runway being contaminated. They tested the aeroplane's anti-icing system and observed that it was operating.

Between 09:16 and 09:20, the crew determined the speeds to be complied with for the approach and landing by consulting the Flight Manual charts. They selected the speeds of 97 kt for the VRef, 102 kt for the VAC and 121 kt for the VFS[2]. These speed values correspond to those suitable for landing in non-icing conditions.

At 09:20, the aeroplane was at FL 340, the crew listened to the Le Bourget ATIS which especially mentioned severe icing between 3,000 ft and 5,000 ft. The captain told the co-pilot that unlike what had been forecast, there was not going to be any snow. He mentioned the icing and explained that this was a common phenomenon at Le Bourget.

The crew carried out the approach briefing and planned for an ILS approach to runway 27 with the flaps in the "FULL" configuration and the autopilot engaged.

At 09:50, the crew contacted the Paris-Charles de Gaulle approach controller who cleared them to descend to 5,000 ft. The engine anti-icing and the windshield demisting/de-ice system were activated. The controller cleared the descent to 3,000 ft QNH and then the ILS 27 approach to Le Bourget.

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[2] The aeroplane Flight Manual defines these speeds as being:
VRef: Landing Reference Speed, VAC: Approach Climb Speed, VFS: Final Segment Speed.

In level flight at 3,000 ft QNH, the aeroplane intercepted the Localizer signal at around 14 NM from Le Bourget. The captain announced the activation of the WINGSTAB (de-ice) system (see paragraph 3.3) and confirmed he could see built-up ice breaking up. The co-pilot added that he saw a small part coming away on his side. The de-ice system was deactivated 21 s later.

At 09:58, the aeroplane intercepted the Glide signal at around 8.5 NM from Le Bourget airport. The crew were transferred to the Le Bourget tower controller who cleared them to land on runway 27 and indicated that the wind was coming from 350° at 4 kt.

At 10:00, the aeroplane was at 3.8 NM from Le Bourget, it flew through 1,380 ft QNH in descent at -360 ft/min and an indicated airspeed of 135 kt. The flaps were in the FULL configuration and the landing gears were extended. The crew carried out the before landing check-list. The captain announced that the engine anti-icing system was deactivated and added that he could also leave it activated as the temperature was 0 °C. He announced that he had runway 27 in sight.

At 468 ft QNH at an airspeed of 100 kt, the approach was stabilized and the autopilot disengaged. At 10:01, shortly before reaching the DH[3] (200 ft), the captain announced that the aeroplane was high on the approach slope.

Five seconds after flying through a radio-altimeter height of 50 ft, the aeroplane's speed decreased from 94 to 90 kt and the angle of attack increased from 10 to 28°. The aeroplane abruptly sunk, the normal acceleration reached -0,4 G, the vertical speed increased from -700 to -960 ft/min and the roll angle alternated between 2° to the left and 10° to the right.

The captain called out that he was taking the controls and started a go-around. The "STALL STALL" aural warning was activated.

The aeroplane stalled in very short final with a right bank angle of around 10° and touched down hard on the runway. The FDR and CVR stopped at the time of the impact[4].

A fire broke out under the fuselage near the wing roots, the aeroplane slid along the runway before coming to a stop on the left edge of runway 27. The airport Aircraft Rescue and Fire Fighting service (ARFF) put out the fire and the occupants evacuated the aeroplane unharmed.

3 INFORMATION ON AEROPLANE AND ITS SYSTEMS

3.1 Examination of site and wreckage

The marks on the runway, the distribution of the debris and the analysis of the video recordings from the Le Bourget airport surveillance cameras were used to determine the accident sequence after the impact with the runway:

- the aeroplane touched the runway 10 m after the displaced threshold of runway 27 with a right bank angle of approximately 10°;

[3] Minimum height at which the pilot decides to continue the landing if the runway is in sight or to carry out a missed approach.
[4] This recorder is equipped with an acceleration sensor which stops the recordings when the normal acceleration reaches a threshold of 5 G.

- the right landing gear broke and perforated the fuel tank when it passed through the right wing;
- the nose gear broke;
- a fire broke out near the engines and at the wing roots;
- the aeroplane slid for a distance of around 1,050 m along the runway;
- it veered off the left side of the runway by pivoting around its yaw axis and came to a halt on a heading of approximately 160°.

