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SAFETY INVESTIGATION REPORT

Incident to the BOMBARDIER CL600 2C10 (CRJ700) registered F-GRZL on 23 January 2020 at Lyon - Saint-Exupéry (Rhône)

Time	Around 19:10[1]
Operator	HOP!
Type of flight	Passenger commercial air transport
Persons on board	Captain (PF), co-pilot (PM), 3 cabin crew, 71 passengers
Consequences and damage	None
This is a courtesy translation by the BEA of the Final Report on the Safety Investigation published in August 2022. As accurate as the translation may be, the original text in French is the work of reference.	

Deviations from flight path on short final, missed approach, flight over airport buildings, in LVP conditions

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

1 HISTORY OF THE FLIGHT

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

Aware of the LVP[2] operation conditions at Lyon-Saint-Exupéry airport, the crew had planned, on departing from Lille, a CAT IIIa precision approach. It is mandatory for the captain to use the Head-Up Display (HUD) for this type of approach on CRJ700s.

On arrival, it was night. Visibility at Lyon-Saint-Exupéry was less than 300 m with freezing fog.

The aeroplane was stabilized on ILS 35R and configured for landing. At a height of 1,400 ft, the PF disconnected the autopilot (see Figure 1, point ❶) and manually followed the orders given by the HUD guidance cue. The aeroplane remained stabilized. The PM monitored the parameters on the PFD.

[1] Except where otherwise indicated, times in this report are local.

[2] Low Visibility approach Procedure.

The PF indicated in his statement, that at a height of around 500 ft (See Figure 1 point ❷, approximately one minute after disconnecting the autopilot), the aeroplane entered the cloud layer and that from this moment, the lateral guidance cue orders started to diverge to the left. At the same time, the PM stopped monitoring the parameters on the PFD in order to fiddle with the jack socket of his headset as he was having radio reception problems.

At 19:12:10, at a height of 320 ft, the PF made four successive left roll inputs for a total time of around seven seconds, of a greater and greater amplitude[3] (refer to Figure 1, point ❸). The left roll angle of the aeroplane reached 11°.

At 19:12:14, the PF also made a nose-up input on the stick[4]. The aeroplane's pitch attitude was 2° and increasing. The aeroplane's calibrated airspeed was 138 kt[5] and decreasing.

At 19:12:17, the aeroplane reached a minimum height of around 265 ft (refer to Figure 1, point ❹). It was left of the centreline (1/4 dot of deviation from localizer) and above the ILS glide path (1/2 dot of deviation from glide).

Two seconds later, the PF quickly moved the stick to the right which brought the wings horizontal again. The aeroplane was on a flight path diverging by 20° from the runway centreline.

The PM specified in his statement:

- that when his eyes came back to the PFD, he observed that the vertical bar[6] of the PFD flight director was offset to the right and called this out;
- that the PF replied that he was correcting it;
- that he perceived that the lateral deviation was increasing and proposed carrying out a go-around to the PF.[7]

Between 19:12:22 and 19:12:30, the aeroplane continued to deviate to the left of the centreline and was above the glide path. The nose-up input, already started, was slightly increased. The aeroplane's pitch attitude, which was 7°, increased up to 11° before progressively decreasing. The power levers were moved forward several degrees in three successive actions. The aeroplane's calibrated airspeed decreased and reached its minimum at 120 kt, i.e. 15 kt below the reference speed, before increasing again. The lateral deviation reached 2 dots (deviation indicator at limit on PFD).

At 19:12:37, i.e. 23 s after the start of the nose-up input, the power levers were moved forward for the last time, from 37° to 50° (TOGA detent). The PF pressed the TOGA button which activated the "Vertical go around" and "Lateral go around"[8] modes (see Figure 1, point ❺). The aeroplane's pitch attitude stabilized at 8°.

[3] The deflection of the stick went from 9° for around 1.5 s for the first input to 17° for around 2.5 s for the last input.
[4] This nose-up input lasted 33 s.
[5] The selected reference speed for this approach was 135 kt.
[6] Indicates the orders in order to stay aligned on the localizer axis.
[7] The exact time of these calls could not be determined from the elements available for the investigation.
[8] Heading hold.

At 19:12:41, the controller asked the crew if they were going around which the latter confirmed (refer to Figure 1, point ❻). The aeroplane flew over the threshold of the parallel runway (35L) at a height of 420 ft with a magnetic heading of 341°. The controller asked the crew to continue on the heading and to climb to 5,000 ft.

F-GRZL flew, in succession, over the taxiway parallel to the runways, over an aircraft parking area and then in proximity to the control tower at a height of 820 ft (refer to Figure 1, point ❼).

The controller asked the crew if they had lost the centreline. The crew replied that there was a small problem with the instruments and that they had got everything back.

