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Swiss Transportation Safety Investigation Board STSB

Investigation Report No. 2369 by the Swiss Transportation Safety Investigation Board STSB

concerning the accident involving the Pipistrel Alpha Electro 167 aircraft, registration HB-SAA

on 3 January 2019

Corpataux-Magnedens, municipality of Gibloux (FR)

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General information on this report

In accordance with

Article 3.1 of the 12th edition of annex 13, effective from 5 November 2020, to the Convention on International Civil Aviation of 7 December 1944 which came into force for Switzerland on 4 April 1947, as amended on 18 June 2019 (SR 0.748.0);

Article 24 of the Federal Act on Civil Aviation of 21 December 1948, as amended on 1 January 2020 (CAA, SR 748.0);

Article 1, point 1 of Regulation (EU) 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 and repealing Directive 94/56/EC, which came into force for Switzerland on 1 February 2012 pursuant to a decision of the Joint Committee of the Swiss Confederation and the European Union (EU) and based on the agreement of 21 June 1999 on air transport between Switzerland and the EU (Air Transport Agreement); as well as

Article 2, paragraph 1 of the Ordinance of 17 December 2014 on the Safety Investigation of Transportation Incidents, as amended on 1 February 2015 (OSITI, SR 742.161);

The sole purpose of an investigation into an aircraft accident or serious incident is to prevent further accidents or serious incidents from occurring. It is expressly not the purpose of the safety investigation and this report to establish blame or determine liability.

Should this report be used for purposes other than those of accident prevention, this statement should be given due consideration.

The German version of this report constitutes the original and is therefore definitive.

All information, unless otherwise indicated, relates to the time of the accident.

All times in this report, unless otherwise indicated, are stated in Local Time (LT). At the time of the accident, Central European Time (CET) applied as local time in Switzerland. The relation between LT, CET and coordinated universal time (UTC) is:
LT = CET = UTC + 1 hour.

Synopsis

Aircraft type	Pipistrel Alpha Electro 167	HB-SAA
Operator	AlpineAirPlanes GmbH, route de l'Aérodrome 19, 1730 Ecuvillens	
Owner	AlpineAirPlanes GmbH, route de l'Aérodrome 19, 1730 Ecuvillens	

Pilot	Swiss citizen, born 1983
Licence	Commercial Pilot Licence Aeroplane (CPL(A)) in accordance with the European Union Aviation Safety Agency (EASA), issued by the Federal Office of Civil Aviation (FOCA), with ratings for flight instructor (FI(A))

Flying hours	**total**	834:43 hours	**during the last 90 days**	29:04 hours
	on the accident type	3:50 hours	**during the last 90 days**	3:50 hours

Location	Corpataux-Magnedens, municipality of Gibloux (FR)
Coordinates	177 391 / 574 562 (Swiss Grid 1903) **Elevation** 668 m AMSL[2] N 46° 44' 50'' / E 007° 06' 21'' (WGS[1] 84)
Date and time	3 January 2019, 14:53

Type of operation	Private
Flight rules	Visual Flight Rules (VFR)
Starting point	Ecuvillens aerodrome (LSGE)
Destination	Ecuvillens aerodrome (LSGE)
Flight phase	Take-off and climb
Type of accident	Engine failure with subsequent emergency field landing

Injuries to persons

Injuries	Crew	Passengers	Total number of occupants	Others
Fatal	0	0	0	0
Serious	0	0	0	0
Minor	1	0	1	0
None	0	0	0	Not applicable
Total	1	0	1	0

Damage to aircraft	Severely damaged
Other damage	Minor damage to the ground

[1] WGS: World Geodetic System: The WGS 84 standard was adopted for aviation by resolution of the International Civil Aviation Organization (ICAO) in 1989.

[2] AMSL: above mean sea level

1 Factual information

1.1 Background and history of the flight

1.1.1 General

The description of the background and history of the flight is based on the pilot's statement, the recordings of his navigation device, the analyses of the flight data recorder as well as the statements of the flight instructor and another pilot.

This final report contains four safety recommendations (see Section 4).

1.1.2 Background

The Pipistrel Alpha Electro 167, registration HB-SAA, was a single-engine electrically powered shoulder-wing monoplane. The aircraft was operated under a Permit to Fly (PtF) issued by the FOCA and under Flight Conditions (FC) defined by the EASA.

The FOCA Permit to Fly also specified which pilots and flight instructors were authorized to fly the Electro 167. The Electro 167 was used to assist EASA in the certification of the Pipistrel Velis Electro SW128.

Pilots with a class rating for single-engine piston aircraft had to complete a difference training in order to fly the Alpha Electro 167 [3]. The course of this training, as described in a document known to EASA, included a theoretical part and five training flights.

The pilot completed his difference training on 31 December 2018 after a flying time of 3:47 hours and 24 landings. In order to also be able to subsequently work as a flight instructor on the type, a total of 10 flying hours were required according to FOCA's conditions.

HB-SAA was parked in an unheated hangar at Ecuvillens aerodrome (LSGE) after the pilot's last training flight. This hangar contained the charging system for the aircraft's two main batteries. The batteries were connected to the charging system after the flight. HB-SAA was not used again until the flight involved in the accident.

On the morning of 3 January 2019, the pilot, acting as a flight instructor, conducted a training flight with a Cessna C172 in Ecuvillens.

1.1.3 History of the flight

In the early afternoon of 3 January 2019, the pilot wanted to carry out his first flight on HB-SAA after difference training. The aircraft had already been pushed out of the hangar in the morning by the flight instructor who had carried out the training with him.

The pilot carried out the pre-flight inspection and determined that the State Of Charge (SOC) of both batteries was 83 % and the State Of Health (SOH) was 90 %. The battery temperatures were 0 °C[4]. After the pilot had boarded the aircraft and completed the before engine start checklist, he increased the engine power

[3] In order to extend the ratings to another aircraft within the same class or type rating, the pilot must carry out difference training.

[4] According to the Pilot's Operating Handbook (POH), the minimum permissible operating temperature of the batteries is 5 °C (see chapter 1.3.3).

and taxied HB-SAA to the runway 09 holding point. At this point, the SOH of both batteries was 100 % and the battery temperatures were 2 °C. The pilot set the flaps to 15° and conducted the before take-off checklist. He then taxied the aircraft onto runway 09 at 14:50 and set the power lever fully forward to the maximum power position. He saw that the Engine Parameters and Systems Indications (EPSI) displayed a motor power of 75 kW. The acceleration of the aircraft during the take-off run was normal.