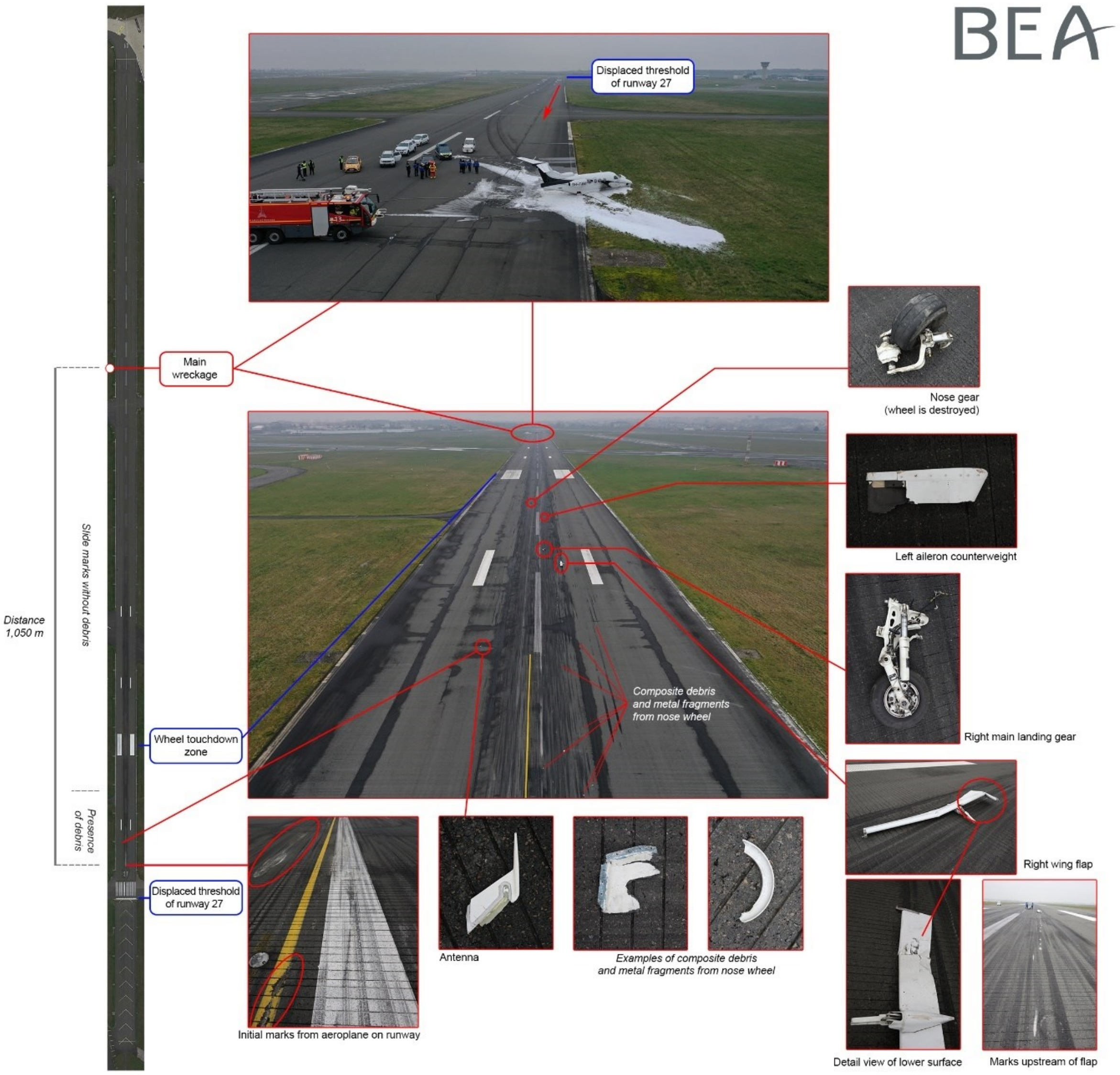


Figure 1: distribution of aeroplane parts on runway

On site, the BEA investigation team observed the presence of built-up ice on the leading edges of the wings and stabilizer.

Figure 2: icing on the leading edge of the left wing still present 3 h after the accident. The white on the upper surface of the wing is the residue of the product used by the fire-fighters (source: BEA)

Figure 3: icing on the leading edge of the elevator still present 3 h after the accident (source: BEA)

3.2 General

The Embraer EMB-500 “Phenom 100” is a CS-23-certified light business jet which can transport up to six passengers. It has low wings, a T-tail and two Pratt & Whitney Canada turbojets situated at the rear of the fuselage.

Figure 4: EMB-500 registered 9H-FAM (source: www.jetphotos.com)

Manufacturer	EMBRAER
Type	EMB-500 Phenom 100
Serial number	50000100
Engines	2 Pratt & Whitney Canada PWF617-E
Registration	9H-FAM
Airworthiness review certificate	25 November 2020 valid until 7 December 2021
Entry into service	2009

The study of the maintenance documents did not reveal any contributory element to the accident.

3.3 Description of de-ice/anti-icing systems

The icing protection systems are composed of thermal (engine air intakes), electric (external probes and windshield) and pneumatic (wing and stabilizer leading edges systems).

3.3.1 Description of WINGSTAB[5] system

This pneumatic system, activated by the crew, breaks up the ice which has built up on the leading edges of the wings and horizontal stabilizers by alternately inflating and deflating the inflatable boots installed on the leading edges (four on the leading edges of the wing and two on the leading edges of the horizontal stabilizers). The inflation/deflation command is described in Figure 5.

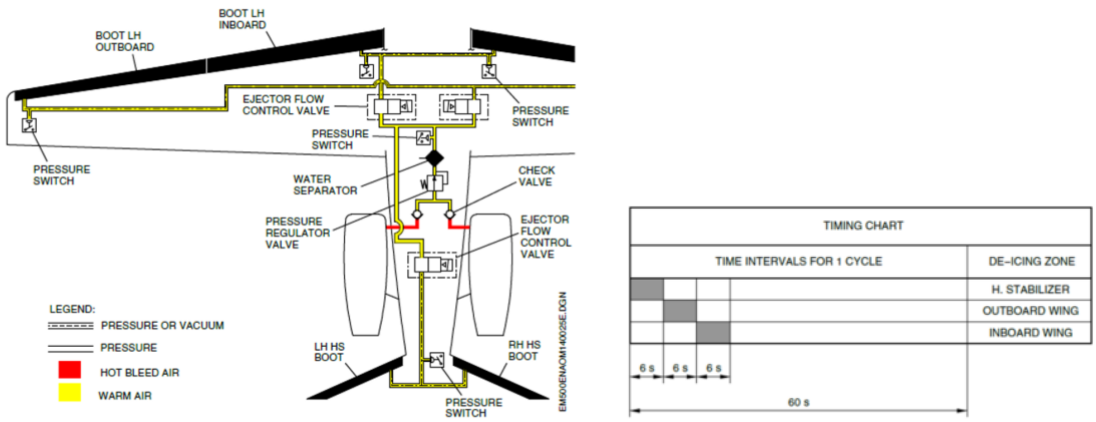


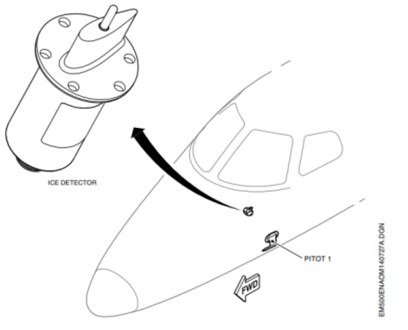
Figure 5: diagram of wing and horizontal stabilizer de-ice system (on left) and system's operating cycle (on right) (source: Embraer)

The readout of the flight data recorded in the FDR, and in particular the pressure sensor data and data concerning the open/closed state of the various valves of the de-ice systems indicates that the de-ice system was operating nominally.

[5] Wing and Stabilizer de-ice System.