A second CAT IIIa approach was carried out without incident.

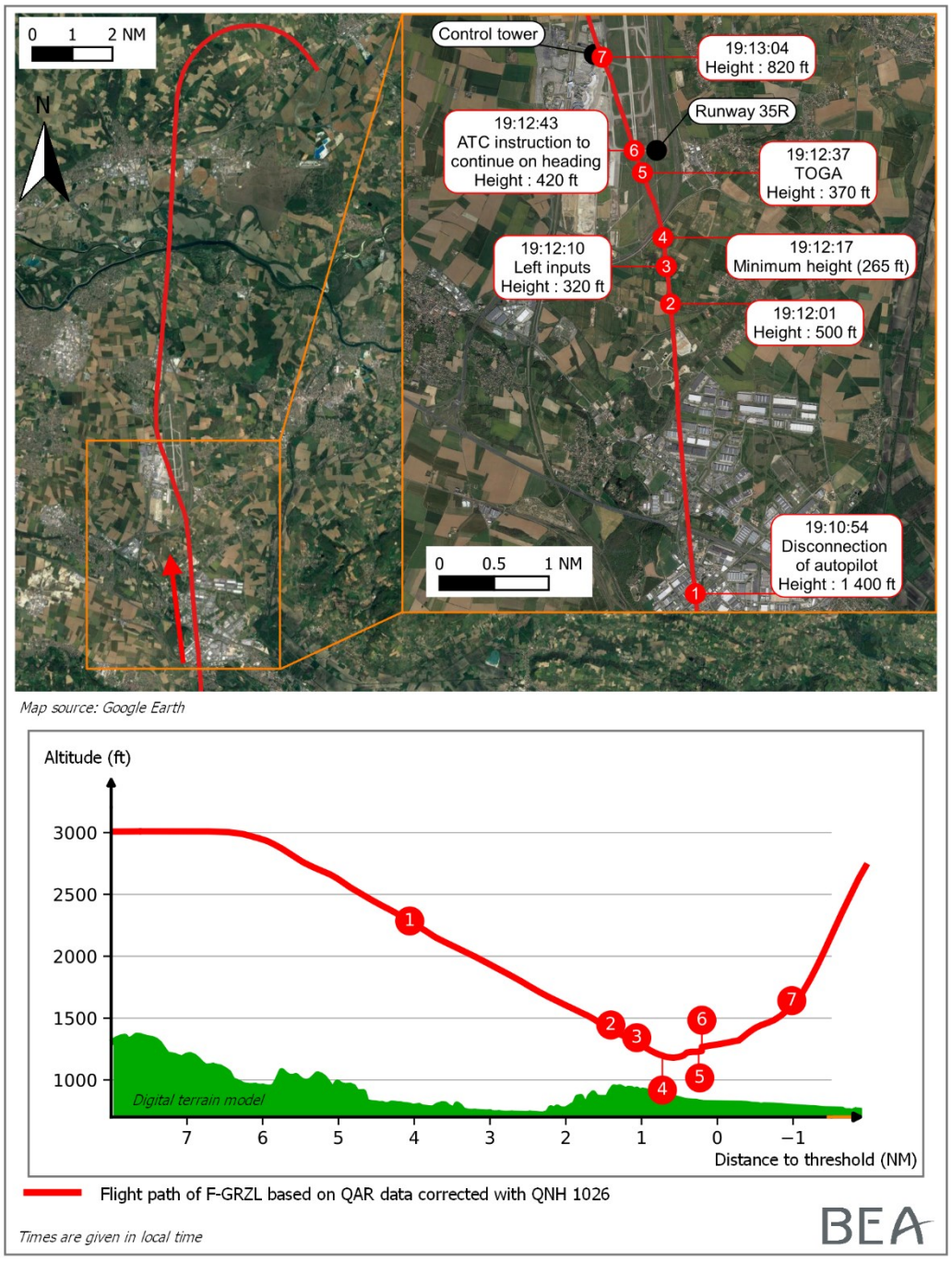

Figure 1: flight path of F-GRZL

2 ADDITIONAL INFORMATION

2.1 Meteorological information

At the time of the occurrence, Lyon-Saint-Exupéry airport was being operated under LVP conditions and it was night. The conditions were the following:

- mean wind: east to south-east, 2 to 5 kt;
- visibility between 140 m and 300 m;
- presence of freezing fog;
- temperature -1°C;
- dew point around -1°C;
- QNH 1026 hPa.

The Runway Visual Ranges (RVR) which the tower controller gave to the crew at 19:09:24 were 325 m to threshold 35R, 300 m to mid-runway and 400 m to opposite runway.