The initial climb took place with an indicated airspeed of 60 kt. Approximately twenty seconds after lifting off and after flying over the end of the runway, the pilot determined that the motor speed, indicated in Revolutions Per Minute (RPM), and the motor power (PWR) were both suddenly displayed on the EPSI in red. In accordance with the normal procedure, he reduced power, whereupon the display of the two parameters returned to green. A few seconds later, at an altitude of 2700 ft AMSL, corresponding to approximately 450 ft above ground, the pilot noticed a sudden loss of motor power to approximately 10 kW. Furthermore, the red warning messages “ERROR” and “DRIVE OVERTEMP” also appeared on the EPSI. The temperature of the power controller was displayed as 68 °C at this time.

Aware of the automatic power derating, which reduces the available motor power in the event of overheating of the power controller (see Section 1.3.8), the pilot initiated a slight descent and accelerated the aircraft in order to achieve better cooling of the propulsion unit. He also set the power lever to the idle position and then to a position corresponding to a motor power of approximately 40 kW. After a delay of a few seconds, the motor power increased sharply, but dropped back to below 10 kW after a few seconds. At that time, the aircraft was at an altitude of 2550 ft AMSL and approximately 300 ft above ground level. Hoping to reset the power controller and regain power control, the pilot moved the power lever back and forth several times between the idle position and the climb position, though this proved unsuccessful.

Because the remaining motor power did not allow level flight or a climb, the pilot decided to make an emergency landing on a field approximately 210 m long near the sports ground of the village of Corpataux-Magnedens (FR), located 2 km east of the runway 24 threshold at Ecuvillens aerodrome. He planned to land in a north-easterly direction because the wind was from the north-east. After flying the downwind leg and short base leg of the approach circuit he turned left onto the final approach when he realised that he was clearly too high to land. He therefore decided to land on the field in the reverse (south-westerly) direction and performed a 180˚ left turn at the end of the field at low height above ground level (see Figure 1).

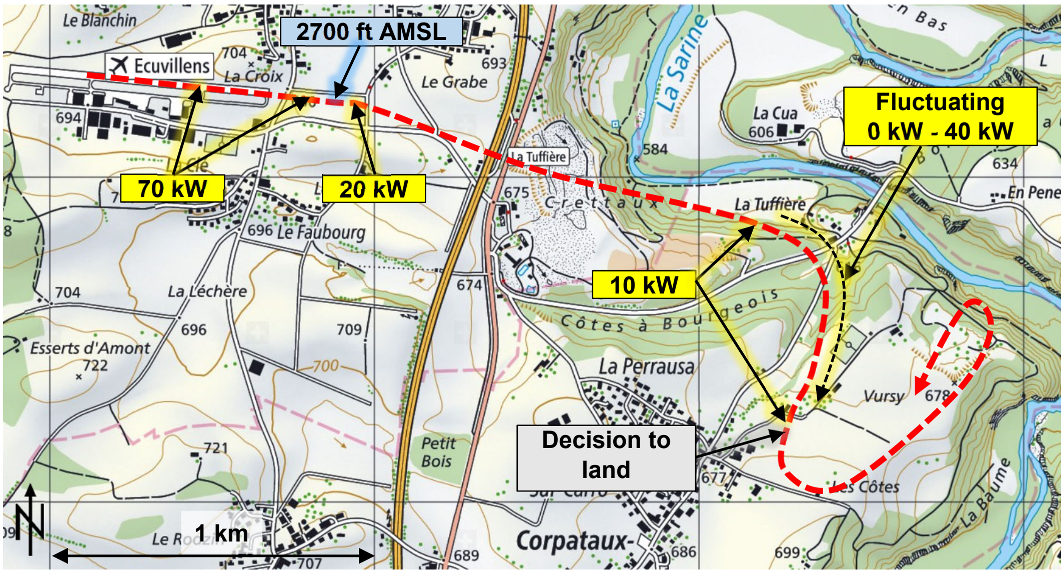

Figure 1: Flight path and altitude of HB-SAA according to the pilot's statement and remaining motor power according to the analysis of the data recorder. Base map source: Federal Office of Topography.

After a flying time of almost 3 minutes, the aircraft first touched down hard on the field on its nosewheel with a tail wind. The landing flaps were still set in the take-off position. The nose landing gear buckled on impact. According to the statement of the pilot, he deployed the Ballistic Parachute Recovery System (BPRS) immediately before or upon impact in order to shorten the landing distance. The BPRS activated as intended, but the canopy did not deploy completely. As a result, the aircraft flipped over its nose, remained lying upside down and was severely damaged (see Figure 2). The two battery compartments in the fuselage including the main batteries and their attachment to the airframe withstood the impact. The attachment of the left lap belt was torn from the airframe (see Section 1.4.2). Fire did not break out. There was little damage to the ground and no liquids escaped from the wreckage.

The pilot suffered minor injuries and was able to vacate the wreckage unaided. Before switching off the power supply on board HB-SAA, he reported the accident on the Ecuvillens aerodrome frequency. Two flight instructors heard this and immediate help was organised.

The Emergency Locator Transmitter (ELT) was triggered upon impact.

The SOC of the batteries immediately after the accident were 94 % and 95 % respectively and the SOH were 92 % and 94 % respectively. The battery temperatures were 9 °C and 8 °C respectively.

Figure 2: Final position of the aircraft (landing direction yellow arrow) with ejected, partially deployed rescue parachute and deployed rocket (red circle). The Corpataux-Magnedens (FR) sports ground is visible in the background.

1.2 Meteorological information

1.2.1 General meteorological situation

A pronounced area of high pressure centred over the British Isles determined the weather in the western Swiss plateau.

1.2.2 Weather at the time and location of the accident

The weather was sunny with moderate winds from the northeast.

