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INVESTIGATION REPORT

Accident to the CIRRUS - SR22 registered N918SE
on 28 September 2020
at La Chevillotte (Doubs)

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

Time	Around 10:20[1]
Operator	Société Civile de Moyens M.C.S.
Type of flight	Cross country
Persons on board	Pilot and two passengers
Consequences and damage	Pilot and passengers fatally injured, aeroplane destroyed

This is a courtesy translation by the BEA of the Final Report on the Safety Investigation published in March 2022. As accurate as the translation may be, the original text in French is the work of reference.

Non-stabilized approach, loss of control during missed approach, collision with ground then fire

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

1 - HISTORY OF THE FLIGHT

Note: The following information is principally based on statements, radio communications and radar data.

The pilot, accompanied by two passengers, took off for a flight under Instrument Flight Rules (IFR) from Caen Carpiquet airport Calvados) at around 08:10 bound for Besançon - La Vèze aerodrome (Doubs). The passenger in the front right seat was a friend of the pilot. The passenger in the rear seat was expected at Besançon for a business meeting. The flight path indicated by the radar data suggests that the majority of the flight was carried out with the AutoPilot (AP) engaged. At around 08:30, the controller accepted the pilot's request to climb in order to have a more comfortable flight, from FL 110 (flight level in flight plan) to FL 130 and then FL 150.

At approximately 09:30, the pilot informed the controller that he wanted to carry out a Required Navigation Performance (RNP) approach, passing via the Initial Approach Fix (IAF) QM403 (refer to paragraph 3.2). The pilot specified that he asked this in order to have an easy approach. On approaching the Dijon DJL VOR at around 09:45, the pilot was cleared to start the descent to waypoint LISMO situated at around 25 NM south-west of Besançon-La Vèze aerodrome to avoid active military zones.

At about 09:50, the controller replied to the pilot's request for information that runway 23 was in use at the destination aerodrome, that visibility was 4,000 m and the ceiling was 400 ft.

At around 10:00, at 9 NM from LISMO, the controller asked the pilot to turn left direct QM403, to descend to FL 080 and to circumvent a zone on the flight path. The latter replied that he did not know the zone and was above the cloud layer. The controller asked him to continue initially to IAF QM402.

At 12 NM from QM403 (refer to Figure 1, point ❶), the controller asked the pilot to head towards QM403 and to descend as he wishes. The vertical descent speed was 500 ft/min, the ground speed was around 180 kt. The aeroplane passed abeam QM403 at 6,500 ft (refer to Figure 1, point ❷).

At around 2 NM from QM402 (refer to Figure 1, point ❸), the rate of descent increased with a vertical speed of the order of 1,250 ft/min, the ground speed decreased to 130 kt. The aeroplane passed QM402 at 4,300 ft. A few seconds later, the vertical descent speed decreased to 500 ft/min (refer to Figure 1, point ❹). The pilot then contacted the aerodrome's AFIS officer to give him his position. Around 30 seconds later, the AFIS officer told the pilot that he had switched on the lighting to maximum brightness (Precision Approach Path Indicator (PAPI) and runway). The pilot replied that he was going to finish with the "LVP"[2].

[2] The pilot was probably referring to the RNP Z RWY23 (LPV only) procedure – refer to para 3.2.

At 10:16:03, at 0.6 NM from QM406 (corresponding to the final descent fix), the aeroplane levelled off at 3,500 ft (refer to Figure 1, point ❺). Fifteen seconds later, the aeroplane exceeded QM406. The final descent was started 30 s later, with a vertical descent speed of 1,400 ft/min. The aeroplane was then around 1 NM beyond QM406 (refer to Figure 1, point ❻). The ground speed decreased to 95 kt. At 5.5 NM from the threshold of runway 23 (refer to Figure 1, point ❼), the aeroplane levelled off at approximately 2,800 ft; at this point it was under the glideslope. The pilot informed the AFIS officer that they had passed QM406 and asked him for the ceiling[3]. The AFIS officer replied that it was around 500 ft.

At approximately 10:17:25, at 5 NM from the runway threshold, the aeroplane intercepted the glideslope (refer to Figure 1, point ❽). The aircraft resumed the descent with a vertical speed in the order of 2,000 ft/min.

At 10:17:42, at 2,100 ft (height of 800 ft), the aeroplane was at 4.5 NM from the runway threshold, under the glideslope. The plane started climbing with a vertical speed in the order of 2,000 ft/min (refer to Figure 1, point ❾), and the altitude increased by 800 ft. This was followed by a descent in which the altitude decreased by 700 ft. At 10:18:15, the aeroplane climbed again and the altitude increased by 1,100 ft. The witnesses indicated that they heard the aeroplane increase power, the noise from the engine becoming louder and louder.

At 10:18:35, at an altitude of 3,330 ft (approximate height of 2,000 ft) and at 3 NM from the runway threshold (refer to Figure 1, point ❿), the aeroplane suddenly started losing altitude. The witnesses saw the aeroplane come out of the cloud layer, in a spin, and then disappear behind trees five seconds later. They saw the activation of the parachute rocket but the parachute did not have time to open.

