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Unattended charging system for electric aircraft

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Abstract

The certification of the Pipistrel Velis Electro revealed a gap in regulations for handling and operating electric aircraft, hindering the shift to more sustainable energy sources in aviation. One of these gaps is regarding unattended charging, which was never needed for combustion aircraft.
This report describes a method which should provide a safe method to recharge an electric aircraft unattended. However, this technology will not yet allow electric aircraft to be recharged unattended, because this requires a change in regulation.
In addition, a gap analysis is performed to list other regulations written with combustion engines in mind but requires changes to suit electric aircraft.

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VI. LIST OF ACRONYMS

Acronym	Meaning
BMS	Battery Management System
DOD	Depth of Discharge
GA	General Assembly
KOM	Kick Off Meeting
OCPP	Open Charge Point Protocol
PBIT	Power-on-built-in-test
POH	Pilot Operating Handbook
RFF	Rescue and Firefighting
SOC	State of Charge
SOH	State of Health
WP	Work Package

1 Executive Summary

This report describes the unattended charging system which will be demonstrated as part of Task T2.5. However, more important than the technical solutions found during this project is the urgent call to civil aviation authorities to implement regulations and share guidelines for electric aircraft design and ground operations at airports.

In chapter 3 these regulations are analysed, and it was found that:

- Electric aircraft should abide to the same regulations as hydrocarbon powered aircraft,
    - Some of the regulations are not applicable to electric aircraft and can be negotiated,
    - Some of the regulations are not applicable but still need to be followed,
    - Some regulations might be important for electric aircraft but are missing or insufficient because they are not applicable to hydrocarbon powered aircraft.
- For airport operations there are no clear regulations how this should be done from the applicable civil aviation authority.
    - Some airports are following national regulations regarding infrastructure and operation of (fast)charging stations in public spaces,
    - Some airports are setting up their own internal guidelines on how to operate electric vehicles and do their own safety assessments,
    - These internal guidelines can differ between airports.

This makes introducing new electric aircraft more difficult because there is no clear set of regulations that need to be followed and irrelevant regulations intended for hydrocarbon powered aircraft are adding extra hurdles, slowing down the switch to sustainable alternatives in aviation. In addition, new risks related to electric aircraft might be missed.

In chapter 4 the technical aspects of the unattended charging system are discussed. The detection system consists of an aircraft dependent detection system, for fast response and accurate internal data, and an aircraft independent system consisting of a smart camera which can detect safety hazards around the aircraft.

If an anomaly is detected the system will automatically inform relevant parties – for the demonstration this is done via a dashboard – and charging could be stopped manually or automatically depending on type of anomaly.

2 Demo development

The purpose of the Unattended charging demo is to identify, analyse and mitigate the missing gaps in regulations to enable unattended charging of electric aircraft and to demonstrate that current technologies have reached the required level of maturity to safely charge an electric arcraft unattended. The demo will be conducted using a Pipistrel Velis Electro EASA CS-LSA certified electric aircraft.

Below is provided a description of the aircraft with its current safety features already present on the aircraft, followed by the scope of the project.

2.1 Description aircraft

The Pipistrel Velis Electro is world's first electric powered airplane to receive a Type Certificate. The two-seater is made of a composite construction with a high wing and is primarily intended for pilot training. The energy of the aircraft is stored using two Li-ion liquid cooled battery packs in parallel. The total capacity is 22kWh, which is sufficient to power the aircraft for approximately 50 minutes (plus reserve).

A list with the aircraft technical specifications can be found in Appendix B:. The technical specifications of the battery pack (PB345V124E-L) used in the Velis Electro are listed below (1):

- Battery mass of 72 kg (one battery pack, 53 kg cell mass)
- Capacity of 11 kWh (@ 23°C)
- Nominal battery pack voltage: 345 V (min 260 V, max 398 V)
- Maximum continuous discharge power: 40 kW
- Current limits: 120 A discharge, 40 A charge
- Operating temperature: discharge 0°C to 58°C, charge 0°C to 50°C (with derating)

Depending on the State of Charge (SOC) and State of health (SOH) of the battery packs, charging takes up to 2 hours. Charging is only allowed with a Pipistrel portable charger or a Pipistrel Sky Charge charger.