Weather	Sunny
Cloud	Clear
Visibility	70 km
Wind	040 degrees, 12 kt
Temperature and dewpoint	0 °C / -8 °C
Atmospheric pressure (QNH)	1034 hPa, pressure reduced to sea level, calculated using the values of the ICAO[5] standard atmosphere
Hazards	None

1.2.3 Astronomical information

Position of the sun	Azimuth: 213°	Elevation: 14°
Lighting conditions	Daylight	

[5] ICAO: International Civil Aviation Organization

1.3 Aircraft information

1.3.1 General

Registration	HB-SAA
Aircraft type	Pipistrel Alpha Electro 167
Characteristics	Two-seater composite light aircraft, designed as a shoulder-wing monoplane, with an electric propulsion unit and fixed tripod landing gear and two side access doors
Manufacturer	Pipistrel D.O.O., Slovenia
Year of manufacture	2017
Certification	Permit to fly issued 2 July 2018 by the FOCA
Motor	Pipistrel PEM 60MVLC, water-cooled electric propulsion unit with 60 kW take-off power and 50 kW continuous power at 2100 - 2500 rpm
Propeller	Three-blade fixed pitch composite propeller
Main batteries	2 main batteries, each with a useful battery capacity of 10 kWh and a rated voltage of 345.6 V DC[6], each weighing 58 kg. The available electrical energy in the main batteries was sufficient for the planned flight.
Ballistic Parachute Recovery System (BPRS)	Galaxy Rescue System (GRS), Czech Republic
Operating hours	11:25 hours TSN[7]
Max. permitted mass	550 kg
Mass and centre of gravity	The mass and centre of gravity were within the limits of the Pilot's Operating Handbook (POH)
Best glide ratio[8]	15:1 according to POH
Maintenance	The last annual inspection was carried out on 10 September 2018 at 4:10 TSN.

1.3.2 Electric propulsion unit

The electric propulsion unit of the Pipistrel Alpha Electro 167, which comprises various components and two main batteries, is shown in Figure 3. Main battery 1 is located in the front battery compartment (battery box front), between the motor bulkhead and cockpit. Main battery 2 is located in the rear battery compartment

[6] DC: direct current

[7] TSN: Time Since New

[8] The glide ratio is the ratio between the distance travelled and the loss of altitude in the case of a gliding flight without propulsion in calm conditions.

(battery box rear) behind the two seats. The main batteries are connected via a junction box to the power controller, which drives the electric motor. The motor and power controller are cooled by a liquid cooling system consisting of an electric circulating pump and a liquid cooler.

The pilot controls the motor power with a power lever which sends an electronic signal to the main computer. This computer controls the power controller accordingly.

A small 12 V DC battery (Bat 12V) is used for operating the main electrical system. It supplies the instruments and avionics in the cockpit even when the main batteries are removed or completely discharged. The 12 V DC battery is normally charged by the main batteries.

An external socket (charge port) allows the main batteries to be recharged on the ground.

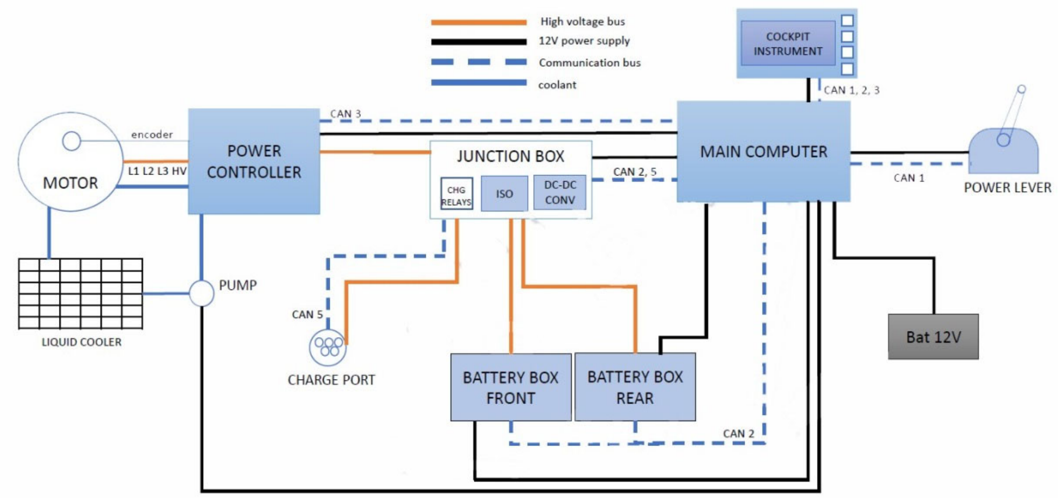

Figure 3: Schematic of the electric propulsion system. Source: Pipistrel.

1.3.3 Main batteries

The two main batteries each have a useful battery capacity of 10 kWh, a voltage between 288 V DC and 398 V DC, a maximum discharge current of 95 A, a weight of 58 kg each, and are made up of small lithium-ion cells. These modules are housed in an appropriate metal housing and are cooled by air flowing past and, if a temperature threshold is exceeded, additionally by fans. The housings are shockproof and equipped with brackets and plug connectors that connect them to the on-board power supply. The main batteries are each equipped with a Battery Management System (BMS) and a display showing the State Of Charge (SOC), State Of Health (SOH) and battery temperature. The batteries are connected in parallel. In the event of a defect in one of the main batteries, the other main battery supplies the electric propulsion unit. The power of the electric propulsion unit must then not exceed 35 kW.

According to the POH, the following limits apply to the main batteries:

- Maximum operating temperature: 55 °C;

- Minimum operating temperature: 5 °C [9];
- Permitted storage temperature range: 10 °C - 40 °C;
- Minimum charging temperature: 0 °C;
- Maximum temperature before take-off: 40 °C.

1.3.4 Power controller

The power controller (or inverter) converts the DC voltage of the batteries into a three-phase, sinusoidal alternating current voltage to drive the stator in the motor. The power controller is cooled by the liquid coolant system (see Section 1.3.6). Automatic power derating protects the power controller in the event of overtemperature (see Section 1.3.8).

According to the POH, the following limits apply to the power controller:

- Nominal power[10]: 60 kW;
- Maximum operating temperature: 65 °C;
- Maximum ambient temperature: 40 °C.

According to a detailed component description by the aircraft manufacturer, the installed power controller can deliver up to 120 kW continuous power.

1.3.5 Motor

The synchronous motor has an external rotor on which permanent magnets are mounted. The latter are driven by the rotating field of the stator. The propeller is also attached directly to the outer rotor. The stator inside the external rotor is supplied with three-phase alternating voltage from the power controller. The motor also acts as a generator when driven by the propeller.

The motor is also cooled by the liquid coolant system in series with the power controller.

Automatic power derating protects the motor in the event of overtemperature.

According to the POH, the following limits apply to the motor:

- Nominal power: 75 kW;
- Maximum take-off power: 60 kW;
- Maximum continuous power: 50 kW;
- Maximum operating temperature: 95 °C
- Maximum ambient temperature: 40 °C;
- Maximum speed: 2500 rpm;
- Revolutions per minute during take-off (guide value): 2400 rpm;
- Revolutions per minute during climb (typical value): 2250 rpm.