2.2 Aerodrome information

The missed approach path published in the AIP for QFU 35° indicates to climb straight ahead to 5,000 ft and expect a radar vector.

The Lyon-Saint Exupéry ILS 35R has a self-monitoring function activated every ten minutes which can detect an ILS anomaly. There were no alerts from this system in the minutes before and after the occurrence.

The examination of the continuous recordings of the runway localizer signal at the runway threshold found that the signal was not affected by an element on the ground (car, aircraft, etc.) during F-GRZL's approach.

Furthermore, the "Localizer deviation" parameter recorded in the QAR during the occurrence was consistent with the aeroplane's flight path[9]. This point confirms the validity of the localizer signal received by the aeroplane.

2.3 Head-up Guidance System (HGS) information

2.3.1 Description of HUD

F-GRZL is equipped with a Collins Aerospace HGS[10], model 4200, installed under STC.

The HUD system is installed on the left side only. It is certified[11] for carrying out category III approaches in manual mode only. The captain, sat in the left seat, is necessarily the PF for category IIIa approaches[12].

[9] The aeroplane's flight path was reconstructed based on the positions recorded in the QAR (see Figure 1).
[10] Flight Dynamics' Head-up Guidance System (HGS®).
[11] Certification Specification - All Weather Operations CS-AWO 321 (b).
[12] The information displayed for the pilot on the HUD is shown in Figure 4.

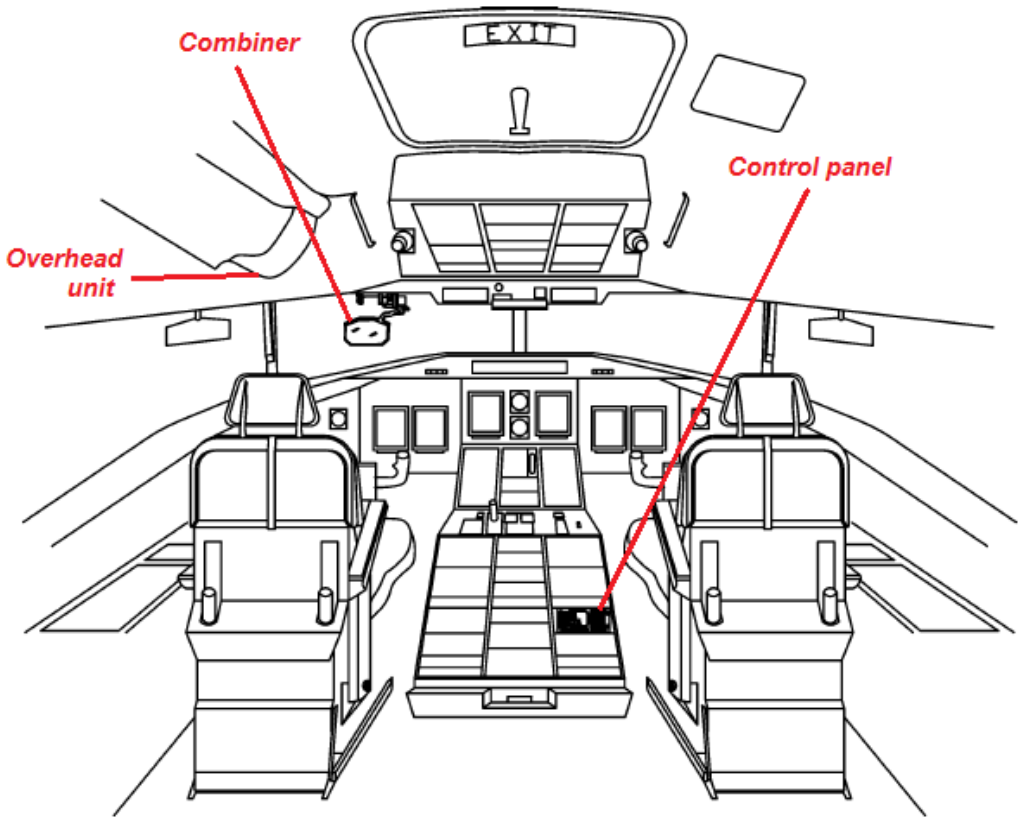

Figure 2: position of various units of HGS in cockpit (source: Collins Aerospace, annotated by the BEA)

2.3.2 HGS operating modes

The HGS has eight operating modes. These modes include the primary mode (PRI), used by default in all the flight phases, and the approach modes, AI, AII and AIII for ILS approaches in manual with respectively, the CAT I, CAT II and CAT III minima. The HGS modes propose a guidance system based on either the FCS[13] flight director or the HGS flight director.