2.1.1 Current safety features

The Pipistrel Velis Electro has already several safety features implemented to protect the aircraft and its passengers from a thermal runaway.

Both batteries are equipped with a Battery Management System (BMS) which monitors the battery cells continuously and can take appropriate action if any failure condition is detected, including:

- Overtemperature protection: battery(ies) automatically disconnect above 58°C.
- Overvoltage protection: battery(ies) automatically disconnect above max cell voltage limit.
- Undervoltage protection: battery(ies) automatically disconnect below min cell voltage limit.

- Overcurrent passive protection: thermal fuses disconnect battery(ies) in case of prolonged overcurrent.
- BMS performs PBIT (Power-on-built-in-test) and would not connect batteries to the load (or charger) in case of any fault.

In addition to these electrical safety features, also mechanically the battery is designed in such a way to minimise the risk of thermal runaway cell to cell propagation.

2.2 Scope of the project

In the pilot's operating handbook (POH) of the Pipistrel Velis Electro is stated to “not leave [the aircraft charging] unattended, unless alternative means are in place.” Currently there are no alternative means defined thus making it effectively impossible to charge the aircraft unattended.

Hence objective of the scope of this demonstrator is to develop these kinds of alternative means and demonstrate unattended charging of an electric aircraft can be done in a safe way.

Safety of the electric aircraft itself is already granted by the certification process, therefore the scope of the demonstration is not to show that electric aircraft are safe. Instead, the objective is to demonstrate that unattended charging can be done in a safe way by developing safety features which protect the aircraft, the airport, and the people around it.

This report focusses on safety features which:

1. Should be considered by aircraft manufacturers to improve response time to anomalies happening internally in the aircraft and to react swiftly to limit damage.
2. Should be implemented from the airport side to detect hazardous events that could cause injury to people or damage to the airport, that work independent from the aircraft.

Safety features that must be implemented from the airport side are required to make sure people/personnel near the aircraft are safe. In addition, it shall form an additional redundancy layer in case the system on the aircraft fails.

Once an anomaly is detected, by either the onboard system of the aircraft or by the external surveillance system, an automatic call to first responders and/or airport authority could be made to inform relevant parties. Emergency response in this way can be executed more efficiently and on-time.

3 Analyses of regulations regarding electric vehicles

As the effects of climate change are becoming more visible in both the EU and the rest of the world – with increasing extreme weather events like: heat waves intensifying wild fires, heavy rainfall resulting in floodings, and a record-breaking Atlantic Hurricane season (2) – it's more important than ever to transition to sustainable alternatives.

Thankfully, battery technology has made leaps of improvements. Although electric cars have been around for over 100 years already, only in the last few decades battery technology has reached the required specific energy to be viable for aviation applications.

In 1973 the Militky MB-E1 was the first manned airplane to fly solely on electric power, with flights lasting only up to 12 minutes. In the 2000s and '10s, a lot of electric powered motor gliders were being developed and produced to further develop the technology and finetune its performance. Next the Pipistrel Velis Electro became world's first electric powered airplane to receive a Type Certificate in 2020.

With the certification of the Pipistrel Velis Electro it was found that there is no regulation regarding ground handling of electric aircraft and the charging of electric vehicles in general at the airside of the airport. And this poses a threat to making both aviation and ground operations more sustainable as this slows down the transition to alternative – more sustainable – energy sources.

This gap in regulation regarding battery powered vehicles is not just limited to the Pipistrel Velis Electro, it affects all electric aircraft and electric ground vehicles present on the airside of the airport.

3.1 Battery electric aircraft ground handling

For the analyses of regulations for battery electric aircraft the focus is on the Pipistrel Velis Electro because this is the only type-certified electric powered airplane to date. However, the points mentioned below are applicable for other electric aircraft as well.

3.1.1 Unattended charging

The main purpose of WP2 Task 2.2 unattended charging is to demonstrate that charging of an electric aircraft unattended can be done in a safe way. Even if the demonstration shows that it can detect all anomalies, this technology cannot be utilised by aircraft operators or airports until regulations are changed to allow unattended charging.