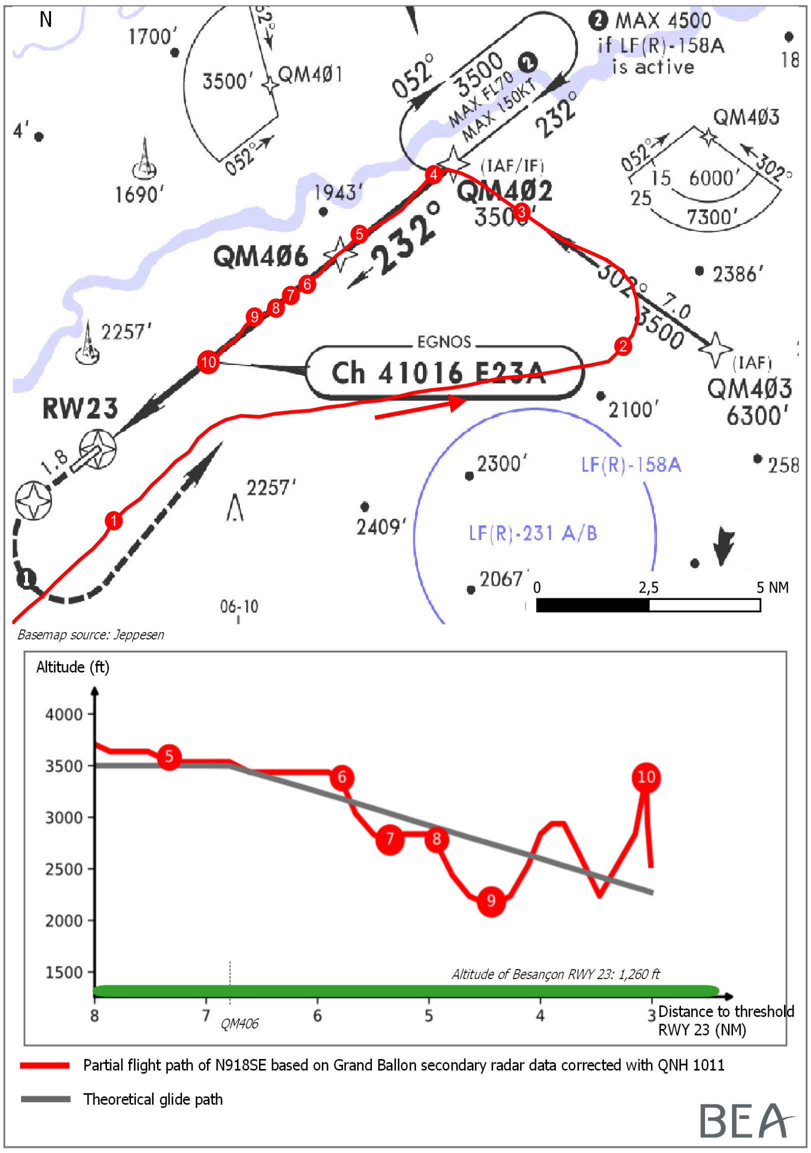

Figure 1: Final path of N918SE

[3] Last message sent by the pilot.

2 - AIRCRAFT INFORMATION

2.1 Main characteristics

The aeroplane belonged to the associates of a company created to operate this aircraft. The associates-owners of the aeroplane included a few pilots, users of the aeroplane and friends along with the company which employed the passenger in the rear seat and which was managed by her father. The pilot was one of the associates. He regularly carried out flights with the passenger or her father in the scope of business appointments. He was not paid.

N918SE, a second generation Cirrus SR22 was equipped notably with:

- A Continental IO-550 N engine providing 310 hp.
- A CAPS[4]. The demonstrated heights for using this system are:
  - 400 ft in stabilized straight flight;
  - 920 ft in a spin.
- A Precise Flight oxygen supply system. The maintenance workshop which serviced this aeroplane indicated that the oxygen supply system was inoperative. This system was not maintained, on the owners' request according to their privileges under the FAA rules and an "*INOP*" label was affixed to the system. The oxygen bottle was empty.

[4] Cirrus Airframe Parachute System.

The aeroplane was equipped with a Primary Flight Display (PFD) and a MultiFunction Display (MFD), an AP and two GNSS computers, one of which had the functionality for flying RNP approaches with vertical guidance (LPV) since November 2019 (refer to paragraphs 2.2 and 3.2).

The main approach and stall speeds of the aeroplane are:

- Approach speed, flaps retracted, Indicated AirSpeed (IAS) = 90 - 95 kt.
- Approach speed, flaps 50% (recommended by Cirrus), IAS = 85 - 90 kt (VFE with flaps 50% = 119 kt).
- Approach speed, flaps 100%, IAS = 80 - 85 kt.
- Stall speed in clean configuration = 70 kt.
- Stall speed, flaps 50% = 67 kt.

2.2 Flying a LPV approach with AP engaged

This type of approach can be flown manually or with the autopilot. The Flight Director (FD), when it is engaged, displays a flight profile corresponding to the modes selected and engaged.

Source: Meggitt

Figure 2: AP selector and screen

Carrying out an LPV approach with the AP engaged requires:

- The selection of the navigation source on the Nav GPS. The approach must have been loaded on the navigation system (GNSS computer) and be active.
- The AP stays in ***GPSS*** mode until interception of the final approach segment.

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[5] Vertical Deviation Indicator.

[6] Horizontal Deviation Indicator.

- When the VDI[5] is displayed and the HDI[6] is " GPS APPR", that the **APR** mode is activated on the PA selector. If the **ALT** mode is selected and the aeroplane's deviation is less than 50% on the HDI, the **GS** mode and the glideslope acquisition capability will be armed.

On approaching the glideslope, the **GS** mode becomes active to follow the descent path generated by the GNSS. This behaviour is similar to the GS function of an ILS approach. The AP then follows the lateral and vertical guidance provided by the GNSS computer in the same way as it would follow an ILS.

When the approach is carried out with the AP engaged, the pilot must monitor that the flight path being followed is actually the one wanted. In all cases, the pilot must also monitor the continuing integrity of the GNSS signal.