The HUD manufacturer specifies that the HGS:

- Uses the same information sources (aeroplane sensors) as the FCS to calculate the guidance commands during the approach.
- Provides guidance commands which enable the pilot to control the aeroplane with greater accuracy in order to comply with the performance requirements of CAT III approaches carried out in manual.

The control panel is accessible for both pilots and can be used to:

- display the active mode (ACT line) and armed mode (STBY line);
- select a mode;
- enter information required for the approach (G/S angle, length and altitude of RWY).

[13] The FCS (Flight Control System) is integral to the aeroplane (unlike the HGS installed under STC). Only the FCS flight director is displayed on the PFDs.

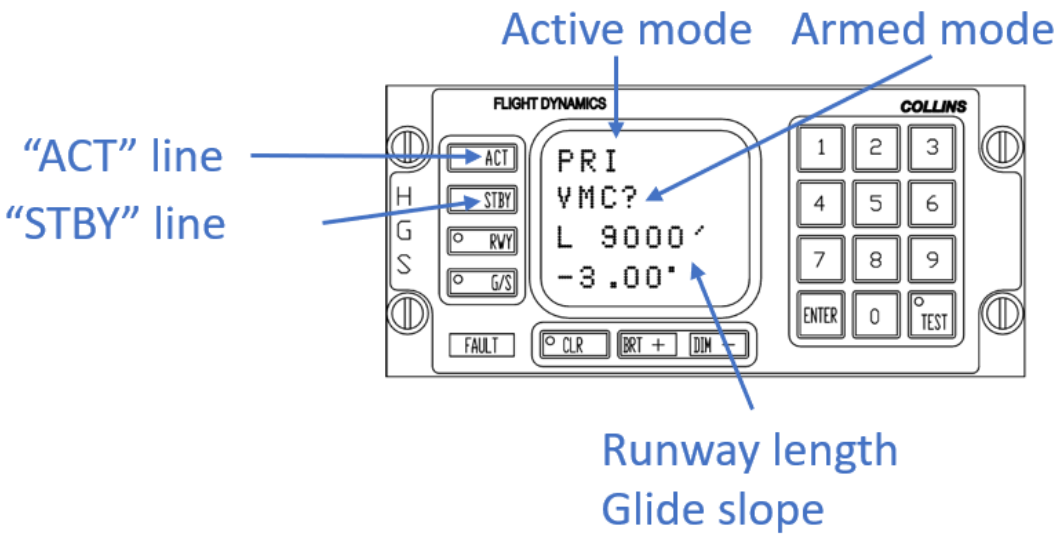

Figure 3: example of control panel display
(source: Collins Aerospace annotated by the BEA)

Pressing the ACT key selects the PRI mode; it is the only mode that can be selected in this way.

The STBY key is used to choose the armed mode.

When all the activation conditions of the armed mode are present, the armed mode becomes the active mode, and the latter is displayed on the ACT line. The PRI mode is then automatically displayed on the STBY line.

The active and armed modes are also displayed on the HUD and on both PFDs.

2.3.3 AIII mode

Several conditions must be met to arm the AIII mode. When the AIII mode is selected on the STBY line before the necessary conditions for it being armed are met, the AIII mode is displayed in yellow on the PFD. AIII is not displayed on the HUD until all the conditions for it being armed are met.

The following conditions are required to arm the AIII mode:

- the runway altitude has been entered on the HUD control panel;
- the glideslope has been entered on the HUD control panel;
- IRS 1 and 2 are in NAV mode;
- all selectors (ATT HDG, AIR DATA, EICAS, DISP CONT, MFD) are in the "NORM" position;
- the HGS does not detect an internal fault;
- the VHF navigation receivers 1 and 2 are set to the same localizer frequency;
- the AGL altitude is above 800 ft;
- the FCS armed modes are localizer (LOC) and glideslope (GS).

Once these conditions are met, AIII is displayed in white on the PFD to indicate it is in armed mode and AIII is displayed as the armed mode on the HUD.

Once the LOC and GS modes are activated, the AIII mode becomes the active mode and is displayed in green on the PFD. In this case, AIII is displayed as the active mode on the HUD.