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[9] Even though in the present case the battery temperatures were 0 °C when starting flight operation, this circumstance was not considered further in the investigation, as the failure of the drive system was independent of this temperature being below minimum limit.

[10] Nominal power is a value specified by the manufacturer and refers to the power that a device can generate or consume.

1.3.6 Cooling system

During operation, the motor and power controller heat up. To ensure the integrity of the components, it is necessary to hold the operating temperature of the motor and power controller within a certain range. A liquid coolant system is therefore installed in the motor compartment. It consists of a tank with an expansion vessel, a cooler, which is exposed to the air flow of the propeller on the ground and also to the ambient air during the flight, and an electric circulating pump (see Figure 3). The coolant consists of a mixture of 50 % antifreeze and 50 % water and passes through the motor and power controller in series. Both the motor and the power controller are equipped with a heat exchanger.

The circulating pump runs as soon as the electric propulsion unit is activated. The supply voltage and current of the pump are permanently recorded in the data recorder (see Section 1.5). If the voltage is not correct or the corresponding signal is missing, the EPSI generates an error message: "COOLANT SENSOR FAILURE" or "PUMP AUX POWER" (see Section 1.3.7).

The coolant temperatures are measured at the feed and return of the circulating pump and these values are displayed on the EPSI (see Section 1.3.7).

The pilot must check the amount of coolant in the expansion vessel before the first flight of the day. Since there is no corresponding access cover, the entire upper part of the motor cover must be removed.

1.3.7 Instrument display in the cockpit

The instrument panel of HB-SAA, containing the instruments and avionics required for a flight under visual flight rules, is shown in Figure 4. The EPSI is in the centre.

Several system pages can be displayed on the EPSI. The pilot can select these via a pushbutton. The main page is selected by default for the flight (flight page) and displays the most important parameters of the electric propulsion unit, specifically motor temperature, the power controller and the batteries (see red section in Figure 4). If certain limits are exceeded, the colour of the displays and values changes or an error message appears. The POH contains a list of possible error messages.

If the temperature of the power controller is between 60 and 64 °C, the corresponding displayed value and bar are coloured yellow; from 65 °C these become red. At normal temperatures the bar is green.

Figure 4: Instrument panel of HB-SAA with EPSI (circled with red dashes, source Pipistrel). The main page of the EPSI has been enlarged (values do not correlate).

The temperatures of the coolant at the flow and return of the circulating pump are illustrated on the system page, which can be called up on demand (see Figure 5).

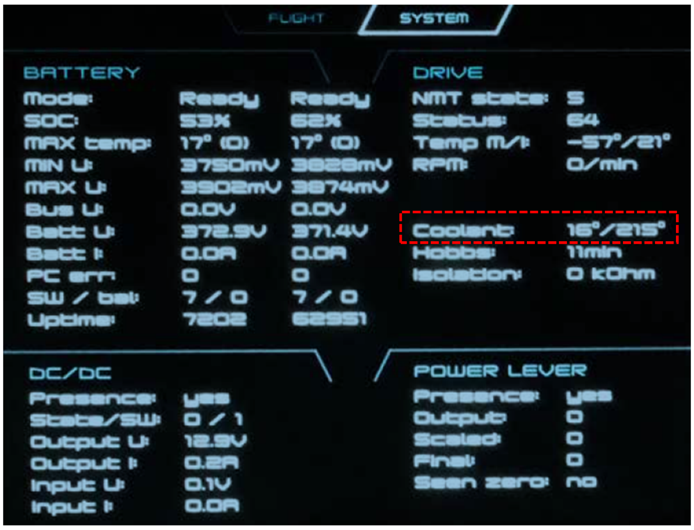

Figure 5: System page with various parameters of the propulsion unit, including the coolant temperatures (circled in red). Source: Pipistrel.

1.3.8 Automatic power derating

An automatic system protects the motor and power controller from excessive temperatures that could cause damage to the electrical components.

If the internal temperature of the power controller rises above 67 °C, the system reduces the motor power so that a temperature of 70 °C is never exceeded. The pilot cannot influence this automatic power reduction (power derating). The power lever remains in its position and does not move autonomously to the reduced value.

The power derating leads to a reduction in the internal temperature of the power controller. As soon as the temperature falls back below 67 °C, the system increases the power to the value dictated by the position of the power lever.

The e-learning documentation[11] provided by the manufacturer contains a description of the automatic power derating. However, the POH does not provide such an explanation of how this system works. The only associated error message with regard to excessive motor and power controller temperatures listed in the POH is "DRIVE OVERTEMP" (displayed in red):

> "*DRIVE OVERTEMPERATURE*
> *This warning appears when maximum power controller or motor temperature is exceeded.*
> *- Reduce power*
> *- Monitor temperature*
> *- Land as soon as practical if the problem persists."*

1.3.9 Ballistic parachute recovery system

A Ballistic Parachute Recovery System (BPRS) was installed behind the pilot seats on HB-SAA. The parachute is deployed by launching a pyrotechnic rocket upwards and to the rear from the top of the fuselage.

The POH and the e-learning documentation provided by the manufacturer contain a description of the BPRS and recommendations for its use. According to information from the e-learning documentation, deployment is also recommended if the landing roll distance should be shortened during an emergency landing.

1.4 Further investigations

1.4.1 Coolant circulating pump

An investigation of the cooling system revealed that the electric circulating pump was functioning only intermittently despite the fact that the supply voltage of 12 V DC was being applied. A slight movement of the red supply cable in the four-pin connector was sufficient to stop or restart the pump. Directly at the plug this cable was offset at an angle and was under slight tension (no strain relief, see Figure 6).

[11] e-learning (electronic learning) is understood to mean forms of learning in which electronic or digital media are used to present and distribute learning materials and/or support interpersonal communication.