Figure 3: PFD during an LPV approach
(source: Avidyne)

2.3 Examinations of site and wreckage

The wreckage was located in a group of trees at around 3 NM north-east of the threshold of runway 23 of Besançon La Vèze aerodrome, on the axis of the runway. The aeroplane was entirely burnt by the post-impact fire. It was complete, and oriented on a heading of 300°. The accident left no chance of survival for the occupants.

Remains of the parachute were visible in the vegetation around the wreckage. The parachute ejection rocket was located at around 80 m from the wreckage. The parachute housing door was found in the forest between the rocket and the main wreckage, around 60 m from the wreckage.

On the wreckage, it was possible to completely check the continuity of the flight control linkages on the three axes. All of the cables were still connected to the various parts (movable surfaces or control rods) except in the tail unit of the aeroplane where the fasteners had melted. No static failure was observed. It was not possible to determine the continuity of the flap controls and their position due to the damage to the aeroplane.

On the engine, no rupture of the crankcase was observed. The end of the flight path taken by the plane was consistent with an engine providing power before the collision with the ground.

The aeroplane's Emergency Locator Transmitter (ELT) was activated on collision with the ground. The Search And Rescue (SAR) operations were initiated by the Aviation Rescue Coordination Centre (ARCC Lyon). As the aeroplane's ELT had been installed in the USA and the owners had not recorded this equipment in the American ELT register, no additional information (in particular, name of owners and emergency contact information) was available for the teams in charge of the SAR operations. The

SAR operations were nevertheless facilitated by the information provided by witnesses close to the accident site.

3 - OPERATIONAL INFORMATION

3.1 Meteorological information

3.1.1 In flight

During the flight and on the flight path, the cloud cover was broken to overcast, the cloud base was between 1,000 ft and 4,000 ft and the cloud top between 12,000 ft and more than 15,000 ft. The freezing level was situated at around FL 100 with locally, moderate icing above this altitude.

In the area surrounding Besançon-La Vèze aerodrome, it was forecast that rain and drizzle with reduced visibility of between 1,500 and 8,000 m along with mist and fog may be locally present. According to the Météo-France satellite images, the top of the cloud layer in the vicinity of the aerodrome decreased to 5,000 ft.

Besançon-La Vèze aerodrome does not have installations providing METARs and TAFs. The 07:00 TAF at Dole Tavaux aerodrome (altitude 645 ft), the alternate aerodrome indicated in the filed flight plan, situated at around 30 NM from Besançon La Vèze aerodrome (altitude 1,270 ft) indicated wind from 220°, 5 kt, visibility greater than 10 km, overcast at a height of 1,200 ft, temporarily between 8:00 and 11:00, visibility reduced to 3,000 m with rain and drizzle, overcast at a height of 300 ft, improvement between 11:00 and 13:00, becoming overcast at a height of 2,000 ft.

Before the departure, the pilot of N918SE had indicated to another pilot that the weather was not good in the vicinity of the destination. A pilot from the company indicated that the pilot used a tablet with in particular, the ADLConnect application to obtain meteorological data in flight.

3.1.2 At the accident site

The French met office, Météo-France estimated that the conditions at the time of the accident were:

- Overcast at a height of 650/1,000 ft, overcast at a height of 2,000 ft, top of cloud layer at around 5,250 ft.
- Mist possible.
- Visibility greater than 10 km but possibly reduced by mist to 2,000 to 5,000 m.
- Mean south-westerly wind of 3 to 5 kt at surface and southerly wind of 10 to 15 kt at around 5,000 ft.
- Temperature 9°C and dew point 8.5°C.

The AFIS officer estimated that at the time of the accident, visibility was 4,000 m and the ceiling around 500 ft on the aerodrome.

3.2 Besançon-La Vèze aerodrome

Besançon - La Vèze aerodrome is situated at 5.5 km south-east of Besançon. An AFIS officer provides a flight information and alert service at the aerodrome. The aerodrome's reference altitude is 1,270 ft.

The aerodrome has a paved runway 05-23 measuring 1,400 m long. A PAPI on runway 23 indicates a slope of 4°. Several instrument approach procedures are possible for runway

23, notably the RNP Z RWY 23 - LPV only procedure (Performance Based Navigation (PBN)), flown by the pilot. In this procedure, the final descent starts at QM406, situated at 6.8 NM from the runway threshold, with a slope of 3°. The minima are Decision Height (DH) of 420 ft and Runway Visual Range (RVR) of 1,500 m.

Three areas with a minimum sector altitude and thus three IAFs are indicated on the RNP Z RWY 23 approach chart:

- QM401 for north-west arrivals with a minimum altitude of 3,500 ft.
- QM402 for north-east arrivals with a minimum altitude of 3,500 and 6,300 ft according to the arrival sector.
- QM403 for south arrivals with a minimum altitude of 7,300 then 6,000 ft.

PBN is a concept developed by the International Civil Aviation Organization (ICAO) which specifies the operational performance required for an airspace, route or approach procedure. Two types of navigation specification are associated with it: Required Navigation Performance (RNP) and area navigation (RNAV).

The approach procedure used by the pilot for Besançon-La Vèze aerodrome was an RNP-LPV procedure, based solely on the use of the GNSS both for the horizontal and vertical guidance. GNSS guidance is supplemented by a SBAS[7] which, using a dedicated satellite constellation and ground stations enhances the accuracy of the GNSS signal by checking its integrity and correcting the errors.

[7] Satellite Based Augmentation System: WAAS in the USA and EGNOS in Europe.

The day of the accident, the performance of the GNSS constellation permitted the RNP Z RWY23 (LPV only) approach to be carried out.