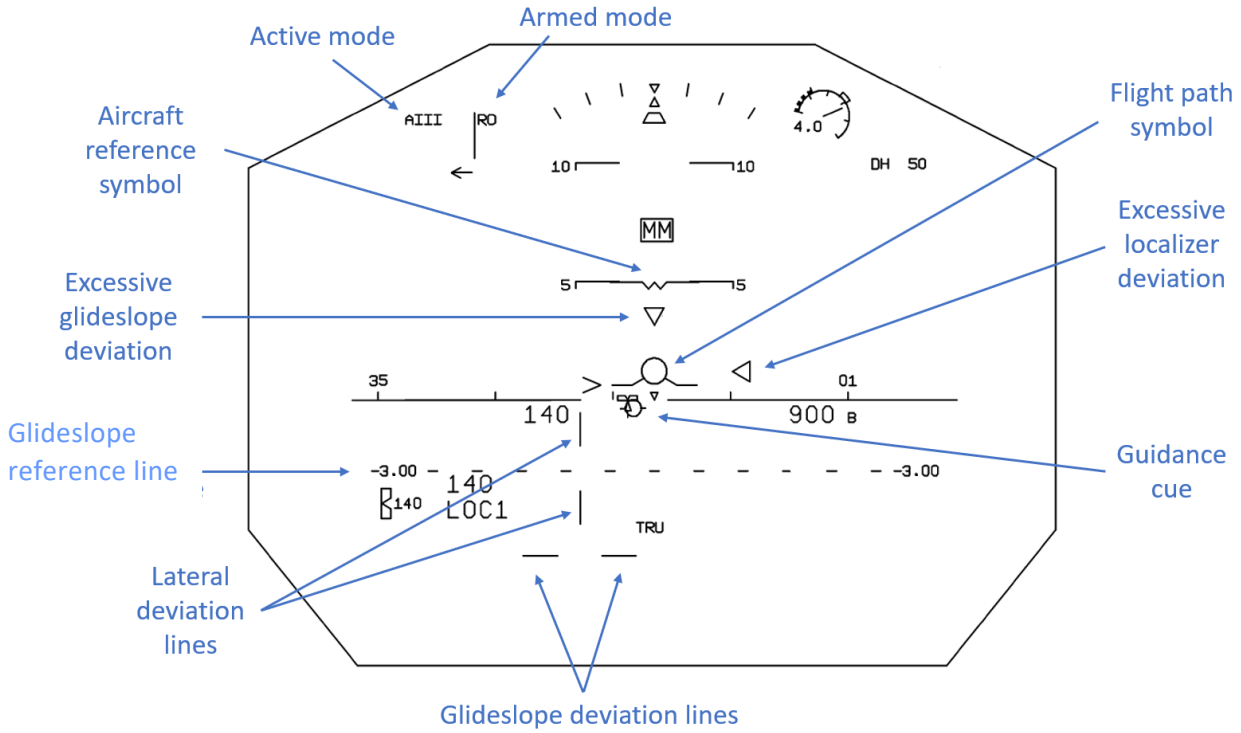

Figure 4: HUD symbology for AIII mode
(source: Collins Aerospace, annotated by the BEA)

In order to follow the flight path calculated by the HGS, the PF manoeuvres to place the Flight path symbol on the Guidance cue (HGS F/D).

A series of dashed lines representing the glide path (selected on the control panel, at -3° in the example in Figure *5*) are displayed on the HUD. Below a height of 300 ft, the runway edge lines appear on the HUD. There are no runway edge lines on the PFD.

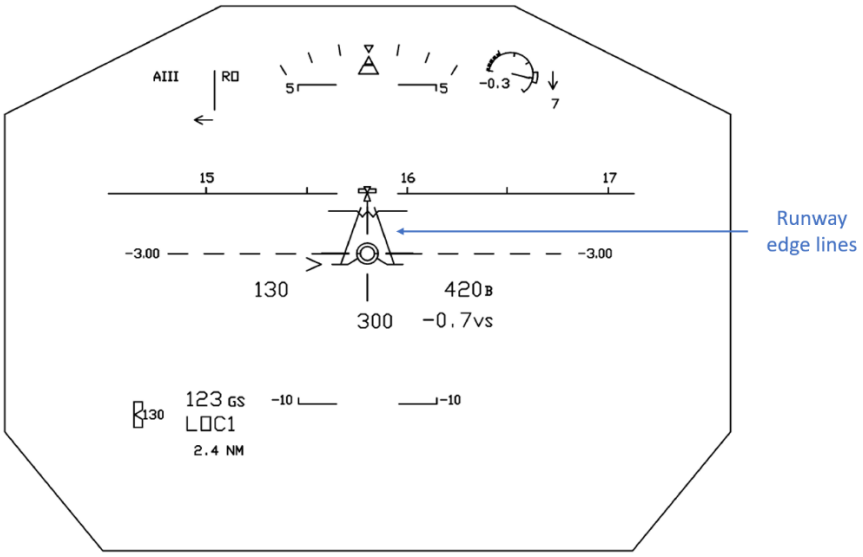

Figure 5: appearance of runway edge lines at 300 ft
(source: Collins Aerospace, annotated by the BEA)

Deviation indications for the ILS approach are shown as lateral and vertical deviation lines. In the event of an excessive lateral deviation, an Excessive localizer deviation indicator appears next to the Flight path symbol in the form of a triangle pointing to the right or left to indicate the direction in which the flight path needs to be corrected (see Figure 4).