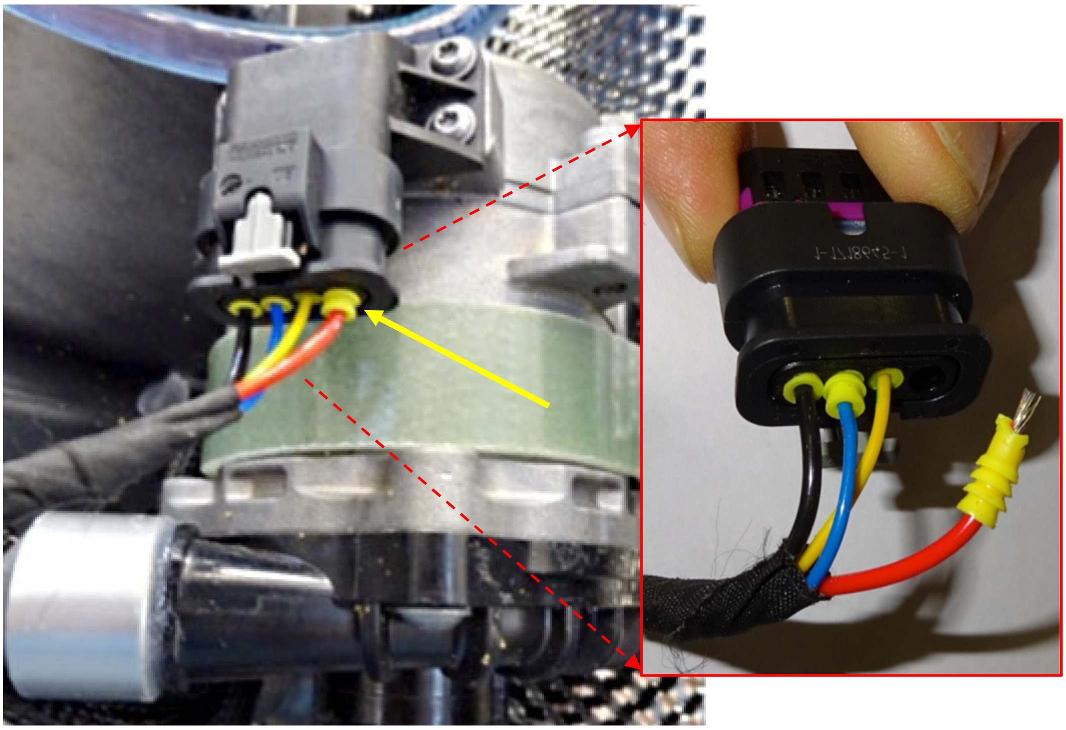

Figure 6: Cable, plug connector and circulating pump on the motor bulkhead of HB-SAA (left) with the red power supply cable (yellow arrow) incorrectly attached. The detail on the right shows the plug after applying light tension to all four cables: the blue cable was also pulled out of the pin.

Disassembling the connector showed that the power supply cable was incorrectly crimped in the pin contact. The cable's copper wires were not mechanically clamped in the pin and were only held by the yellow rubber grommet in the pin contact. The ends of some copper wires showed traces of burning due to electric arcs (see Figure 7), which indicates that the current flow must have been interrupted several times at these points.

Figure 7: Close-up of the end of the red power supply cable. Traces of burning (electric arcs) can be seen on several copper wires (red circle).

The blue wire on the connector (see Figure 6) was also insufficiently crimped in the pin contact. Some copper wires were not contained within the pin socket. The cable could be pulled out of the pin with little force.

1.4.2 Seat belts

The two seats were equipped with four-point belts. The pilot had fastened both lap and shoulder straps during the flight involved in the accident. The left attachment point of the lap belt tore out of the airframe on impact (see Figure 8).

Figure 8: Torn off attachment point of the pilot's left lap belt.

1.5 Recording devices

HB-SAA was equipped with a mobile data recorder (datalogger), which was situated in a storage compartment in the instrument panel and connected to the on-board power supply via a multiple socket. The graphic analysis of the recorded data is illustrated in Figure 9.

The installation of the data recorder was not prescribed and was carried out on 31 October 2018, at 4:18 operating hours.

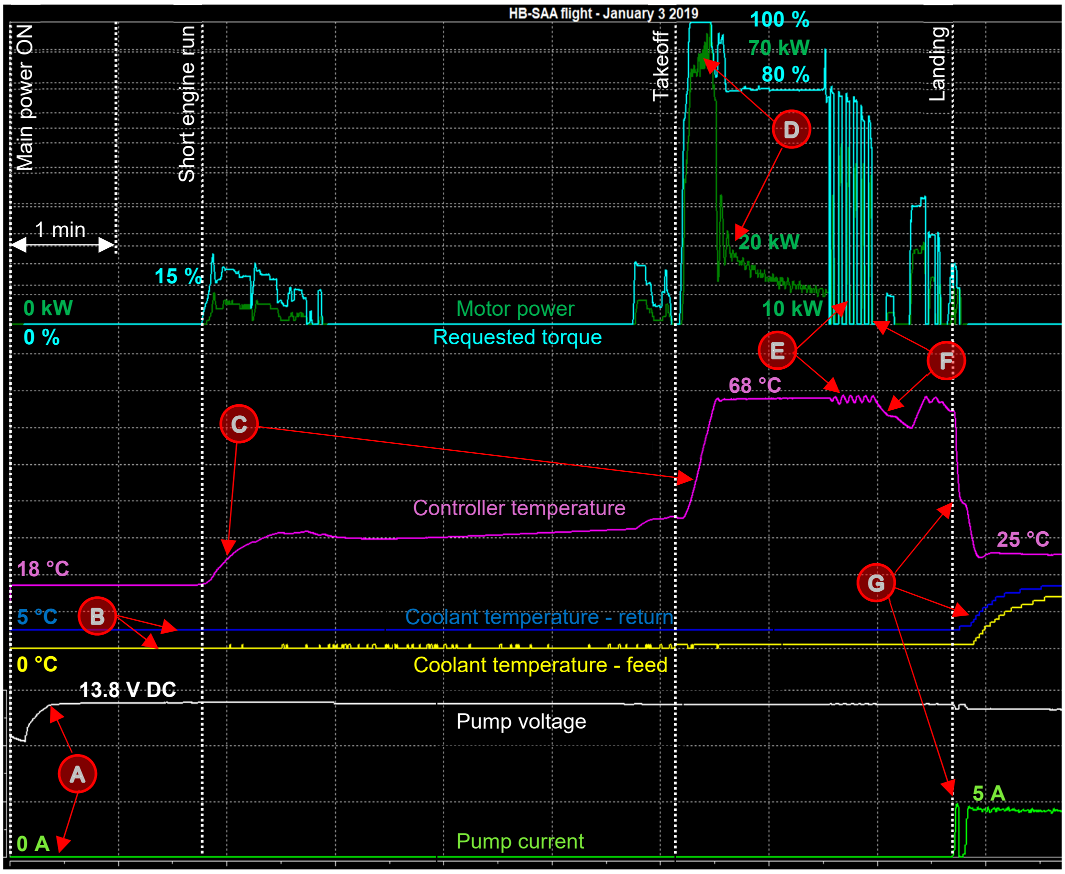

Figure 9: Analysis of the data from the data recorder of the flight involved in the accident.