Aid in detecting icing conditions

All the EMB-500 Phenom 100s equipped with a Garmin G3000 avionics suite are equipped with an ice detector as a standard feature. In October 2019, Embraer published an optional service bulletin[6] to also permit the installation of an ice detector on EMB-500s equipped with a G1000 avionics suite[7]. The build-up of ice modifies the resonance frequency of the detector probe and activates the display of the *"ICE CONDITION"* message on the MFD[8].



ICE DETECTOR

Figure 6: diagram of ice detector (source: Embraer)

On 16 November 2021, EMBRAER indicated to the BEA that 373 EMB-500 Phenom 100s were in service and that 39 of these had been equipped with this detector. 9H-FAM was not equipped with one.

3.3.2 Embraer procedure when operating in icing conditions

During flights in icing conditions, the aeroplane Flight Manual indicates:

[6] SB-500-30-0006.

[7] The EMB-500s equipped with a G1000 suite are not equipped with this detector as a standard feature.

[8] Multifunctional Display

PHENOM 100
Airplane Flight Manual
Normal Procedures

PHENOM™ BY EMBRAER

AFTER TAKEOFF/CLIMB, CRUISE, DESCENT OR APPROACH

The crew must activate the ice protection system when flying in icing conditions or if icing conditions are forecasted as follows:

If TAT is between 5°C and 10°C with visible moisture:

ENG 1 & 2 Switches .... ON

WINGSTAB Switch .... OFF

WSHLD 1 & 2 Switches .... OFF

The CAS messages A-I E1 (2) ON must be displayed after a delay of approximately 10 seconds.

If TAT is below 5°C with visible moisture, or at the first sign of ice accretion anywhere on the airplane, or ICE CONDITION message (if applicable) is displayed, whichever occurs first:

ENG 1 & 2 Switches .... ON

WINGSTAB Switch .... ON

WSHLD 1 & 2 Switches .... ON

The CAS messages A-I E1 (2) ON, D-I WINGSTB ON and SWPS ICE SPEED must be displayed after few seconds.

PHENOM™ BY EMBRAER

PHENOM 100
Airplane Flight Manual
Normal Procedures

(Continued from the previous page)

After leaving ice conditions and if there is no ice accretion on the airplane:

ENG 1 & 2 Switches .... OFF

WINGSTAB Switch .... OFF

WSHLD 1 & 2 Switches .... OFF

<u>WARNING:</u> **THE ICE PROTECTION SYSTEM MUST BE KEPT ON UNTIL CREW IS CERTAIN ALL ICE HAS BEEN REMOVED.**

Figure 7: excerpt from Flight Manual (source: Embraer)

The “*ICE CONDITION*“ message only appears if the aeroplane is equipped with the ice detector. Crews must therefore consider that they are in icing conditions and that they must activate the WINGSTAB de-ice system as soon as the total outside air temperature descends below 5°C in the presence of visible moisture (flying in clouds), even when there are no signs of ice accretion.

The manufacturer also underlines that when flying in icing conditions, it is preferable to disconnect the autopilot in order to feel on the controls, any possible consequences of ice build-up on the behaviour of the aeroplane. This behaviour may be concealed by the use of trims if the autopilot is activated.

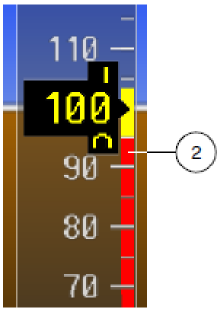
The manufacturer prohibits the use of the autopilot in severe icing conditions.

The manufacturer has also produced an information video aimed at EMB-500 Phenom 100 pilots about flying in icing conditions.

3.4 Stall Warning and Protection System (SWPS)

The SWPS has two main functions:

- to inform the crew of an imminent stall by the activation of the “*STALL STALL*” aural warning and the display of specific indications on the airspeed tape of the PFD;
- to activate the Stick Pusher when the aeroplane is in flight conditions close to stall.



2 – LOW SPEED AWARENESS TAPE

– Indicates proximity to stall speed.

YELLOW: from the top of red band plus 3 kt.

RED: the red band extends from the smallest airspeed displayed (i.e.: bottom if the airspeed tape) to the airspeed on which the Stall Warning aural message will be activated.

Figure 8: excerpt from Flight Manual (source: Embraer)

The stall aural warning, the appearance of information on the airspeed tape and the Stick Pusher are activated when the aeroplane's measured angle of attack is more than the predefined threshold values. These values are modified by the SWPS according to the configuration of the aeroplane and the operation of the WINGSTAB de-ice system.

The manufacturer indicated that in the landing configuration with the landing gear extended, the flaps set to FULL and the WINGSTAB de-ice system deactivated, the angle of attack values to activate the "*STALL STALL*" warning are 21° and 28.4° for the Stick Pusher. In the same configuration but with the WINGSTAB system activated, these values are respectively 9.5° and 15.5°.

Based on the flight data from the FDR, the manufacturer simulated the operation of the SWPS with the WINGSTAB system activated. Taking the speeds selected by the crew during the accident flight (Vref = 97 kt), the aural stall warning would have been activated twice: at an altitude of between 1,000 and 850 ft QNH and then just after 150 ft. The Stick Pusher would have then been activated shortly after flying through the radio-altimeter height of 50 ft.

3.5 Calculation of landing performance

At the time of the accident, the conditions were the following:

- runway 27 in use, measuring 1,847 x 45 m, Landing Distance Available (LDA): 1,847 m, threshold (THR): 166 ft;
- dry runway;
- wind: 350° 4 kt;
- temperature: 0 °C.

The aeroplane was configured as follows:

- flaps: FULL
- landing weight: 4,080 kg (based on FDR data).

At time of the accident, the weight and balance of the aeroplane were within the limits recommended by the manufacturer.

In these conditions, the manufacturer's Flight Manual indicates that the landing distances and limitations are the following:

	Without de-ice system	With WINGSTAB de-ice and engine heating systems
VRef (Landing Reference Speed)	96 kt	119 kt
VAC (Approach Climb Speed)	102 kt	119 kt
Landing distance	1,296 m	2,301 m
Climb gradient One Engine Inoperative (OEI)	4.1%	-0.2%
Climb gradient All Engines Operative (AEO)	17.7%	10.1%

With the WINGSTAB de-ice system activated, the plane’s performance did not permit it to land on runway 27 or runway 25. The landing distances on runways 27 and 25 were greater than the length of runway available by respectively 450 m (LDA of runway 27 being 1,847 m) and 200 m (LDA of runway 25 being 2,100 m).