The main bottleneck for unattended charging to make market entry is therefore not hardware related but requires civil aviation authorities to provide a clear set of regulations to enable unattended charging.

3.1.2 Swappable batteries

Swappable batteries are a way of replacing the depleted battery of an electric vehicle with a fully charged one in a matter of minutes. This has a couple benefits compared to fast charging:

- Improved cycle life as the batteries can be charged more slowly, reducing internal stress.
- It's faster, some cars can replace their battery in less than five minutes for a fully charged battery, compared to 30 minutes for fast charging till 80% SOC, or over an hour to fully recharge it.
- Reduced power hikes on the electrical grid because charging of the batteries could be spread out more evenly over the day.

However, with the current regulations a battery swap is seen as replacing an aircraft part and thus a maintenance activity. This requires all checks and paperwork related to replacing flight critical components and is therefore not feasible within the current regulations.

3.1.3 Mixing of battery modules/packs

Mixing battery packs with different SOH might pose new risks which are currently not fully assessed. Different SOH will result in different available capacity and different power/current outputs from the battery packs. Therefore, if a Pipistrel Velis Electro needs a new battery pack, it is required to replace both battery packs to prevent differences in SOH of the batteries.

For the Pipistrel Velis Electro, which only uses two 11 kWh battery packs, this is acceptable. However, for a small commuter aircraft the battery capacity will be much higher and replacing the entire battery pack because a single module fails is not desired as this increases waste and costs.

It is therefore important to define clear regulations regarding mixing of battery modules/packs with different SOH, including means of compliance to demonstrate if/how batteries modules/packs can be mixed in a safe way.

3.1.4 Protective gear

The requirements for protective gear depend on the application. When working with hydrocarbon powered aircraft a different kind of protection is needed compared to electric aircraft. Protective gear requirements might need to be updated. This applies for both operations and maintenance.

3.1.5 Maintenance

In general, the wear and tear of an electric motor is significantly less, mainly due to less moving parts, no polluting gasses/particles clogging up the system, less vibrations, and no extreme temperatures from burning fuel. The main components which encounter depreciation are the inverters and the bearings of the motor.

The batteries on the other hand pose a serious risk if not taken care of properly. Cracks and dendrites could grow in the layers inside a battery cell which could cause a thermal runaway. The forming of these cracks and dendrites are seen as part of the ageing process of battery cells. It is therefore important to know when these cracks and dendrites pose a risk, but even an extensive D check will not be able to spot this. Other methods are therefore needed to measure the ageing of the cell to determine whether the battery packs are still safe for use.

3.2 Battery electric aircraft design requirements

Most regulations were written with hydrocarbon (kerosine/petrol/SAFs/e-fuels) powered aircraft in mind. Although the reasoning makes sense for hydrocarbon powered aircraft, for electric aircraft they not always do, and there could be electric aircraft specific safety hazards that are missed in the current regulations.

3.2.1.1 Engine/motor fire

Although the chance of a motor fire is significantly lower compared to combustion engines, and the risks involved in such a fire are lower as well, there is still a fire wall needed between the motor and cabin. At the same time, there is no firewall needed between the battery packs and the cabin, hence, when looking at the Pipistrel Velis electro, there is a firewall between the motor and front battery pack, but no firewall between any of the battery packs and cabin, which seems counterintuitive.

3.2.2 Power and Energy

In contrast to a hydrocarbon powered aircraft where you have an engine which can provide power independent of the amount of fuel left in the tank, the power available from batteries is dependent on the SOC and decreases as the battery voltage decreases.

The relation between power available and battery SoC is shown in Figure 1.