3.3 Licences and ratings

3.3.1 Instrument rating and PBN training

To obtain the FAA[8] Instrument Rating (IR)[9], pilots must have followed a training course terminating with a flight check. In order to be able to exercise the privilege of his IR, the pilot must be able to prove recent experience, notably a minimum of six actual or simulated Instrument Meteorological Condition (IMC) approaches (clouds on the final approach segment, transition to VFR on this segment) in an aircraft or in a simulator, carried out in the six months preceding the month of the flight. In the absence of recent experience, the pilot must pass a proficiency check.

[8] Federal Aviation Administration.

[9] To fly under IFR.

Due to the COVID-19 pandemic, the FAA published a temporary regulation (SFAR[10]) effective from 25 June 2020 to 31 March 2021. This document specifies that pilots have a period of nine months, instead of six, to establish recency for flights carried out between July and September 2020 in order to keep their IR.

[10] Special Federal Aviation Regulation.

To obtain the EASA[11] IR, pilots must have followed a training course terminating with a flight check. To fly in accordance with the PBN concept, pilots must have followed a specific training course supplemented by a flight check. This training contains a theoretical part and a practical part in flight or in a simulator with at least four RNP approaches and notably a missed approach following a simulated degraded situation. It is then indicated on the pilot's licence that the holder holds the IR-PBN qualification. To keep this qualification current, the pilot must carry out a flight check each year (including the PBN procedures). Since 25 April 2021, a pilot can no longer revalidate or renew his/her IR without the PBN privilege. In France, the civil aviation safety directorate (DSAC) published a guide regarding PBN training and operations. A similar document was also published by the FAA.

[11] European Aviation Safety Agency.

The FAA IR can be converted into an EASA IR after following theoretical and practical training terminating in a flight check.

From 20 June 2022, in the scope of the implementation of the Bilateral Aviation Safety Agreement between the European Union and the USA (EU-US BASA), private pilots holding an American licence and residing in Europe shall hold a European licence and its associated qualifications in accordance with regulation (EU) 2011/12 *"Aircrews"*[12], even when flying in an aeroplane registered in the USA. In this respect, pilots must have met the requirements of the theoretical and practical training as well as the flight check.

(12) Commission regulation of 3 November 2011 laying down technical requirements and administrative procedures related to civil aviation aircrew.

3.3.2 Pilot information

The 73-year-old pilot held a French and then European (EASA) private pilot licence PPL(A) issued in 1984 in France. He held the Single Engine Piston (SEP) rating. He also held an IR issued by the FAA in 2009 after following a training course in France.

According to the pilot's log book, the pilot had totalled around 3,600 flight hours including a large part under IFR. He had flown nearly exclusively on N918SE for the last few years. The investigation was not able to precisely determine the number of flight hours under IFR flown by the pilot as when he carried out such a flight, only a fraction was recorded in his log book, in the column for *Operational condition time (IFR)*. For example, for a flight under IFR for a total time of 60 min, the pilot indicated an IFR time of 5 minutes whatever the weather conditions. The pilot had thus logged 365 IFR hours but he had probably totalled more than 1,500 h according to witnesses.

In the last three years, the pilot had not flown to Besançon-La Vèze aerodrome.

Since November 2019 and according to his log book, the pilot had carried out seven RNP approaches, carried out in good weather conditions, and nine ILS approaches. In the months following the lockdown due to the COVID-19 pandemic (between March and May 2020), he had carried out seven approaches (two ILS, four RNP and a *visual approach*), three of which were in IMC according to the METAR data at the flight times and dates indicated. Witnesses, pilot friends, indicated that he practised LPV approaches and his log book specified one of these[13].

(13) He had recorded "*LVP*" for a flight carried out at the beginning of September 2020.

During his IFR training in 2009, the pilot had not been trained to fly LPV approaches. Mid 2019, shortly before the avionics were upgraded on the N918SE (refer to paragraph 2.1), the pilot had obtained information from instructors and training organizations about PBN training and obtaining the EASA IR at the same time, but had not followed this up. In 2019, he had nevertheless followed a theoretical course of a few hours, part of this course concerned PBN. According to his log book, in the last three years he had not carried out any instruction flights except for those to revalidate the SEP rating associated with his PPL or in the scope of Biannual Flight Reviews (BFR[14]) for the FAA licence (VFR flights). He had also had a few simulator instruction hours in 2019; he had solely worked on non-RNP approaches. The pilot does not seem to have had any additional practical training regarding PBN operations. The investigation was not able to determine the proficiency really acquired by the pilot to fly LPV approaches.

(14) Bi-annual Flight Review.

3.3.3 Passenger in front seat

The 72-year-old passenger in the front right seat held a PPL(A) issued in 2000 in France. He did not hold an IR rating. He also held a fixed wing microlight pilot certificate. He had logged more than 1,000 flight hours according to witnesses.

He was a doctor, qualified in hyperbaric medicine and the pilot's friend. He was in the habit of accompanying the pilot on flights.

3.3.4 Witness statements

Several witnesses, notably one of the pilots of the company, pilot friends and instructors who had flown with the pilot during the last few years indicated that the pilot was at ease with the aircraft's automatic systems and avionics. In their opinion he had good handling skills. One of them indicated that the pilot had not followed the PBN training (EASA rules). The pilot from the company added that the pilot had already encountered similar meteorological conditions. Lastly, he mentioned that during the flights he had carried out with the pilot, he had referred to the procedure for using the parachute and the various scenarios leading to its use.

The person who the passenger in the rear seat was set to meet in Besançon indicated that this meeting had already been postponed, notably due to a flat tyre on the plane. Nevertheless, he specified that there was no pressing need to have this meeting and that it could have been postponed again.

3.4 Hypoxia and post-hypoxic symptoms

The aeroplane flew around 90 minutes above FL 100, including around 60 minutes in level flight at FL 150. The flight plan filed by the pilot indicated cruise flight at FL 110. The oxygen supply system installed in the aeroplane was inoperative (refer to paragraph 2.1). A functional pulse oximeter was present on the aeroplane (refer to paragraph 3.4.4).