In addition, the plane’s performance meant that a go-around with one engine inoperative was not possible.

The manufacturer also indicated that the certification airspeeds (in the conditions of the accident) were the following:

	Stall speed (kt)	Landing speed (kt)
De-ice systems not activated	73.9	96.3
De-ice systems activated	91.3	118.7

The data recorded in the FDR just before the impact indicated that the aeroplane was manoeuvring in speed and angle-of-attack envelopes where it was likely to stall in the event of ice contamination. Five seconds after flying through the radio-altimeter height of 50 ft, the aeroplane’s speed decreased from 94 to 90 kt and the angle of attack increased from 10 to 28°.

3.6 Effects of wing and horizontal stabilizer contamination on aeroplane performance

Ice contamination of the wing, even in small quantities, locally modifies the airflow and can cause the airflow to separate from the surface. The wing’s aerodynamic characteristics can then be significantly degraded. In particular, there is a reduction in:

- lift for a given angle of attack;
- the maximum lift;
- the angle of attack at which a stall will occur.

In these conditions, the actual stall angle-of-attack may be much lower than the thresholds for the stall alarm calibrated for a "clean" wing.

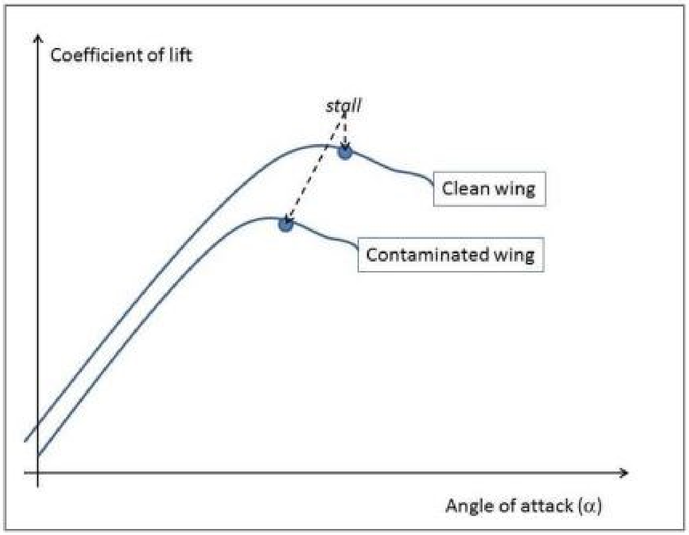


Figure 9: effects of contamination on lift (source: BEA)

Ice build-up can also cause instability in roll characterised by successive, uncontrolled roll movements to the left and right. In addition to these negative effects on lift, the drag and weight of the aeroplane increase. The effects of ice contamination are described in numerous studies including those by the French civil aviation authority (DGAC) and the American civil aviation authority (FAA).

4 OPERATIONAL INFORMATION

4.1 Meteorological information

4.1.1 Meteorological conditions available before the flight

The flight file which Flight Operations handed to the crew before the flight mentioned the probable presence of snow at destination.

4.1.2 Meteorological conditions at time of accident (ATIS)

The ATIS in force mentioned a temperature of -1°C, a dew point at -3°C and severe icing at an altitude of between 3,000 and 5,000 ft.

4.1.3 Météo-France analysis

The day of the accident there was a disturbance over the north of France with scattered precipitation, most often in the form of snow. Le Bourget was under a dense but thin cloud layer with a base between 1,000 and 1,500 ft and cloud tops between 5,000 and 6,000 ft and locally 6,500 ft. The temperature on the ground was -1°C and at the top of the cloud layer, it was estimated as being between -10 and -12°C.

All of the cloud layer was at a negative temperature and contained supercooled liquid water and significant amounts of ice. The conditions were conducive to severe icing.

4.1.4 Statement made by pilot of aeroplane behind 9H-FAM on final for runway 27

The pilot of the aeroplane on final behind 9H-FAM indicated that the conditions were particularly icy and that he had activated all the de-ice systems. He added that he was based at Le Bourget and that he had rarely encountered such conditions. He specified that he was flying a Piaggio P180 equipped with a visual ice accretion probe which had accumulated so much ice that he took a photo of it, around ten minutes before the accident to 9H-FAM (see Figure 10).

Figure 10: photo taken by pilot of aeroplane on final behind 9H-FAM, ten minutes before accident

4.2 Crew information

4.2.1 Captain (PM)

The 40-year-old captain held a Commercial Pilot Licence (CPL) issued on 1 April 2014 and the EMB-500 type rating issued on 1 March 2019. He had logged around 3,625 flight hours including 2,961 h on the Embraer EMB-500 and around 2,500 h as captain. He was recruited by the operator in 2013.

4.2.2 Co-pilot (PF)

The 25-year-old co-pilot held a CPL issued on 13 August 2020 and the EMB-500 type rating issued on 10 September 2020. He had logged approximately 625 flight hours of which 425 h on the Embraer EMB-500. He was recruited by the operator in 2020.

4.2.3 Training and recurrent training & checking

From the initial certification in 2013, the Brazilian aviation authority (ANAC), followed by the FAA and the European Aviation Safety Agency (EASA) imposed that the pilot training to obtain the type rating for the Embraer EMB-500 includes, in addition to the conventional training, specific TASE training (Training Area of Special Emphasis) relating to operations in icing conditions and the relationship between the de-ice system and the SWPS.

The operator's EMB-500 crews were trained in an Approved Training Organization (ATO) in Finland. The operator's EMB-500 training manager told the BEA that this ATO provides the specific training imposed by the TASE and that it was validated by its oversight authority.

The crew had carried out:

- training in DE/ANTI-ICING Procedures on 24 August 2020 for the captain and 17 February 2020 for the co-pilot;
- training in de-ice systems on 4 September 2020 for the captain and the co-pilot;
- training in Cold Weather Operations – CWO on 11 September 2020 for the captain and 28 December 2020 for the co-pilot.