The HGS includes an approach monitoring feature that can detect an HGS failure, configuration or data problem, or loss of AIII capability. Below a height of 500 ft, an *Approach warning* may be triggered in the event of an out-of-tolerance approach. In this case, the “APCH WARN” message is displayed on the HUD. The same APCH WARN message is displayed in red on the PFD.

2.3.4 Comparison of AIII mode with other approach modes

The information displayed on the HUD (see Figure 4) is similar for the AIII, AII and AI modes.

The appearance of the runway edge lines at 300 ft is specific to the AIII mode. It is not provided for the AII and AI modes (nor for any other mode).

The "APCH WARN" message only appears in the AIII and AII modes. It is not provided for the AI modes (nor for any other mode).

The conditions for arming all three AIII, AII and AI approach modes are identical. The guidance offered by the HGS is the same regardless of the approach mode used.

2.3.5 Data downloaded from data recorder

The FCS flight director data (flight director bars displayed on the PFD) was not recorded.

Only two parameters related to the HUD are recorded in the QAR data:

- *HUD Fault*;
- *Approach warning*.

The analysis of these parameters showed that no *HUD fault* or *Approach warning* was recorded during the occurrence.

The HUD manufacturer indicated that in AIII mode or AII mode, the *Approach warning* would have been triggered for at least 20 s from 19:12:18. From that moment on, the lateral deviation was greater than 0.3 dots and exceeded the tolerance threshold monitored by the HGS. Therefore, it is very likely that the active mode of the HGS during the approach was neither AIII nor AII.

2.3.6 Operating procedure defined by operator

The operator's operations manual specifies that CAT IIIa approaches must be flown manually using the HUD.

The operations manual specifies that the Radio Altimeter (RA) test must be performed before setting the control panel. If the test is performed when the AIII mode has already been selected, the latter will be deselected. The crew must ensure that the AIII mode has been correctly selected after the RA test.

Before the descent:

- The captain must deploy and adjust the HUD.
- The co-pilot must insert the descent angle (G/S), the runway threshold altitude and the runway length and select the AIII mode on the control panel.
- The captain must check these settings.

On the ILS intercept heading, the captain must call out "APP MODE DISPLAYED, LOC WHITE, GLIDE WHITE, AIII WHITE." The co-pilot must check and respond "CHECKED".

On intercepting the glide path, the captain must call out "GLIDE GREEN, AIII GREEN". The co-pilot must check and respond "CHECKED".

At a height of 1,000 ft, if the stabilization criteria are met, the co-pilot must call out "1,000 FT AIII AP OFF". The captain must then respond "CONTINUING".

When the runway edge lines appear at 300 ft, the captain must call out "SYNTHETIC RUNWAY".

The operator recommends that pilots fly one CAT III approach per month. Pilots are required to fly two CAT III approaches between two proficiency checks.

2.3.7 CAT IIIa go-around

On starting a missed approach, the captain must position the power levers in the TOGA position and press one of the TOGA mode engagement buttons (located on the power lever). Engaging this mode generates a "heading hold" command, meaning that the target heading becomes the current heading.

Engaging the TOGA mode also changes the HGS flight mode from AIII to PRI mode. The pilot uses the Aircraft reference symbol on the HUD to adopt the correct pitch attitude. Once the go-around has been engaged, the PF must return to head down and use the PFD to continue the procedure.

2.4 Crew information

2.4.1 Captain

The 55-year-old captain held an ATPL (A) licence issued in 2004 and a CL65 (CRJ700) type rating. His recent experience on the CRJ700 (in flight hours the morning of the day of the incident) is summarized in the table below:

Previous 24 hours	Previous week	Previous month	Previous year
3 h 30 min	13 h 51 min	42 h 21 min	486 h

He had been captain since 26 March 2019.

He indicated that he extended the HUD on the long downwind leg. From 1,000 ft, he specified that he remained concentrated on the HUD and the two circles[14]. On entering the cloud layer at a height of 500 ft, the HUD Guidance cue slowly moved to the left. He indicated that he followed the Guidance cue. He specified that he found it strange and asked himself why the Guidance cue had moved to the left.

The co-pilot then indicated that he was going to the left. He replied that he knew and that he had things under control. After a few seconds, the captain observed that the approach was not nominal, which the co-pilot confirmed. The captain initiated a go-around. He said that he started the go-around using the HUD to pitch the nose up to obtain the climb attitude and then continued it using the PFD. The heading was followed manually and he did not try to return to the runway axis.

The captain did not see the *Approach warning* displayed on the HUD during the occurrence. He could not remember seeing the runway edge lines coming up on the HUD. He thought that he must have started the go-around just before they appeared.