3.4.1 FAA regulations

[15] US Code of Federal Regulations.

Sub-part C of Part 91 of the Code of Federal Regulations[15] Title 14 - Equipment, Instrument and Certificate Requirements specifies in paragraph 91.211 "*Supplemental oxygen*":

"(a) General. No person may operate a civil aircraft of U.S. registry -
(1) At cabin - pressure altitudes above 12,500 feet (MSL) up to and including 14,000 feet (MSL) unless the required minimum flight crew is provided with and uses supplemental oxygen for that part of the flight at those altitudes that is of more than 30 minutes duration;
(2) At cabin pressure altitudes above 14,000 feet (MSL) unless the required minimum flight crew is provided with and uses supplemental oxygen during the entire flight time at those altitudes; and
(3) At cabin pressure altitudes above 15,000 feet (MSL) unless each occupant of the aircraft is provided with supplemental oxygen. […]"

Furthermore, sub-part H of part 91 of the Code of Federal Regulations Title 14 regarding the operations of civil aircraft of U.S. registry outside of the United States specifies in paragraph 91.703:

"(a) Each person operating a civil aircraft of U.S. registry outside of the United States shall -
[…]
(2) When within a foreign country, comply with the regulations relating to the flight and maneuver of aircraft there in force; […]"

Hence, the pilot flying over France, a Member State of the European Union, was also duty bound to comply with the supplemental oxygen rules applicable in France. A pilot from the company indicated that they only used the criteria of the American regulations during flights.

[16] Commission Regulation of 5 October 2012 laying down technical requirements and administrative procedures related to air operations ([Version in force on the day of the accident]).

[17] Non-Commercial Other than complex aircraft.

[18] This paragraph was modified in 2016 to better take into account crew performance.

3.4.2 EASA regulations

Regulation (EU) No 965/2012 (Air Ops)[16] specifies in paragraph NCO[17].OP.190[18]:
"*Use of supplemental oxygen*":

> *"(a) The pilot-in-command shall ensure that all flight crew members engaged in performing duties essential to the safe operation of an aircraft in flight use supplemental oxygen continuously whenever he/she determines that at the altitude of the intended flight the lack of oxygen might result in impairment of the faculties of crew members, and shall ensure that supplemental oxygen is available to passengers when lack of oxygen might harmfully affect passengers.*
> *(b) In any other case when the pilot-in-command cannot determine how the lack of oxygen might affect all occupants on board, he/she shall ensure that:*
> *(1) all crew members engaged in performing duties essential to the safe operation of an aircraft in flight use supplemental oxygen for any period in excess of 30 minutes when the pressure altitude in the passenger compartment will be between 10 000 ft and 13 000 ft; and*
> *(2) all occupants use supplemental oxygen for any period that the pressure altitude in the passenger compartment will be above 13 000 ft."*

Unlike the previsions of the FAA regulations, paragraph NCO.OP.190(a) of the EASA regulations gives the pilot the possibility of self-determining the oxygen needs when carrying out essential duties, whatever the flight altitude. Acceptable Means of Compliance (AMC) and Guidance Material (GM) clarify this paragraph.

The ways to determine the supplemental oxygen need to comply with the previous paragraph are described in AMC1 NCO.OP.190 (a). They include taking into account in the preflight phase, factors contributing to risks of hypoxia (for example, altitude, duration of flight, individual factors such as age, experience in flights at high altitudes, health) and during the flight, the monitoring of conditions conducive to hypoxia along with the associated decisions (descent when possible or use of supplemental oxygen).

Furthermore, paragraph GM1 NCO.OP.190 (c) specifies that, "*The pilot-in-command should be aware that flying below altitudes mentioned in NCO.OP.190(b) does not provide absolute protection against hypoxia symptoms, should individual conditions and aptitudes be prevalent.*" Lastly in paragraph GM2 NCO.OP.190, reference is made to the Safety brochure published by EASA, "Preventing Hypoxia" which gives information about hypoxia and the assessment of individual conditions. It is mentioned that certain methods for monitoring early symptoms of hypoxia can be facilitated by personal equipment such as a finger mounted pulse oximeter.

3.4.3 Altitude hypoxia

As the altitude increases, the partial pressure of oxygen in the air inhaled by the pilot decreases, resulting in a reduction in the quantity of oxygen carried to the organs (hypoxia). When the organs do not receive a sufficient quantity of oxygen for their needs, they find themselves in a situation of hypoxia which impairs their operation on a more or less lasting basis. Outward signs of hypoxia can appear above FL 050 and more regularly so above FL 070.

These signs correspond to the body adapting to maintain the same level of organ oxygenation as on the ground. They take the form of an increase in the cardiac output and the ventilation of the lungs, more often than not without the pilot's knowledge; as a consequence of these, the latter's body may be greatly taxed. The brain, particularly sensitive to hypoxia, is quickly affected. Cognitive impairments may appear insidiously in flight. These vary from one pilot to another and even from one day to another for the same pilot.

Altitude hypoxia can also give rise to "hangover" effects in the "recovery period". These effects appear upon descending to altitudes at which a pilot is no longer subject to insufficient altitudes-pressure (FL 070, indeed FL 050). In a review written in 2021[19], it is indicated that *"Cognitive impairment may persist for several minutes-to-hours following arterial blood reoxygenation"* after exposure to hypoxic conditions. In other words, "... *the performance of operational tasks or implementation of emergency recovery procedures may continue to be compromised following apparent recovery from hypoxia.*"

On top of these cognitive impairments, there is the extra fatigue due to the body's compensation efforts in the period spent at high altitude (post-hypoxic asthenia), thus reducing vigilance and increasing the occurrence of errors. The increased reaction time linked to this fatigue can be detrimental to the correct coordination of actions.