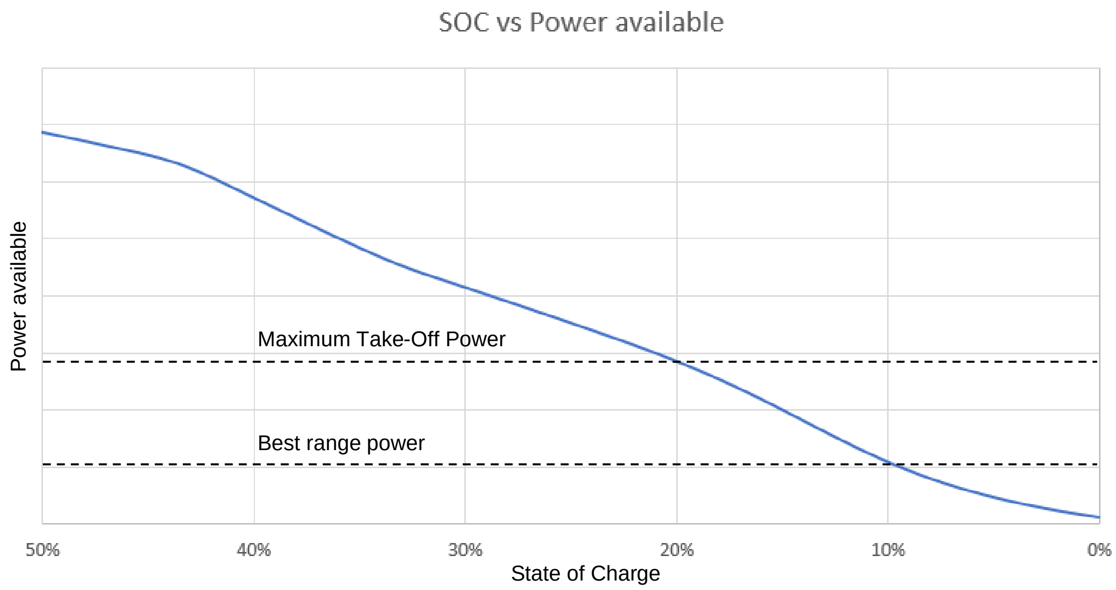

Figure 1 – Relation between State of Charge and Power Available at SOC < 50%

The dashed horizontal line indicating maximum take-off power crosses the power available line at SOC of 20%, meaning the battery cannot provide sufficient power for take-off at a SOC below 20%.

The current regulations require to always be able to provide maximum power, even when landing with only a few percent of the fuel/energy left. For electric aircraft this effectively means that the last part of the energy from the battery cannot be used as reserve energy,

However, if a go-around is performed with the Pipistrel Velis Electro, there is only an initial peak in power to 60 kW for one minute, and then decreases to 48 kW climbing power. After gaining sufficient altitude, the power is decreased even more to 20 kW for optimal cruise speed, and a new landing attempt can be made.

When comparing this example with Figure 2 it can be seen that a new go-around should not be initiated with a SoC of <20%. But with as little energy as 25% SoC, a go-around could be performed safely where MTOP and climb uses up to 5% of the SoC to clear 50ft obstacle altitude. Next the aircraft transitions to level flight and can continue to fly for 6 more minutes at 20 kW to make a safe landing.

Economically, it would make a sense to increase the DOD window of the batteries to include the part of SOC where available power is less than maximum take-of power, but still sufficient for level flight. This would increase the usable capacity of the batteries while still allowing the pilot to perform a go-around. A more detailed study of the safety risks in such reasoning should be performed, followed by corresponding change in guidelines and regulations.

3.2.3 Differently shaped refuelling connector

One of the regulations specifically for hydrocarbon powered aircraft is the requirement to have a different shape of refuelling connector to prevent refuelling with the wrong type of fuel.

For the Pipistrel Velis Electro this requirement didn't cause problems as the connector for recharging is already inherently different compared to a fuel connector. However, this might pose a problem for future aircraft since there are many different voltage and current ranges possible, dependent on battery pack design. Hence, a clear definition is needed detailing when different connectors are needed and when the same connector can be used. Below can be found more information regarding the voltage and current differences that can be seen during charging.

3.2.3.1 Voltage range

If an aircraft is designed with a modular battery pack which can rearrange the module configuration from an 800V pack – consisting of two 400V modules in series – to a 400V pack – consisting of two 400V modules in parallel – the aircraft can accept a much wider voltage range.