4.2.4 Crew statements

The day of the accident, the co-pilot indicated that he had carried out the pre-flight inspection and had not observed anything abnormal. While preparing the Venice-Le Bourget flight, Orly airport was selected as the alternate airport. The weather file forecast the presence of snow on arrival. The captain added that he was aware that the aircraft's landing performance meant that it could not land at Le Bourget airport if the icing conditions on approach required the continuous use of the de-ice systems up to landing.

The crew indicated that the flight had proceeded normally up to the approach to Le Bourget. They specified that in level flight at 5,000 ft, they were in VMC just above the cloud layer and that they activated the engine anti-icing before starting the descent. During the descent, the crew added that they visually detected ice on the wing and decided to activate the WINGSTAB de-ice system. They observed that the ice had broken up and deactivated the de-ice system. They came out of the cloud layer at around 2,000 ft and flew through a thin layer again at around 1,500 ft. Visually observing the absence of ice build-up on the leading edges of the wings, the crew did not activate the WINGSTAB de-ice system again.

The captain explained that he had experience operating in icing conditions and specified that he used the WINGSTAB de-ice system only when he visually observed the presence of ice on the leading edges of the wings and deactivated it once this ice had broken up. He added that the landing performance limitations imposed by the use of the de-ice system meant that it was not possible to land at certain airports served by the operator. To avoid having to divert, the crew did not leave this system continuously activated contrary to the procedure.

The crew explained that they disconnected the autopilot around 100 ft above the minima and felt the plane sink as if it were in a strong downdraft. The captain added that they were high on the approach slope and that after flying through the minima, he decided to take the controls and carry out a go-around. He remembered that just after increasing power, the "*STALL STALL*" warning was activated and that he lost control of the aeroplane which touched down hard on the runway.

The captain specified that he had no recent flight experience in severe icing conditions and had not had to use the wing and stabilizer de-ice system in the previous year. He explained that he had, however, already encountered similar icing conditions and that the temporary activation of the WINGSTAB de-ice system had permitted him to land without difficulty. The co-pilot specified that he had never flown in icing conditions.

4.2.5 Statements from Phenom 100 pilots

A pilot on the Phenom 100 told the BEA that when flying in icing conditions on the approach to airports where the activation of the de-ice system meant that it was not possible to land (insufficient landing distance available), he had been unofficially taught that it was possible to deactivate the de-ice systems after 1,000 ft if the leading edges of the wings were not contaminated by ice.

The consultation of Phenom 100 pilot forums also shows that this deviation from the manufacturer's procedure is common. For example, on a forum, an anonymous pilot explained:

"Frequently, in Northeast, accompanied by bad weather and icing. Phenom book Vref increases when hots are on. For some reason Cessna does not have same requirements. Spoke with one pilot

who did a lot of 100 flying in cold wx. Said that as soon as he cleared the clouds on approach would turn off the hots so that he could approach & land at normal speeds. Seems reasonable, as long as you remember to turn them back on if you need to go missed."

4.3 Operator information

Luxwing holds an Air Operator's Certificate (AOC) issued by the Malta civil aviation authority. This operator operates a fleet of 21 business jets which includes seven EMB-500 Phenom 100s, and carries out on-demand unscheduled commercial flights.

Luxwing has a Flight Operations department which prepares the flights and provides the crew with the flight file. In its operations manual, a chapter specifies that this department must check that the performance of the aeroplanes operated is in keeping with the characteristics of the runways at the airports used.

4.4 Similar events

4.4.1 Accident to the Embraer EMB-500 on 8 December 2014 on approach to Gaithersburg airport (United States)

During the approach in icing conditions, the aeroplane stalled and collided with buildings. The three people on board and three other people on the ground were fatally injured.

In June 2016, the National Transportation Safety Board (NTSB) published the final report and determined that the probable cause of this accident was the pilot carrying out an approach at a landing speed below that recommended in the manufacturer's normal procedures in icing conditions and the non-activation of the wing and horizontal stabilizer de-ice system. The combination of these two factors led to a stall at an altitude which made recovery impossible.

The landing speed selected by the pilot was consistent with the manufacturer's normal procedures in non-icing conditions.

The LDA on runway 14 was around 1,280 m. In the conditions of the occurrence (weight, configuration and speeds selected by the pilot), the landing distance was 700 m in non-icing conditions with the de-ice system de-activated. If the latter system was activated, the aeroplane could no longer land due to an insufficient rate of climb in the event of an engine failure.

In its report, the NTSB mentioned three probable scenarios which could explain why the pilot did not activate the wing and stabilizer de-ice system:

- the pilot was concerned about the landing distances;
- the pilot forgot to activate the de-ice system;
- the pilot did not accurately assess the effect of ice build-up in icing conditions on aeroplane performance.

The NTSB issued safety recommendations addressed to:

- The FAA and the General Aviation Manufacturers Association (GAMA), to develop a system that automatically alerts pilots that they are flying in icing conditions.
- The National Business Aviation Association (NBAA), to work with manufacturers and training providers to develop enhanced pilot training guidelines pertaining to risk management in winter weather operations.

4.4.2 Accident to the Embraer EMB-500 on 15 February 2013 at Berlin-Schönefeld airport (Germany)

During the landing flare on runway 07L at Berlin-Schönefeld airport, the aeroplane banked left, struck the runway and came to a halt on the right side of the runway. The two pilots and the passenger were not injured.

In December 2018, the German safety investigation authority (the BFU) published the final report which indicated the following causes of the accident:

- The crew carried out the approach in known icing conditions and did not activate the wing and horizontal stabilizer de-ice system, contrary to what is requested in the manufacturer's Standard Operating Procedures (SOP).
- Due to a build-up of ice on the wings and the horizontal stabilizer and the non-compliance with the required approach speed, the aeroplane took an abnormal attitude during the flare and stalled.

The BFU also considered that the crew's insufficient knowledge of the connection between the de-ice system and the SWPS was a factor which contributed to the accident.

The BFU's safety recommendations included safety recommendations to EASA and the ANAC to ensure that Embraer improves the EMB-500 type rating training in order to increase pilot awareness of the importance, the operation and use of the ice protection systems.