Furthermore, age reduces a person's ability to adapt to altitude hypoxia and increases the risk of post-hypoxic impairments.

The accidents to the glider D-6393 [20] (flight of 2 h 30 min between FL 065 and FL 100) and to the aeroplane F-WVSG[21] (flight of 4 h 30 min between FL 090 and FL 100) relate to scenarios which could have given rise to such hypoxia phenomena

3.4.4 Use of a pulse oximeter

The pulse oximeter indicates the percentage of hemoglobin transporting oxygen (SpO2[22]). It is an instantaneous indication. The use of a pulse oximeter to warn of hypoxia calls on advanced knowledge of respiratory physiology. This system has not been scientifically assessed to provide guidelines for its use in aviation.

The brochure, "Preventing hypoxia" published by EASA specifies, in particular, that a pilot can use a pulse oximeter to monitor the evolution of his/her SpO2 and thus detect early symptoms of hypoxia. It is specified that a reading below 90% must be considered as a warning sign as it is generally below these values that pilots begin to experience hypoxia.

The Pilot's Handbook of Aeronautical Knowledge produced by the FAA indicates that, "*Because of their portability and speed, pulse oximeters are very useful for pilots operating in nonpressurized aircraft above 12,500 feet where supplemental oxygen is required. A pulse oximeter permits crewmembers and passengers of an aircraft to evaluate their actual need for supplemental oxygen.*"[23]

Part 9 of the N918SE Cirrus flight manual, dedicated to the oxygen supply system, specifies that the FlightStat NONIN pulse oximeter is available as an option. Its operation is described in the flight manual. The manufacturer of the oxygen supply system recommends making regular checks during high-altitude flights to adjust the oxygen supply if a person experiences symptoms of hypoxia or if the SpO2 decreases. This pulse oximeter is not accompanied by any guide to interpret the measured values and is not the subject of specific maintenance.

A pilot from the company indicated that the pilots of N918SE were in the habit of flying at around FL 100. They sometimes flew for a short time a little higher to avoid storm cells for example. He explained that they regularly used the pulse oximeter provided. He indicated that from FL 100, they measured the value every ten minutes and that the value usually read was 95%. He believed that the value to be monitored was 90% but that he had never reached this.

[19] https://www.frontiersin.org/articles/10.3389/fphys.2021.665821/full

[20] Accident to the Schleicher ASW22 registered D-6393 on 12 April 2017 at Valdeblore (06)

[21] Accident to the Dyn'Aéro MCR 4S registered F-WVSG on 10 October 2005 at Dijon Darois (21)

[22] Also called Oxygen saturation of the blood.

[23] FAA-PHAK, 2016, Chapter 7 page 39.

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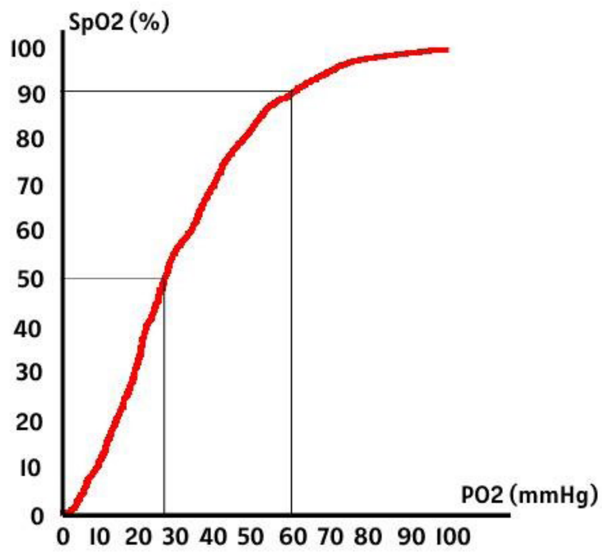
[24] Air Accidents Investigation Branch (UK).

[25] Serious incident to the Reims Cessna F406 on 06 March 2021 over the North Sea

A pulse oximeter can also be used to detect a malfunction in the supplemental oxygen supply system. The UK AAIB[24] highlighted this in an investigation report[25]. In its analysis, the AAIB specified that, "*Being vigilant, using a pulse oximeter and taking quick action if hypoxia is suspected can ensure the safety of the crew and any passengers. However, it should also be noted that hyperventilation – one of the symptoms of hypoxia – may mean that a pulse oximeter does not indicate at the finger what it is purporting to 'measure' in the brain.*"

3.4.5 Limits in use of pulse oximeter

The relationship between SpO2 and the partial pressure of oxygen in the blood (PO2) inside the alveoli, in other words, the oxygenation of blood, follows a sigmoid curve, the critical range being characterized by a slight decrease of the SpO2, between 100 and 90%, for a substantial decrease of PO2, between 100 and 60 mmHg.



Source: Université Médicale Virtuelle Francophone

Figure 4: Hemoglobin dissociation curve - pH 7.4[26] / PCO2 40 mmHg / T° 37°C

[26] The hemoglobin dissociation curve keeps its sigmoid shape whatever the blood's pH. However, it is offset to the right when the pH decreases and to the left when the pH increases.

The oximeter therefore provides imprecise information about the point at which the body starts experiencing hypoxia (PO2 below 80 mmHg, SpO2 of 93-95%). Below this threshold, the conditions for oxygenating the body have started to degrade due, in particular, to the compensation mechanisms being insufficient or even exhausted.

This data is absent from all the documents consulted (flight manual, oximeter user manual, EASA brochure and FAA manual). The affirmations as to the usefulness of this device are not supported by any reference.