He specified that the second approach carried out with the HUD took place in identical meteorological conditions, without further incident.

The pilot indicated that before the incident, he had never carried out an ILS CAT IIIa approach using the HUD in real LVP conditions. This type of approach is carried out every six months in the simulator.

2.4.2 Co-pilot

The 43-year-old co-pilot held an ATPL (A) licence issued in 2010 and a CL65 type rating. His recent experience on the CRJ700 (in flight hours the morning of the day of the incident) is summarized in the table below:

Previous 24 hours	Previous week	Previous month	Previous year
0 h	16 h 43 min	44 h 22 min	496 h 34 min

During the CAT IIIa approaches that he had carried out previously, he had always observed that the bars were centred and, in particular, had never observed a path deviation.

He indicated that he had problems with his headset on flying through 1,000 ft. His eyes left the PFD at an estimated height of 500 ft when he fiddled with the jack socket of his headset. When he looked at the PFD again, at a height which he thought was around 400 ft, he perceived a small deviation. He indicated that he had never seen this. He initially thought that the ILS data displayed was erroneous. He saw that the PFD flight director bar was moving to the right. He then turned to the captain and indicated that the latter had seen this deviation and told him that he was correcting it. He thought that the deviation was going to be corrected and that the plane was going to move right, but the deviation increased. When the co-pilot observed that the plane was approaching a height of 300 ft, he suggested a go-around to the captain. The latter replied that he was right. He specified that the go-around was quite smooth. He observed that they did not fly straight ahead. At the end of the go-around, he noted that the PFD bar was flashing at the right limit.

[14] Flight path symbol and Guidance cue.

The co-pilot specified that there had been no *Approach warning,* or “Synthetic runway” call-out by the captain.

2.5 Feedback and studies concerning use of HUD

2.5.1 In-service malfunctions

No HUD malfunction similar to that described by the captain of F-GRZL during the incident flight had been reported to the HUD manufacturer between the period March 2019 to February 2020. This period covers around 220,000 HUD operating hours (including 26,000 hours on the CRJ700).

2.5.2 Similar events

The examination of the European Central Repository identified in the period 2004-2020, around 400 incident reports in connection with the HUD, notified by operators. Malfunctions linked to the validity of the information displayed on the HUD are few in number on CRJ type aircraft. The occurrences[15] of this type reported by the crews include:

- A deviation on short final, of the Flight path symbol during a CAT III approach (in 2006); the PM called out a LOC deviation and the *Approach warning* was activated, leading to a go-around.
- Off-set displays of the runway edge lines (in 2009 and 2016).
- A drift to the right of the centreline during a CAT III approach (in 2011) even though the Flight path symbol and Guidance cue were aligned (it is possible that this drift can be explained by the use of a true heading reference rather than a magnetic heading).
- The display of a Left Excessive Localizer Deviation symbol at 900 ft during a CAT III approach (in 2015) even though the Guidance cue remained in the centre of the Flight path symbol (the cause of this problem was not identified).

2.5.3 Cognitive impact of using HUD

Several scientific articles have specifically dealt with the cognitive impact of the use of the HUD in piloting activities. Crawford & Neal (2006) summarized these in "*A Review of the Perceptual and Cognitive Issues Associated With the Use of Head-Up Displays in Commercial Aviation*". The authors detailed several possible problems with using the HUD, some of which are presented below.

Attention related problems

Studies suggest that pilots do not pay attention to the HUD symbols and the outside environment at the same time, but alternate their attention between the HUD and the external scene. It is suggested that the HUD may act as an attention trap and that the pilot is more able to focus on the symbols than on the outside world.

Problems with detecting anticipated and unanticipated events

Studies show that the HUD can cause difficulties in detecting unexpected events in the outside environment (such as a runway incursion). The focus on the HUD symbology can be excessive and lead to inattentional blindness. This is called cognitive tunnelling.

Workload related problems

A high workload can exacerbate the phenomenon of "cognitive tunnelling" without pilots being aware of it. Pilots think they see "everything" because all the information is presented to them in

[15] These occurrences were not the subject of a safety investigation by a safety investigation authority.

their visual field, when in reality they cannot pay attention to everything and do not process all the information.

In the study Symbologie des collimateurs tête haute (HUD)[16] by the ONERA System Control and Flight Dynamics Department carried out in 2002, a Brit'Air captain, who was also an instructor and former pilot on the Mirage III and 2000, was questioned about the possible traps linked to the use of the HUD. He reported the following elements in particular:

- excessive precision in following the flight director, which may be tiring;
- an over-focalisation on the HUD to the detriment of cross checks or a more general situational awareness.