Even a "400V" battery pack could have different voltage ranges. In the table below are given three different automotive battery packs which are all considered to be a 400V battery pack. In case of the battery pack for the Volvo XC40, the 400V refers for the nominal voltage while for the Tesla Model 3's it refers to the maximum voltage.

Table 1 – Comparison voltage range of automotive battery packs

	NMC cell	LFP cell	Volvo XC40	Tesla Model 3 LR	Tesla Model 3
Capacity	-	-	82 kWh	78 kWh	60 kWh
Chemistry	NMC	LFP	NMC	NMC	LFP
Cell configuration	1s	1s	108S	96S	108S
V max	4.2	3.65	454	**403**	**394**
V nom	3.7	3.2	**400**	355	345
V min	2.5	2.5	270	240	270

It's important to note that all packs are considered 400V battery packs and can use the same charging infrastructure. There is communication between the car and charger to prevent overcharging the battery and optimise charging power during the charging session.

3.2.3.2 Current range

Current from the chargers is adjusted continuously based on the battery pack parameters like voltage and cell temperature. At low SOC and ideal battery temperature the current can be higher without causing significant increase in battery degradation, but at higher temperatures and higher SOC the current needs to be reduced to protect the battery and prevent overvoltage of the battery.

Overcurrent results in increased ageing of the battery cell, higher temperature and potentially a thermal runaway. It is therefore important that aircraft/battery can communicate with the charger to make prevent unsafe conditions during charging.

3.2.3.3 Conclusion different charging connector

Differences in charger connector should be limited only to different power classes (for example: specific connector for up to 50kW, 400kW and 1 MW) while exact needs and limitations of the battery are communicated to the charger by software. The physical differences in connector between these power classes are mainly necessary to accommodate the increase in contact area needed to allow higher currents.

Clear guidelines are therefore needed to make sure a battery can't be electrically abused by accident due to miscommunication between charger and aircraft. These guidelines should cover the communication protocol between charger and aircraft and make sure that connectors within the same power class are always compatible with each other.

3.3 Gaps found in regulations regarding airside charging

The regulations found below were found in Easy Access Rules for Aerodromes (Regulation (EU) No 139/2014) (3)

3.3.1 ADR.OPS.B.010(a)(2) Rescue and firefighting services

The current level of rescue and firefighting (RFF) services at airports is based on the longest aeroplanes normally using the aerodrome and their fuselage width. This does not take into account the different new fuels (batteries/hydrogen) that will be introduced in the upcoming years. Pipistrel currently prescribes to use 1000L of water per battery pack. This is significantly higher than the amount of water that is needed to extinguish a fire for a comparable 'conventional' aircraft that is powered by fossil fuel. Based on its dimensions the Pipistrel Velis Electro requires RFF category 1, while the amount of water needed to douse both battery packs actually corresponds to what must be available for RRF category 4 (2400 L).

Next to that, the current EASA Easy Access Rules for Aerodromes prescribe that the aerodrome operator *should ensure that any other duties carried out by rescue and firefighting personnel do not compromise the response, or their safety.* This means that airports should provide the right equipment to their rescue and firefighting personnel so that they can safely and efficiently handle battery-electric incidents at the airport.

Rescue and firefighting personnel should also be made aware of *(a) aerodrome familiarisation* and *(b) aircraft familiarisation.* This means that the aerodrome operator should inform the rescue and firefighting personnel on which charging equipment is installed at the airport. This would include the exact location(s) of the charging equipment and their specific characteristics – think of: power, emergency buttons (if applicable) and any specific procedures. Rescue and firefighting personnel should be trained on the specific aircraft type that is commonly present at the airport. Specific attention for electric aircraft will become more important as electric aircraft will become more common on airports in the next years. This would mean that training methods on how to deal with Lithium-Ion fires should be developed.

Finally, the type of fire extinguisher could be different, depending on the type of fire. in case of a motor fire, a waterless agent fire extinguisher should be used, as water could result in short-circuit, worsening the situation. In case of a battery fire on the other hand, a lot of water is needed to cool down the battery cells while adding extinguishing agents does not help because battery fires are self-sustaining. Short-circuit of the battery is not an issue in this case since the batteries are already in short-circuit during a thermal runaway.