NONIN specifies in its documentation that the measurement error is a standard deviation (the accuracy of the SpO2 measurement is generally to within 2%). It indicates that the measurement must be considered as an approximate value and that at a high altitude, the measurement must be interpreted in coordination with a medical expert. The indication given by the pulse oximeter also depends on the temperature of the body and the tonicity of the blood vessels (vasoconstriction).

Bearing in mind the accuracy of the oximeter, the value of 90% proposed by EASA (when the sigmoid curve bends), may correspond to either a nearly normal oxygenation situation (93% - PO2 in the order of 75 mmHg), or a degraded situation (87% - PO2 in the order of 55 mmHg). EASA specifies that the value of 90% must be increased by the oximeter's SpO2 measurement error. However this information is rarely brought to the pilots' attention.

Note: at FL 150, without the use of supplemental oxygen, the SpO2 value is around 80-85% i.e. a PO2 of around 50 mmHg.

3.5 Radio and radar recordings

The aeroplane's flight path to QM402 (refer to Figure 1, point ❹) did not show obvious signs that the pilot might have been experiencing difficulties while carrying out the essential flight duties, such as controlling the flight path. The analysis of the radar flight path showed that this part of the flight was very probably carried out with the AP engaged.

The analysis of all of the messages transmitted by the pilot over the frequency did not show any obvious sign of fatigue or altitude hypoxia. The flight path changes were carried out in accordance with the air traffic controllers' instructions.

The pilot and the AFIS officer had three exchanges during the three minutes in which they were in contact. None of the messages gave any forewarning of a non-stabilized approach or any failure. The pilot did not mention a missed approach or a diversion to another aerodrome. The AFIS officer had not felt that there was anxiety in the pilot's voice.

Several reasons may explain why the aeroplane did not descend at the final descent fix QM406, the main ones being:

- The AP was not engaged and the pilot, flying manually, did not realise that he had gone past QM406 and detected this at a late stage.
- The AP was engaged, the APR mode for the RNP Z 23 approach was activated but the ALT mode had not been previously selected which meant that the glideslope was not automatically acquired.
- The AP was engaged but the APR mode had not been activated although the approach had been correctly loaded and activated in the GNSS computer, which meant that the glideslope was not automatically acquired.

An AP failure after the last turn cannot be excluded.

During the last minute of the flight (from point ❾), the average calculated rates were in the order of +/- 2,000 ft/min. The AP is limited to climb and descent rates of +/- 1,600 ft/min. The vertical profile of the flight path was not controlled by the AP.

4 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

A large part of the IFR flight was flown above FL 100 probably in order to fly above the cloud layer. The pilot and passengers did not use supplemental oxygen as the aircraft system was inoperative. It is probable that the pilot used a pulse oximeter during the flight in order to assess his state of hypoxia as he had been in the habit of using it during previous flights.

On the approach to Besançon-La Vèze aerodrome, the pilot had to adapt the aeroplane's path to avoid various zones. On the RNP approach path, carried out in the cloud layer, the final descent was started around 30 s after passing the final descent fix. The investigation was not able to determine if the AutoPilot (AP) was engaged or not, on approaching the final descent fix. The pilot continued the approach and tried to intercept the glideslope from above and then from below.

The analysis of the radar data parameters during the final approach shows path deviations above and below the nominal glideslope probably linked to the pilot making large-amplitude inputs on the stick. The last manoeuvre started by the pilot, still without external visual references, seems to correspond to a missed approach during which he lost control of the aeroplane.

The activation of the airframe parachute at an insufficient height, during the loss of control, meant that it was not completely deployed before collision with the ground.

Contributing factors

The following factors may have contributed to the destabilization of the approach and to the loss of control during the missed approach:

- A high workload during the approach due to the flight path constraints in the horizontal and vertical profiles.
- Insufficient monitoring of the flight parameters and/or AP guidance modes on approaching the final descent fix.
- Manual control inputs which did not bring the aeroplane back onto the glide path during the final approach.
- The small amount of recent experience for carrying out IFR approaches in the absence of external visual references.
- The probable absence of specific training with respect to the systems recently installed on the aeroplane allowing LPV approaches to be flown in good safe conditions and the small amount of experience in the use of the associated systems.

Flight in conditions conducive to hypoxia, in particular above FL100 for nearly 90 minutes without supplemental oxygen may have generated post-hypoxic cognitive impairments during reoxygenation of the brain during the descent. In addition, post-hypoxic asthenia[27] following the body's adaptation efforts could also have set in. These effects, when they occur, are generally more pronounced with age. However, in the absence of positive signs of cognitive impairments during the descent to the initial approach fix (normal exchanges with air traffic control), it was not possible to determine if a post-hypoxic impairment contributed to the loss of control. Nonetheless, the investigation revealed questionable management of the supplemental oxygen and the associated equipment, as well as gaps in available regulations and documentation related to the use of supplemental oxygen.

[27] Loss or lack of bodily strength, overwhelming fatigue.

5 - SAFETY RECOMMENDATIONS

Note: in accordance with the provisions of Article 17.3 of Regulation No. 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation, a safety recommendation in no case creates a presumption of fault or liability in an accident, serious incident or incident. The recipients of safety recommendations report to the issuing authority in charge of safety investigations, on the measures taken or being studied for their implementation, as provided for in Article 18 of the aforementioned regulation.