The following facts were derived from the recorded data:

- Immediately after switching on the power supply, the electrical voltage to the cooling system's circulating pump (pump voltage) increased to 13.8 V DC. Measurements showed no current (pump current 0 A) to the circulating pump (Point A).
- The temperature of the coolant (coolant temperature), measured at the feed and return of the circulating pump, showed constant values between take-off and the emergency landing. These were approximately equal to the ambient temperature (Point B).
- When the motor was switched on for the first time whilst on the ground, the internal temperature of the power controller (controller temperature) increased continuously and rose to over 67 °C (Point C) within almost 20 seconds during the take-off.
- The motor power increased to over 70 kW in this initial take-off phase, but then fell abruptly to below 20 kW (Point D).
- Approximately 80 seconds after take-off the motor power was still 10 kW. The internal temperature of the power controller was still above 67 °C.
- The motor power then increased for a few seconds to approximately 40 kW, but then immediately dropped back to 0 kW several times. Correlating to this, the internal temperature of the power controller increased and decreased slightly (Point E).

- After approximately 100 seconds it can be seen that the power lever was set back to the idle position and then moved back and forth several times (Point F).
- At the same time as the emergency landing, which took place approximately 2 minutes 40 seconds after take-off, the current to the circulating pump jumped to approximately 5 A (Point G). At the same time, the temperature of the coolant increased and the internal temperature of the power controller fell below 25 °C.

1.6 Other incidents

On 6 December 2018, during a training flight with another crew, the HB-SAA motor suffered a loss of power shortly after the take-off, accompanied by a red warning on the EPSI, after the climb power had been set to 40 kW. The flight instructor responded by moving the power lever to the idle position and then to the maximum power position, restoring normal power of the engine again. The flight continued uneventful. It was no longer possible to determine which red warning had been displayed.

During another training flight on 14 December 2018 with the same crew, a yellow warning appeared briefly after a motor failure exercise immediately after take-off. This warning disappeared again without any action on the part of the crew. It was not possible to determine which yellow warning had been displayed.

1.7 Useful or effective investigation techniques

After an accident of a battery-powered aircraft, a thermal runaway of the battery units can occur up to 14 days after the impact. A thermal runaway refers to the overheating of a technical device due to a self-reinforcing, heat-producing process.

For this purpose, the two main batteries of the accident aircraft were stored in a transportable, fireproof and watertight special container. This container is equipped with a fire extinguishing system that is automatically triggered when a temperature limit is exceeded. In addition, there is a 220 V power connection inside the container that allows the continuous operation of a cooling or heating unit to keep the temperature-sensitive batteries at a favorable temperature. In this way, additional damage to the batteries, which can be of central importance in determining the cause of the accident, can be avoided.

2 Analysis

2.1 Technical aspects

2.1.1 Cooling system

After switching on the power supply before the flight, an electrical voltage to the cooling system's circulating pump was recorded, though no current (see Section 1.5). This leads to the conclusion that the circulating pump did not run as intended in the system design. This conclusion is additionally confirmed by the fact that the temperature measurements of the coolant over the entire time up to the emergency landing corresponded approximately to the ambient temperature and remained approximately constant. With a functioning cooling system, these temperatures would increase immediately when the motor power is increased.

Due to the failure of the cooling system, the temperature of the power controller increased at a continuous and rapid rate. During take-off and climb at maximum motor power, the temperature limits of the power controller were exceeded after less than 20 seconds. First, at a temperature of 65 °C, the warning "DRIVE OVERTEMP" appeared on the Engine Parameters and Systems Indications (EPSI). Immediately afterward, when a temperature of 67 °C was exceeded, the motor power was automatically reduced (power derating) despite the fact that the power lever remained in the position for maximum motor power. The motor power fell to below 10 kW, i.e. less than 15 % of the take-off power (see Section 1.3.8).

Nevertheless, the internal temperature of the power controller continued to rise due to the lack of cooling and the automatic power derating therefore abruptly reduced the motor output to zero a little later. The power controller temperature therefore fell to below the limit for a short time and a certain amount of motor power was delivered again for a few seconds. As a result, however, the internal temperature of the power controller suddenly increased again. This in turn led to a repeated exceedance of the temperature limit after a few seconds and the motor power again fell to zero. This cyclical motor power behavior occurred a total of seven times.

Approximately 110 seconds after take-off, the pilot set the power lever to the idle position and then moved it back and forth several times in the hope of resetting the activated automatic power derating. However, it was only possible to reset the power derating temporarily because the lack of cooling led to the immediate overheating of the power controller whenever the motor output was increased, which again activated the automatic power reduction. The remaining, intermittent motor power was not sufficient to continue the flight.

At the time of the emergency landing, the current to the circulating pump increased sharply from 0 A to 5 A. Immediately afterwards, the temperature of the coolant rose and the temperature of the power controller dropped very rapidly. This leads to the conclusion that the circulating pump started to operate at this point in time. This could be explained by a temporary re-closing of a loose contact in the circulating pump circuit caused by the hard impact.

Subsequent investigations of the cooling system revealed that insufficient crimping on contact pins in the circulating pump connector had caused precisely such a loose contact and that this had led to an interruption to the power supply and consequently to the failure of the pump. It was revealed that the connector had been mounted incorrectly.

Neither before take-off nor during the flight did the pilot notice that the circulating pump and thus the entire cooling system was not functioning properly.

As this accident shows, a functioning circulating pump is required to operate the propulsion unit of the Alpha Electro 167. A pump failure leads to failure of the entire motor power within a very short time. The STSB recognised that a single pump installed in the cooling system lacked redundancy and constituted a high safety risk and the STSB therefore issued a corresponding safety recommendation (see Section 0).

2.1.2 Safety belt attachment points

The investigation on the aircraft wreckage revealed that the attachment point of the left lap belt to the airframe did not withstand the forces during the impact, even though the impact could not have been excessively violent, as the pilot sustained only minor injuries. The STSB identified a serious safety risk and issued a corresponding safety recommendation (see Section 4.1.1.2).