5 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.

5.1 Scenario

Before starting the descent to destination, the crew listened to the Le Bourget airport ATIS which indicated the presence of severe icing between 3,000 and 5,000 ft. They carried out the approach applying the manufacturer's normal procedure for an approach in non-icing conditions, the approach speed selected by the crew (Vref 97 kt) was thus 22 kt below the approach speed in icing conditions and was, according to the manufacturer, close to the stall speed in the event of ice contamination.

At 3,000 ft, the crew activated the wing and stabilizer de-ice system for a period of 21 s which corresponded to a complete de-ice cycle. The crew indicated that they observed through the cockpit window that the ice which had built up on wing leading edges had broken up. They then deactivated the de-ice system and did not active it again. This decision was solely based on the visual observation of the wing leading edges.

The presence of ice on the wing and stabilizer leading edges observed after the accident shows that ice built up on the aeroplane on final. The following hypotheses can thus be made:

- Either the light and clouds did not allow the crew to determine the actual degree of contamination of the wings.
- Or the shapes and thickness of this built-up ice were visible from the cockpit and in this case:
  - after deactivating the de-ice system, the crew no longer actively monitored the leading edges to ensure that there was no formation of ice or,
  - the crew observed this build-up of ice but underestimated the consequences of this.

In the conditions of the day, the aeroplane's weight and the configuration selected by the crew, compliance with the manufacturer's procedure for an approach in icing conditions would have meant that the aeroplane would not be able to land at Le Bourget airport. This was because firstly, in the event of a go-around with one engine inoperative, the aeroplane's climb rate was not sufficient to safely clear obstacles. Secondly, the landing distance available was less than the landing distance required by the aeroplane. The crew told the BEA that they were aware of these limitations even before taking off and that they knew that if they had to continuously activate the de-ice system until landing, they would have to divert.

Given that it was impossible to meet the operational constraints by strictly complying with the procedure, the strategy chosen by the crew was to carry out the landing according to the manufacturer's procedures for an approach and landing in non-icing conditions while ensuring that ice had not built up on the aeroplane. The captain explained that this was a standard adaptation of the procedure.

The deactivation of the de-ice system had the following consequences:

- The ice that may have built up on the leading edge of the horizontal stabilizer may not have been completely broken up.
- Ice built up again on the aeroplane at the end of the approach.
- The Stall Warning Protection System (SWPS) was not configured to cut in effectively in the icing conditions of the accident: the speed tape displayed on the PFD was not configured to alert the crew that they were flying at a speed close to the stall speed and the aural stall warning and the Stick Pusher protection were not configured to activate at the appropriate angles of attack.

Just before the impact, the aeroplane was flying in low speed and high angle-of-attack envelopes where the aircraft was likely to stall in case of ice contamination of its structure. The recorded flight data did not enable the exact degree of contamination to be determined, but the presence of ice on the leading edges of the wings and horizontal stabilizer observed after the accident confirmed that ice had built up on the aeroplane.

5.2 Contributing factors

The three accidents discussed in this report have some similarities and highlight the difficulty for a crew to make an appropriate decision about using de-ice systems in icing conditions.
This decision is influenced by the high operational constraints due to the landing performance limitations in icing conditions on this type of plane.

The extent of the landing performance penalties in icing conditions, compared to landing performance in non-icing conditions on this type of aircraft results in crews frequently encountering situations where the destination airport is accessible with comfortable safety margins in non-icing conditions but becomes inaccessible if the conditions are icing (i.e. total outside temperature below 5°C and visible moisture on approach, even in the absence of any signs of accretion on the aircraft). This may lead crews, both during flight planning and while carrying out the flight, to underestimate the risk of encountering icing conditions during the approach and landing in order to comply with the requested flight schedule or to avoid a diversion.

Although compliance with the Flight Manual procedures is mandatory, the commercial pressures associated with this type of operation may encourage crews not to comply with the proper procedures for the approach and landing in icing conditions by deactivating the de-ice systems as soon as they visually observe that the leading edges of the wings are free of ice, and they consider that the risk of further contamination before landing is low. The statements gathered during the investigation suggest that this inadequate practice is common in the Phenom 100 pilot community.

The following factors may have contributed to the crew not diverting and to them continuing the approach without the activation of the de-ice system:

- The operator's choice to use an aeroplane type for flights to destinations where icing conditions on approach are not unlikely, although the performance of this aeroplane type is degraded in icing conditions and becomes incompatible with the runway landing distances available, even though these runway landing distances provide substantial margins in the absence of icing conditions.
- The degraded landing performance of the Embraer EMB-500 Phenom 100 in icing conditions compared to performance in non-icing conditions. Crews thus frequently encounter situations where the destination airport is accessible with comfortable safety margins in non-icing conditions but becomes inaccessible in icing conditions.
- A deviation in the application of the de-ice/anti-icing system activation procedure, due to the landing performance penalties in icing conditions on this aircraft type, which does not appear to be limited to this crew or this operator. Instead of activating the wing and horizontal stabilizer de-ice system as soon as the temperature drops below 5°C in the presence of visible moisture, this system is only activated by the crews when they visually observe ice on the leading edges of the wing. It is then deactivated as soon as these crews note the absence of ice on the leading edges of the wings and consider that the risk of further ice accumulation before landing is low.

6 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.

6.1 Improvement in the crews situational awareness when operating in icing conditions

When crews are confronted with conditions in which there is or there is likely to be ice accretion (total outside temperature below 5°C and visible moisture), they must apply the manufacturer's procedures and use the de-ice systems. Activating these systems increases the manoeuvring speeds to mitigate against a loss of control due to the aeroplane's aerodynamic characteristics degrading.

The landing performance of the Embraer EMB-500 Phenom 100 in icing conditions is degraded compared to performance in non-icing conditions. Crews thus frequently encounter situations where the destination airport is accessible with comfortable safety margins in non-icing conditions, but becomes inaccessible in icing conditions. These airports, such as Le Bourget airport, are, however, one of the classic destinations for passenger-customers of this type of on-demand commercial operation.