Knowledge of effects and consequences of altitude hypoxia on operation of flight (refer to paragraph 3.4.3)

The brochure "Preventing Hypoxia", published by the European Aviation Safety Agency (EASA) mentions situations in which a pilot might be confronted with hypoxia conditions, in particular when flying under Instrument Flight Rules (IFR) at higher altitudes than those planned, due to degraded weather conditions. This brochure focuses on the ways of preparing and managing flights so that the pilot will not have to have recourse to supplemental oxygen. The brochure does not encourage pilots to fix themselves clear limits beyond which they shall self-impose the use of supplemental oxygen, in a context where the current wording of part NCO.OP.190 of the European Air Ops regulation has deleted from the regulations, all mandatory altitude limits beyond which the use of supplemental oxygen would be compulsory. This brochure may therefore encourage behaviour with respect to the risk of hypoxia similar to that observed during the accident to N918SE.

The brochure specifies that the Acceptable Means of Compliance (AMC) and Guidance Material (GM) associated with the regulatory requirement NCO.OP.190 "*provide means to help the pilot assess the need to carry supplemental oxygen before the fight and to take the appropriate precautions in case oxygen equipment is not installed or portable bottles are not carried*." In reality, these AMC and GM only list the factors to be taken into account, with no indications or associated threshold.

Lastly, the brochure places exceptional individuals who can climb Everest (FL 290) without supplemental oxygen side by side with less uncommon individuals who may be sensitive to hypoxia from FL 070. This brochure may thus lead to pilots making an erroneous assessment of their supplemental oxygen needs. Furthermore, the proposal to carry out training in altitude chambers at Aeromedical centres to improve their ability to recognise hypoxia seems to be somewhat academic.

Generally speaking, the effects of altitude hypoxia brought to the pilots' knowledge are limited to the direct and acute effects of pressure altitudes above the FL 050 to FL 070 range. Historically, the most visible effects which most often occur well above FL 100 were the only ones recognized as being signs of hypoxia. Even today, this tendency persists despite the growing volume of work and feedback concerning mild hypoxia.

Over the last ten years or so, scientific work has confirmed the deferred consequences of altitude hypoxia on the operation of flights. They occur when the pilot is at an altitude of less than 5,000 ft and is trying to land after a more or less extended period of exposure to even mild hypoxia. They seem to be the result of the effort to compensate for the hypoxia during the flight and the reoxygenation conditions of the brain cells, generally during the descent and approach. These consequences are characterized by increased fatigue and post-hypoxic cognitive impairments. The accidents to D-6393 in 2017 and to F-WVSG in 2005 relate to scenarios which could have given rise to hypoxia phenomena of this type.

Consequently, the BEA recommends that:

- **in the absence of specific training and information about post-hypoxic impairments;**
- **in the absence of up-to-date, referenced documents addressed to pilots concerning altitude hypoxia and post-hypoxic impairments;**
- **given that paragraph NCO.OP.190(a) gives the pilot-in-command freedom to judge whether to carry supplemental oxygen;**
- **whereas the improvement in performance of non-HPA[29] light aircraft permits flights at higher and higher levels;**

EASA amend the brochure, "Preventing Hypoxia" to include information about mild hypoxia and post-hypoxic impairments along with their symptoms, and encourage pilots to be more prudent when the limits mentioned in paragraph NCO.OP.190(b) are exceeded and supplemental oxygen is not being used.
[Recommendation FRAN-2022-003].

[29] High-Performance Aircraft.

Pulse oximeter (refer to paragraph 3.4.4)

Signs of hypoxia can appear from FL 050 without, however, being accompanied by effects which are immediately detectable by the pilot and his/her passengers. A greater physiological effort has to be made to compensate for the lack of oxygen en route which may result in post-hypoxemic asthenia.

The use of a medical-technical device in a non-medical environment is accompanied by a risk of misuse. The portability of the device along with the user-friendly display of a measurement do not reflect the complexity of the underlying physiological aspects relating to its operation and use. Moreover, given the harmful effects of altitude hypoxia on the cognitive functions, the ability of the pilot to exercise good judgement in the use of a pulse oximeter during a critical phase of the flight at a pressure altitude conducive to hypoxia can be called into question.

The use of a pulse oximeter may expose the pilot to an illusion of safety with respect to the risk of hypoxia. This feeling of safety may be reinforced by the display of a measurement with respect to a threshold value. However, the actual oxygenation of tissues cannot be reliably determined by the oximeter due to the non-linear relationship between oxygen saturation (SpO2), the partial pressure of oxygen in the blood (PO2) and the capacity of the haemoglobin to release oxygen in the organs. The statements collected during the investigation suggest that the occupants of N918SE were very probably victim of this illusion of safety linked to excessive confidence in the significance of the pulse oximeter readings.

The pulse oximeter cannot be considered a sufficient means for identifying the consequences of an exposure to hypoxia-conducive conditions. This device may be used in addition to other means, in particular in the case of use of supplemental oxygen to assess if there is a need for more supplemental oxygen.

Consequently, the BEA recommends that:

- **in the absence of up-to-date, referenced documents addressed to pilots concerning the use of the pulse oximeter as a means of determining the flight envelope in which supplemental oxygen would not be necessary;**
- **whereas the pulse oximeter, used on its own, cannot be considered a sufficiently reliable system to permit an objective assessment of the oxygen pressure in arterial blood;**
- **whereas the pulse oximeter, used on its own, cannot therefore be used to assess the need for supplemental oxygen;**
- **given that regulatory requirement NCO.OP.190(a) gives the pilot-in-command freedom to judge whether to carry and use supplemental oxygen;**

EASA amend and update the brochure, "Preventing Hypoxia" in order to delete references to the pulse oximeter as a means of determining supplemental oxygen needs above the thresholds mentioned in regulatory requirement NCO.OP.190(b) and limit reference to the pulse oximeter to that of an additional means to ensure that there is a sufficient oxygen supply during the flight phases in which supplemental oxygen is used.
[Recommendation FRAN-2022-004].