3.3.2 AMC2 ADR.OPS.B.010(d) Rescue and firefighting services

The EASA Easy Access Rules for Aerodromes prescribes that the aerodrome operator should ensure that *rescue and firefighting personnel actively participate in live fire drills commensurate with the types of aircraft, and type of rescue and firefighting equipment in use at the aerodrome, including pressure-fed jet fuel fire drills or any other type of fuel, provided that they apply the same extinguishing techniques as for jet fuel.*

This would mean that aerodromes with home-based electric aircraft or frequent visits by electric aircraft should actively train on incident response for these specific type of aircraft. As standardised training on incident response with electric aircraft isn't common yet, aerodrome operators need to fall back on customised training methods and procedures.

Requirements to cover rescue and firefighting on aerodromes regarding electric aircraft should be provided at 'Acceptable Means of Compliance (AMC)' and 'Guidance Material (GM)' level.

3.3.3 ADR.OR.D.017 Training and proficiency check programmes

Aerodrome operators *shall establish and implement a training programme for personnel involved in the operation, maintenance and management of the aerodrome, to ensure their continued competence, and that they are aware of the rules and procedures relevant to operation of the aerodrome and the relationship of their functions and tasks to the aerodrome operation as a whole.*

This means that any new procedures or rules regarding electric aircraft should be included in training and maintenance programmes at the airport.

3.3.4 AMC1 ADR.OPS.C.005 Maintenance

New aerodrome facilities like electric charging infrastructure should be included in the aerodrome's maintenance programme, which specifies the aerodrome facilities, systems, installations and equipment that are subject to maintenance. Maintenance can be outsourced in case a third-party provides charging services at the airport.

3.3.5 ADR.OR.F.085 Apron management service

The introduction of electric aircraft also leads to the introduction of new charging infrastructure (mobile or fixed) at airports. This leads to the question who will provide these new 'refuelling/recharging' operations at airports. This could be airports themselves or third-parties. In case of the latter, a formal agreement including service-levels, responsibilities etc. should be established between the airport and party that would provide the charging service at the airport.

3.3.6 ADR.OPS.D.001 Apron management safety related activities

The aerodrome operator shall ensure that means and procedures are established and implemented on the apron in order to appropriate regulation on multiple activities, including stand allocation, aircraft parking procedure and aircraft refuelling. This means that there should be procedures in place to allocate electric aircraft to the correct aircraft stand (with fixed or mobile charging infrastructure) and procedures for charging electric aircraft. These specific responsibilities may be allocated (outsourced) to other organisations. If the aerodrome operator allocates such responsibilities, it shall include the allocation in the aerodrome manual.

3.3.7 ADR.OPS.D.025 Aircraft stand allocation

The aerodrome operator shall ensure that multiple parameters, like: aircraft characteristics, facilities serving the aircraft stand, the vicinity of infrastructure and the aircraft stand dependencies are taken into consideration when allocating aircraft to aircraft stands. This would mean that the aerodrome operator should take the allocation of electric aircraft to the correct aircraft stand into account. In this case this would be an aircraft stand that has charging infrastructure available or has the possibility to bring in mobile charging infrastructure.

3.3.8 ADR.OPS.D.045 Dissemination of information to organisations operating at the apron

Knowledge on possible limitations at the apron improve the efficiency and the safety at airports. Aerodrome operators have the obligation to disseminate information regarding limitations to operations on the apron in a timely manner to relevant organisations operating on the apron. Think of the availability of installations at the parking stands, like charging infrastructure. This information could include third-party operators that are involved in the charging process of electric aircraft or any potential user of electric charging infrastructure.

3.3.9 ADR.OPS.B.055 Fuel quality

For hydrocarbon powered aircraft there is a clear responsibility who needs to ensure fuel quality, found in Easy Access Rules for Aerodromes, ADR.OPS.B.055. These regulations include information about the equipment to store and dispense the fuel, markings, checks, and qualifications of staff using this equipment.