2.2 Human and operational aspects

2.2.1 History of the flight

After the "DRIVE OVERTEMP" warning was displayed in the cockpit and automatic power derating occurred as a result, the pilot quickly realized that he could not maintain altitude with the remaining motor power. Due to the low height above ground, he decided that rather than fly a 180° turn back to the aerodrome, he would make an emergency landing on a field outside the aerodrome area. Due to the low, intermittent motor power, which was less than 15 % of the maximum take-off power, this decision was adequate and safety-conscious.

The fact that the propulsion unit did not fail completely in this flight phase, but delivered a certain power for a short time, must have been an aggravating factor for the pilot with regard to further decision-making.

The Alpha Electro 167 has a glide ratio of 15:1. This is a much flatter glide than conventional single-engine aircraft, which typically have glide ratios of less than 10:1. Since the pilot had only minimal flying experience on the aircraft type, it is understandable that he misjudged the height when sub-dividing the approach circuit. As a result, he had to approach the landing field with a tail wind and after completing an additional 180° turn at low altitude, which entailed risks.

2.2.2 Deployment of the ballistic parachute recovery system

On the final approach the pilot was aware of his increased ground speed due to the tail wind. For this reason, he decided to activate the Ballistic Parachute Recovery System (BPRS) on impact, as specified in the aircraft manufacturer's training program, in order to shorten the rolling distance. This consideration was understandable in view of the short length of the landing field and the fact that the opening for the rocket on this aircraft type pointed upwards and to the rear[12]. An undeployed BPRS and its pyrotechnic rocket also poses an additional hazard that should not be underestimated in the event of an emergency field landing.

[12] On certain types of aircraft with BPRS, the rescue parachute is launched with the rocket in a lateral direction.

2.2.3 Hazards associated with electrically powered aircraft

In the event of an aircraft accident involving an electrically powered aircraft, the batteries can be mechanically damaged on impact and ignite. It is well known from the automotive industry that it is very difficult to extinguish a fire in an electrically powered vehicle with high-capacity batteries afterwards.

This is based on the following mechanisms: If the lithium ion cells contained in the main batteries (see Section 1.3.3) are exposed to high temperatures, the layered structure of the metal oxides breaks down. During this process, which is highly exothermic and releases high amounts of energy, elemental oxygen is formed. The high thermal energy leads to evaporation of the organic electrolyte liquid, resulting in highly combustible gases.

If the flash point of the gas is exceeded, it ignites and the lithium ion cell catches fire. Since this is a self-reinforcing process, it usually leads to a thermal runaway[13] in which the lithium atoms are ignited (metal fire). Such a fire can be fought with water only to a limited extent and is also very difficult to extinguish even with the aid of special metal-fire extinguishing agents.

The wreckage of an electrically powered aircraft represents an additional danger to the emergency services, as there is a serious risk of electric shock[14]. Due to the high power and electrical voltage of the main batteries, such an electric shock, which can occur as a result of contact with the batteries or the entire aircraft structure, can have fatal consequences.

For the above reasons, it is essential that rescue and recovery personnel know whether the aircraft involved in the accident is electrically powered and are aware of the associated hazards, which require appropriate precautions and procedures. In order to counter the hazards which may occur in connection with electrically powered aircraft, the STSB has made two safety recommendations (see Section 4.1.3.2 and Section 4.1.3.3).

Likewise, after an accident involving a battery-powered aircraft, special attention must be paid to the storage of the batteries, as a battery fire can still occur within about 14 days of their damage (see chapter 1.7).

[13] Thermal runaway refers to the overheating of a technical apparatus due to a self-reinforcing, exothermic process.

[14] Direct voltages above 120 V are dangerous for people, as electrical flow through the body can then occur. Direct current do not primarily lead to muscle cramps. However, if the electric current flowing through the heart exceeds about 150 mA, there is an acute danger of ventricular fibrillation. In addition, the risk of internal burns and organ failure due to electrolytic effects is greater with direct current than with alternating current. Such a risk of electrocution was therefore present in the main batteries of the HB-SAA with 398 V DC and 95 A maximum discharge current.

3 Conclusions

3.1 Findings

3.1.1 Technical aspects

- The aircraft was licensed for Visual Flight Rules (VFR)
- The aircraft was in the EASA certification phase and was operated with a FOCA permit to fly.
- The last annual inspection took place on 10 September 2018.
- At the time of the accident both the mass and centre of gravity of the aircraft were within the limits permitted by the Pilot's Operating Handbook (POH).
- According to the system design, the circulating pump which supplies the coolant to the cooling system must run continuously as soon as the electrical system is switched on.
- This circulating pump never ran during the flight involved in the accident. It did not start until the aircraft impacted during the emergency landing.
- The power supply cable in the circulating pump electrical connector was crimped incorrectly, which led to a loose contact.
- It was not possible for the pilot to recognize the failure of the circulating pump.
- The Emergency Locator Transmitter (ELT) was triggered upon impact.

3.1.2 Crew

- The pilot was in possession of the licenses necessary for the flight and had completed the necessary difference training.
- He had little flying experience on the aircraft type.
- There are no indications of the pilot suffering any health problems during the flight involved in the accident.
- The pilot sustained minor injuries as a result of the impact.

3.1.3 History of the flight

- On 3 January 2019, the pilot performed his first flight with HB-SAA after completing difference training.
- The take-off from runway 09 in Ecuvillens (LSGE) was normal.
- During the initial climb, approximately 20 seconds after the start of the take-off roll, the warning “DRIVE OVERTEMP” appeared, which indicated that the propulsion unit power controller was overheating.
- A few seconds later, the motor power was automatically reduced to approximately 15 % of the maximum take-off power.
- With the reduced motor power, level flight without loss of altitude was not possible.
- The pilot carried out an emergency landing on a field approximately 210 m long.

- Shortly before the impact, the pilot activated the ballistic parachute recovery system in order to shorten the roll-out distance.
- The aircraft flipped immediately after the impact on the field.

3.1.4 General conditions

- The meteorological conditions did not influence the occurrence of the accident.

3.2 Causes

In order to achieve its objective of prevention, a safety investigation authority shall express its opinion on risks and hazards that have been identified during the investigated incident and which should be avoided in the future. In this sense, the terms and formulations used below are to be understood exclusively from the perspective of prevention. The identification of causes and contributory factors does not, therefore, in any way imply assignment of blame or the determination of administrative, civil or criminal liability.

The accident, during which the pilot performed an emergency landing outside the aerodrome area and the aircraft flipped over after touchdown, was due to a significant loss of power of the electric propulsion unit. This power loss was caused by overheating of the power controller, which in turn was due to a failure of the cooling system's circulating pump.