The crews flying to this type of airport may believe that temporary activation of the system will be sufficient to prevent ice build-up, and take the risk of not complying with the manufacturer's published procedures in order to avoid diverting. This decision is based on a visual assessment limited to a part of the aircraft's structure (leading edge of wings) and on the estimation of the low risk of further ice accretion after stopping the de-ice system.

In the case of the accident to 9H-FAM, the presence of the ice detector would have alerted the crew and improved their situational awareness of the level of contamination on the aeroplane.

More generally, in marginal icing weather conditions, the ice detector can provide crews with information to help them decide, more objectively, whether it is necessary to apply the approach in icing conditions procedure, and/or to divert to an accessible aerodrome.

Consequently, the BEA recommends that:

- ***whereas the performance penalties in icing conditions for Embraer EMB-500 Phenom 100 types of aircraft encourage crews to apply a divergent and potentially dangerous interpretation of the manufacturer's procedures for the approach and landing in icing conditions;***
- ***whereas Embraer has an optional system for the EMB-500 Phenom 100 equipped with the G1000 avionics suite, available to operators, which improves crew situational awareness during flights in icing conditions;***
- ***whereas this system is installed in series production on other versions of the EMB-500 Phenom 100 equipped with the G3000 avionics suite;***

- ***whereas this system, by providing objective information on the presence of icing conditions, is likely to assist in deciding on the need for full and strict application of the flight in icing conditions procedures;***
- ***whereas a small proportion of Embraer EMB-500 Phenom 100s in service, equipped with the G1000 avionics suite, have this detector;***

the ANAC in coordination with Embraer, assess the improvement to safety that would be obtained by installing an ice detector on all EMB-500 Phenom 100 aircraft and the need to impose this modification on all Phenom 100 aircraft authorised for flight in icing conditions. [Recommendation-FRAN-2023-001].

6.2 Consideration given by operators to operational constraints related to operations in icing conditions

Ultimately it is the crew who are responsible for ensuring that the landing performance of their aircraft is compatible with the weather conditions encountered.

The landing performance of the Embraer EMB-500 Phenom 100 in icing conditions is degraded compared to performance in non-icing conditions. Crews thus frequently encounter situations where the destination airport is accessible with comfortable safety margins in non-icing conditions, but becomes inaccessible in icing conditions. These airports, such as Le Bourget airport, are, however, one of the classic destinations for passenger-customers of this type of on-demand commercial operation.

The crews who have to fly in icing conditions are then faced with difficult choices: either refuse to carry out the flight, or accept a very high probability of diversion, or lastly accept a deviation from procedures and take the risk of landing with a contaminated aircraft.

The operator, when preparing the flight, could take these limitations into consideration when choosing the aircraft in relation to the proposed destinations.

The United Kingdom Civil Aviation Authority (CAA-UK) published the document Safety Notice SN-2022/005 Commercial, Organisational and Client Pressure in Flight Operations in July 2022. It states that commercial, organisational and client pressure is a contributing factor to a number of aircraft incidents. Whether perceived or actual, this pressure can have a detrimental impact on key operational decisions, particularly in marginal conditions.

The subject of choosing an aircraft whose performance corresponds to the scheduled commercial program was also mentioned in a report by the Norwegian safety investigation authority (AIBN) into the serious incident to the ATR 72-212A registered OY-JZC operated by Jet Time on 14 November 2016.

This report mentions that AIBN considers that icing should be a priority item in risk analyses for operators that plan to operate in Norway during the icing season. The AIBN underlines that it is important to take the characteristics of the aircraft type into account. Such analysis should conjointly consider the flown routes, the flight levels, expected icing conditions, and mitigation actions to adverse conditions including icing, with regard to the aircraft type and specific performance.

Consequently, the BEA recommends that:

- ***whereas the large differences between the operational performance in icing and non-icing conditions of certain jet aircraft covered by CS-23 certification rules, such as the one involved in the accident;***
- ***whereas certain operators do not systematically take into account the operational constraints arising from the performance of the aeroplanes they operate in icing conditions;***

EASA, in coordination with the national oversight authorities, in the interest of promoting safety, make operators aware of the need to give better consideration in flight planning to the landing performance of aircraft which have significant differences in performance in icing and non-icing conditions. [Recommendation-FRAN-2023-002].

6.3 Consideration given to operational constraints during certification process

During the certification process, the authorities took into account the specificities of the Embraer EMB-500 Phenom 100 when operating in icing conditions. In particular, they imposed specific training for crews (Training Areas of Special Emphasis (TASE)) with respect to flights in icing conditions, and the relationship between the de-ice system and the Stall and Warning Protection System (SWPS).

The purpose of this training is to improve crew understanding of operations in icing conditions. However, the extent of the landing performance penalties in icing conditions, compared to landing performance in non-icing conditions on this type of aircraft results in crews frequently encountering situations where the destination airport is accessible with comfortable safety margins in non-icing conditions, but becomes inaccessible in icing conditions.

In order to comply with the requested flight schedule or to avoid a diversion, some crews, both during flight planning and while carrying out the flight, may underestimate the risk of encountering icing conditions during the approach and landing.

Although compliance with the Flight Manual procedures is mandatory, the commercial pressures associated with this type of operation may encourage crews not to comply with the proper procedures for the approach and landing in icing conditions, by deactivating the de-ice systems as soon as they visually observe that the leading edges of the wings are free of ice, and they consider that the risk of further contamination before landing is low. The statements gathered during the investigation suggest that this inadequate practice is common in the Phenom 100 pilot community.

These practices, which are a direct result of commercial pressures and the performance of this category of aircraft in icing conditions, lead to an actual operating safety level that is below the theoretical safety level envisaged at the time of certification of these aircraft, and which is based on the assumption, invalidated by in-service experience, that the flight in icing conditions procedures will be strictly complied with.

Consequently, the BEA recommends that EASA consider revising the certification criteria (by applying special conditions, for example) when the differences between an aircraft's performance in icing and non-icing conditions lead to operational constraints that are difficult for crews to manage. [Recommendation-FRAN-2023-003].

Appendix 1: Comments made by the Brazilian safety investigation authority (CENIPA) concerning the BEA's draft final report

After the consultation phase of the draft final report, the CENIPA requested, in accordance with the provisions of Annex 13 to the Convention on International Civil Aviation (ICAO Annex 13), that the following comments be appended to this report.