For electric aircraft there is no information about quality of the charger (fast charging degrades cells, overvoltage is potentially dangerous), nor who is responsible for the charging equipment (aircraft OEM, charger OEM, or airport operator).

3.3.10 ADR.OPS.D.060 Aircraft refuelling

Current aircraft refuelling standards have been developed for conventional aircraft that run on fossil fuels, like JET-A1 (kerosene) and AVGAS. Fuel handlers, whether done by the airport operator itself or through third-party fuel suppliers, make use of existing standards like the Joint Inspection Group (JIG). These standards and corresponding procedures at the airport and on the apron are suitable for the current conventional aircraft, but not applicable to electric aircraft. The introduction of these new type of aircraft will result in the need of new procedures at airports for aircraft refuelling, or in this case recharging. Airports currently have to rely on self-created procedures that are based on current state-of-art knowledge as long as standard electric charging procedures are not in place.

4 System design of the demonstrator

This chapter will describe the system design of the demonstrator which consists of three parts: the detection system, response system and the communication architecture between these two systems. Detection is the first part of the system that involves identifying anomalies such as a thermal runaway event or unauthorised personnel entering the charging area. The second part is the automatic response to disconnect the HV battery and inform first responders. Finally, communication architecture is the third part of the system that describes how the information is shared between the systems and relevant parties.

Below in Figure 2 is given an overview of the unattended charging system. On the left can be found the detection system, consisting of aircraft dependent systems and aircraft independent systems. On the right is shown the automatic response system, split between an action (stop charging) and sharing data with relevant parties.

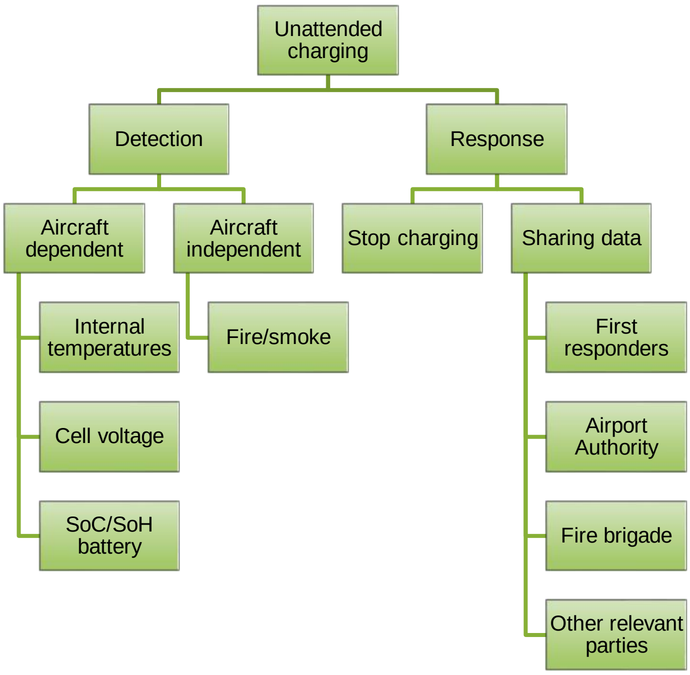

Figure 2 – Overview of unattended charging system

4.1 Detection system

There are two different detection systems available. The first is the aircraft dependent detection system, which is already in place to protect the aircraft. The second is the aircraft independent detection system which, using a smart camera system, can detect dangers around the aircraft and will function as a redundancy for detecting a battery thermal runaway event and that will function as a remote monitoring tool for airport stakeholders.

4.1.1 Aircraft dependent detection system

The aircraft dependent system is relying on the BMS to detect anomalies. Currently the BMS already monitors the batteries continuously and can take appropriate action if any failure condition is detected, including disconnecting the battery in case the BMS detects an overtemperature, overcurrent or overvoltage event to protect the system.

The main advantage of this system is response time. Anomalies can be detected close to the source before they become apparent from the outside of the aircraft. In addition to detecting anomalies in an early stage, taking action to stop charging and disconnect the battery does not require communication with systems external to the aircraft, improving reliability of the system.