The study also points out the possible transition difficulties during a go-around. This manoeuvre requires a change in flight management, from managing the flight path to managing the pitch attitude. The study points out the lack of indications to encourage the pilot to use the pitch reference instead of the flight path reference.

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

On the day of the incident, LVP procedures were in force at Lyon-Saint-Exupéry airport due to the presence of freezing fog down to the ground. In this context, the crew of F-GRZL performed an ILS CAT IIIa approach for runway 35R. It is mandatory for the captain to use the HUD for this type of approach in CRJ700s.

Standard procedures on the CRJ700 require the crew to set the HGS parameters before the descent. It is specified that the AIII mode must be set to standby when carrying out a manual ILS CAT IIIa approach. The investigation showed that a different mode was very probably active during the approach, without it being possible to determine the precise cause for this. The use of a mode other than AIII did not necessarily degrade the quality of the guidance, but deprived the crew of important information for conducting a CAT IIIa approach (in particular the *Approach warning* in case of deviation and the display of the runway edge lines).

At a height of about 500 ft, as the aeroplane, stabilized on ILS 35R, entered the cloud layer, the captain noted that the HGS flight director was indicating lateral guidance orders to the left. The investigation could not determine why the flight director would have indicated "make a left turn" when the aeroplane was stable on the approach path and the localizer signal received by the aircraft was correct.

The captain entered a left turn, probably without identifying the LOC deviation. The aeroplane then deviated from the runway centreline. The captain started making a nose-up input that lasted about 30 s, resulting in the aeroplane passing above the glide path.

[16] Symbology of Head Up Displays (available in French)

The co-pilot was busy resolving a radio reception problem on his headset. When he resumed his monitoring of the PFD parameters, he noticed deviations and called them out to the captain. The captain told the co-pilot that he was correcting them.

The wings were levelled off but the aeroplane continued to diverge by 20° from the runway centreline. Observing on the PFD that the deviations were increasing, the co-pilot suggested to the captain that he go around.

The slow and progressive manner of flying the missed approach, which did not follow the conventional dynamic of a go-around, contributed to the aeroplane losing height and ending up at a speed 15 kt below the reference speed. The slow and progressive manner of flying the missed approach can be explained by:

- The crew's hesitation for a time on short final, linked to the captain focusing his attention on the HUD symbols to align the Flight path symbol on the Guidance cue, and to the co-pilot's late resumption of the monitoring of the approach, and
- The absence of the *Approach warning* message due to the use of an HGS mode which was not the AIII mode, although the conditions for its activation were met. The crews are used to starting a go-around as soon as this message appears.

The aircraft then flew over the airfield buildings at an unusually low altitude, but high enough to avoid any risk of collision with obstacles.

Contributing factors

The following factors may have contributed to the approach being carried out in a mode other than AIII:

- The crew's improper use of the control panel which could have caused:
  - either an erroneous selection of the control mode on the control panel at the start of the descent,
  - or a de-selection of the AIII mode linked to the performance of the RA test, having previously set the AIII mode to standby.
- The conditions for arming the AIII mode were not all present which might have resulted in this mode, although correctly selected, not being armed.
- Improper check of the approach parameters on the PFDs and the HUD, notably during the call-outs specified in the standard procedures, which meant that the crew did not detect that the AIII mode was not the active mode.

The following factors may have contributed to the deviations from the flight path and the destabilization of the approach:

- The captain's repeated corrections of an increasing amplitude while following the flight path indicated by the HGS flight director, in a context where he was flying his first ILS CAT IIIa approach using the HUD without flight visibility.
- The captain focusing his attention on the HUD symbols in order to align the Flight path symbol with the Guidance cue and not following the LOC deviation indication.
- The co-pilot's partial monitoring of the flight path on short final, his attention having been diverted to correct a radio reception problem concerning his headset.

Although in-service malfunctions of this type are very rare, it was not possible to exclude the possibility of an erratic performance of the HGS flight director during the approach.

APPENDIX 1: GLOSSARY

Abbreviation	English version
AGL	Above Ground Level
AIP	Aeronautical Information Publication
ATPL	Airline Transport Pilot Licence
CVR	Cockpit Voice Recorder
FCS	Flight Control System
HGS	Head-up Guidance System
HUD	Head-Up Display
ILS	Instrument Landing System
IRS	Inertial Reference System
LVP	Low Visibility Procedure
PF	Pilot Flying
PFD	Primary Flight Display
PM	Pilot Monitoring
QFU	Magnetic orientation of runway
QNH	Altimeter sub-scale setting to obtain elevation when on ground
RA	Radio-Altimeter
RVR	Runway Visual Range
STC	Supplemental Type Certificate
TOGA	Take-Off Go-Around
UTC	Universal Time Coordinated