Each of the following factors was recognized as causal in the occurrence of the accident:

- There was no redundancy in relation to the cooling system circulating pump.
- There were no warnings that indicated the failure of the cooling system before take-off.
- It was not possible to identify the failure of the cooling system when performing the prescribed pre-flight inspections.

During the investigation, the following factors were identified which, though not having influenced the occurrence and sequence of the accident, nevertheless represent a safety risk (factors to risk):

- An attachment point for the occupants' lap belts did not withstand the impact.
- Extinguishing a fire on an electrically powered aircraft requires specific precautions and procedures which the emergency services must be familiar with.
- Due to the high power and electrical voltage of the main batteries, the wreckage of an electrically powered aircraft represents a particular hazard.

4 Safety recommendations, safety advice and measures taken since the accident

4.1 Safety recommendations

> In accordance with international[15] and national[16] legal bases, all safety recommendations are addressed to the supervisory authority of the competent state. In Switzerland, this is the Federal Office of Civil Aviation (FOCA) or the supranational European Union Aviation Safety Agency (EASA). The competent supervisory authority must decide on the extent to which these recommendations are to be implemented. Nonetheless, any agency, organisation and individual is invited to strive to improve aviation safety in the spirit of the safety recommendations expressed.
>
> The STSB shall publish the answers of the relevant federal office or foreign supervisory authorities at http://www.sust.admin.ch to provide an overview of the current implementation status of the relevant safety recommendation.

4.1.1 Redundancy of the cooling system

4.1.1.1 Safety deficit

A Pipistrel Alpha Electro 167 cooling system's circulating pump failed due to a faulty electrical connection, causing the propulsion unit's power controller to overheat within a short time. As a result, the available motor power was automatically reduced to less than 15 % of the maximum take-off power. As a result, the pilot was forced to make an emergency landing outside the aerodrome area during which the aircraft was severely damaged.

The fact that a single pump was installed in the cooling system was recognized by the STSB as a lack of redundancy and a high safety risk.

4.1.1.2 Safety recommendation no. 569

The EASA should ensure that the aircraft manufacturer adapts the propulsion unit's cooling system in such a way that the failure of a single system component, such as the circulating pump, does not significantly affect cooling and consequently motor power.

4.1.2 Seat belt attachment points

4.1.2.1 Safety deficit

During an emergency landing outside the aerodrome area, which was due to a loss of motor power, the Pipistrel Alpha Electro 167 made a hard impact with the ground and then flipped over. The left attachment point of the pilot's lap belt was torn from the airframe.

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[15] Annex 13 of the International Civil Aviation Organization (ICAO) and article 17 of Regulation (EU) 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 and repealing Directive 94/56/EC.

[16] Article 48 of the Swiss Ordinance on the Safety Investigation of Transport Incidents (OSITI) of 17 December 2014, as at 1 February 2015 (OSITI, SR 742.161).

4.1.2.2 Safety recommendation no. 570

The EASA, in cooperation with the aircraft manufacturer, should ensure that the seat belt attachment points can withstand such forces in all aircraft types which have an airframe similar to the Alpha Electro 167.

4.1.3 Hazards associated with electrically powered aircraft

4.1.3.1 Safety deficit

During an emergency landing outside the aerodrome area, which was due to a loss of motor power, the Pipistrel Alpha Electro 167 made a hard impact with the ground and then flipped over. In the current accident, the two main batteries were not damaged and there was no fire.

In the context of the investigation it was revealed that an electrically powered aircraft involved in an accident poses specific hazards. Extinguishing a fire on an electrically powered aircraft requires special precautions and procedures on the part of the emergency services. This is due to the built-in high-performance batteries. The wreckage of an electrically powered aircraft also poses a particular hazard due to the high electrical voltage and current of the main batteries.

4.1.3.2 Safety recommendation no. 571

The FOCA should supplement the aircraft register with an entry for electrically powered aircraft.

4.1.3.3 Safety recommendation no. 572

The FOCA should, in cooperation with aerodrome operators and the emergency services which are usually involved in accidents involving aircraft, take measures to raise awareness of the hazards posed by electrically powered aircraft and how these can be countered.

4.2 Safety advice

None

4.3 Measures taken since the accident

The measures taken, of which the STSB is aware, are mentioned below without further comment.

4.3.1 Aircraft manufacturer

After the accident, the aircraft manufacturer published Service Bulletin No. SB-167-002 on 23 January 2019. According to this document, the coolant temperature at the feed and return of the circulating pump must be read on the Engine Parameters and Systems Indications (EPSI) at a motor power of at least 10 kW before take-off. An increase in these temperatures confirms that the circulating pump is functioning.

4.3.2 Federal Office of Civil Aviation

The letter from the FOCA dated 30 March 2020 includes the following:

"The following measures have already been implemented:

1. *Presentation by the FOCA on the subject of electric aircraft at the annual meeting of Swiss aerodrome fire brigade commanders on 8. - 9.11.2018. All Swiss aerodromes that have an airport fire brigade are represented at the meeting. These are the airfields of Bern-Belp, Birrfeld, Bressaucourt, Ecuvillens, Geneva, Grenchen, Lausanne, Les E-platures, Lugano, Samedan, Sion, Zurich, Buochs, Locarno, Payerne, Saanen and St. Gallen Altenrhein.*
2. *The Swiss Fire Brigades Association (SFV), in collaboration with the SUST and the FOCA, has produced a guide to accidents involving small aircraft and helicopters. This guide is available for purchase in three languages on the SFV website (www.swissfire.ch).*
3. *The FOCA has published an article on electric aircraft in the SFV magazine. The FOCA also aims to implement the following additional measures this year:*
4. *Updating FOCA Guideline AD I-001 on the subject of fire and rescue services at aerodromes, adding a specific chapter on electric aircraft.*
5. *Creation of a new section on the FOCA website on the hazards of electric aircraft.*
6. *Publication of an information brochure.*
7. *Raise awareness among aerodrome managers about the dangers of battery charging and electric aircraft in hangars.*
8. *Exchange of information with aerodrome managers and aerodrome fire brigade commanders on the handling of electric aircraft."*

This final report was approved by the Board of the Swiss Transportation Safety Investigation Board (STSB) (Art. 10 lit. h of the Ordinance on the Safety Investigation of Transportation Incidents of 17 December 2014.

Bern, 27 April 2021 Swiss Transportation Safety Investigation Board