In the final report, these comments were partially taken into account.

Recommendation #3 relative to consideration given to operational constraints during the certification process

Extract from the draft final report

"During the certification process, the authorities took into account the specificities of the Embraer EMB-500 Phenom 100 when operating in icing conditions. In particular, they imposed specific training for crews (Training Areas of Special Emphasis (TASE)) with respect to flights in icing conditions, and the relationship between the de-ice system and the Stall and Warning Protection System (SWPS).

The purpose of this training is to improve crew understanding of operations in icing conditions. However, the extent of the landing performance penalties in icing conditions, compared to landing performance in non-icing conditions on this type of aircraft results in crews frequently encountering situations where the destination airport is accessible with comfortable safety margins in non-icing conditions, but becomes inaccessible in icing conditions.

In order to comply with the requested flight schedule or to avoid a diversion, some crews, both during flight planning and while carrying out the flight, may underestimate the risk of encountering icing conditions during the approach and landing. In addition, although compliance with Flight Manual procedures is mandatory, these high operational constraints may encourage crews to implement a divergent interpretation of the procedures concerning the approach and landing in icing conditions and deactivate the de-icing systems as soon as they visually observe that the leading edges of the wings are free of ice, and they consider that the risk of further contamination before landing is low. The statements gathered during the investigation suggest that this practice is common among the Phenom 100 pilot community.

These practices, which are a direct result of the characteristics of the aircraft, lead to an actual operating safety level that is much lower than the theoretical safety level envisaged at the time of certification of the aircraft, and which is based on the assumption, invalidated by in-service experience, that the procedures for flight in icing conditions will be strictly complied with."

Consequently, the BEA recommends that EASA consider revising the certification criteria (by applying special conditions, for example) when the differences between an aircraft's performance in icing and non-icing conditions lead to operational constraints that are difficult for crews to manage. [Recommendation FRAN - 20xx-xxx][9]"

Comments

As discussed on the conference call held on Dec 1st, 2022 between Embraer, BEA and CENIPA, proper adherence to operational procedures guarantee the safety of the flight in icing conditions. While

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9 ***[Recommandation FRAN-2023-003]***

Embraer understands the meaning and the intent of the text, its wording (in red) may lead the reader to conclude that the operation of the Phenom 100 in icing conditions imposes a significant reduction in the safety levels and important operational difficulties, which is not true.

Also, the timing for the application of special conditions may not be adequate to achieve BEA's goal addressed in this recommendation. Embraer suggests keeping it in a more generic way so the certification authority can assess the best way to do so.

As the recommendation is not limited to the Phenom 100, Embraer requests the removal of the text highlighted in red above and the adjustment of the text to make the rationale more generic with the intent to avoid incorrect conclusions related to the operation of the Phenom 100 in icing conditions. Embraer requests the BEA to consider using the text below:

"During the certification process, the authorities took into account the specificities of the Embraer EMB-500 Phenom 100 when operating in icing conditions. In particular, they imposed specific training for crews (Training Areas of Special Emphasis (TASE)) with respect to flights in icing conditions, and the relationship between the de-ice system and the Stall and Warning Protection System (SWPS).

The purpose of this training is to improve crew understanding of operations in icing conditions. However, the extent of the landing performance penalties in icing conditions, compared to landing performance in non-icing conditions on this type of aircraft results in crews frequently encountering situations where the destination airport is accessible with comfortable safety margins in non-icing conditions, but becomes inaccessible in icing conditions. In order to comply with the requested flight schedule or to avoid a diversion, some crews, both during flight planning and while carrying out the flight, may underestimate the risk of encountering icing conditions during the approach and landing. In addition, although compliance with Flight Manual procedures is mandatory, the commercial demands associated with the operation may encourage crews to not follow proper procedures concerning the approach and landing in icing conditions by deactivating the de-icing systems as soon as they visually observe that the leading edges of the wings are free of ice, and they consider that the risk of further contamination before landing is low. The statements gathered during the investigation suggest that this inadequate practice is common among the Phenom 100 pilot community.

Consequently, the BEA recommends that EASA consider revising the certification criteria of this aircraft category within the framework of the Agency's rulemaking process, taking into consideration the differences between performance in icing and non-icing conditions. [Recommendation FRAN - 20xx-xxx]"

Appendix 2: Glossary

Abbreviation	English version	French version
AEO	All Engines Operative	
AIBN	Accident Investigation Board Norway	
ANAC	Brazilian Civil Aviation Authority	
AOC	Air Operator's Certificate	
ARFF	Aircraft Rescue and Fire Fighting service	
ATIS	Automatic Terminal Information Service	
ATO	Approved Training Organization	
BAAI	Bureau of Air Accident Investigation (Malta)	
BFU	German safety investigation authority	
CAA-UK	Civil Aviation Authority – United Kingdom	
CENIPA	Brazilian safety investigation authority	
CPL	Commercial Pilot Licence	
CVR	Cockpit Voice Recorder	
CWO	Cold Weather Operations	
DGAC	French Civil Aviation Authority	Direction Générale de l'Aviation Civile
DH	Decision Height	
EASA	European Aviation Safety Agency	
FAA	Federal Aviation Administration	
FDR	Flight Data Recorder	
FL	Flight Level	
ft	Feet	
GAMA	General Aviation Manufacturers Association	
ICAO	International Civil Aviation Organization	
ILS	Instrument Landing System	
LDA	Landing Distance Available	
MFD	MultiFunctional Display	
NBAA	National Business Aviation Association	
NM	Nautical Mile	
NTSB	National Transportation Safety Board	
OEI	One Engine Inoperative	
PF	Pilot Flying	
PFD	Primary Flight Display	

Abbreviation	English version	French version
PM	Pilot Monitoring	
QNH		Calage altimétrique requis pour lire une altitude
SOP	Standard Operating Procedures	
SWPS	Stall Warning and Protection System	
TASE	Training Areas of Special Emphasis	
THR	Threshold	
UTC	Universal Time Coordinated	
VMC	Visual Meteorological Conditions	

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