4.1.2 Aircraft independent detection system

The aircraft independent system uses a smart camera system with visual recognition to detect anomalies visible from the outside.

For anomalies directly related to the battery system, the aircraft dependent detection system will detect these first. However, in case there is a failure with the aircraft dependent detection system, this system is needed as an additional redundancy. The smart camera system will not be able to check internal parameters inside the battery pack such as voltage levels and should instead be able to detect fire and smoke. The camera functions as a remote monitoring tool, thereby giving a visual image to airport stakeholders, like airport security and the airport authority.

4.2 Automatic response system

The unattended charging system should respond effectively when an anomaly is detected, and the right parties should be notified. In Table 2 below is a list provided of potential safety risks and the desired type of action (stop charging and/or notify specific party). The desired type of action is based on the danger potential for persons/personnel and the airport.

It is deemed acceptable that an aircraft could get destroyed if it does not pose a threat to personnel or passengers on the airport. A reasoning for the type of action for each potential safety risk can be found below the table.

Table 2 – List of safety risks and appropriate action

No	Description	Data source	Actions/ mitigations	Type of party to be informed
1	Automatic detection of smoke and fire.	Smart camera	Stop charging	Inform Fire brigade, airport security and airport authority.
2	BMS issues (high risk)	BMS		Inform Fire brigade and airport authority
2a	*Overtemperature (>58°C)*	"	*Disconnect battery*	"
2b	*Overvoltage*	"	*Disconnect battery, locked*	"
2c	*Overcurrent*	"	*Passive action: Thermal fuse*	"
3	BMS issues (low risk)	BMS		Airport authority.
3a	*High temperature (>51°C)*	"	*Stop/reduce charging speed, show caution*	"
3b	*Low temperature*	"	*Stop/reduce charging speed*	"
3c	*Undervoltage*	"	*Disconnect battery, locked*	"
3d	*Battery pack voltages not equal*	"	*Show caution*	"
3e	*Battery disconnected*	"	*Show reason for disconnection*	"
3f	*SOC unreliable*	"	*Show caution*	"
3g	*Auxiliary battery failure*	"	*Show caution*	"
4	Charging cables/power supply interruption	Aircraft	Stop charging.	Airport authority.

4.2.1 Automatic detection of smoke and fire

Fire needs to be detected as soon as possible to so appropriate action can be taken to reduce the hazards and damage of the fire.

A battery fire should be prevented by the BMS in the first place, but if this system fails or if the fire is happening external of the battery pack, an automatic smoke and fire detection system is employed as a redundancy which can recognise fire and smoke and alert appropriate parties.

When fire or smoke is detected, either from the aircraft, charger, or surroundings, there is clearly an increase in hazard. It is therefore deemed necessary to summon the fire brigade so they can inspect the source and take appropriate action. Also airport authority should be notified so they can inform other relevant parties or evacuate the space for example. An initial notification can be sent out to the airport security that has an overview of the airport through its video control centre. Finally, the aircraft should stop charging if this hasn't been done automatically already. Disconnecting the battery is mainly important in case the smoke is caused by the battery,

4.2.2 BMS errors

The safety risks related to the BMS have been split between high and low risks. The high risk safety issues include all errors which could cause a thermal runaway in the short term so immediate action is required. The low risk safety issues should not pose an immediate hazard.

4.2.2.1 High risk

Three high risk cases have been identified, and all result in the battery being disconnected. In case of overvoltage or overtemperature the battery will be disconnected from the HV bus. In case of overcurrent the internal fuses will blow.

4.2.2.2 Low risk

Most low risk safety issues will trigger a caution or warning message being sent to the monitoring system. In addition, the charging speed could be adjusted in case of high or low battery temperature.

When the battery has been disconnected due to one of the high risk issues a caution will be shown as well indicating why the battery pack has been disconnected.

4.2.3 Charging cables/power supply interruption

If the power supply to the charger is interrupted the charger will automatically stop charging the aircraft, and a manual input is needed to restart the charging process.

4.3 Aircraft operations monitoring system

In addition to the safety features which already monitor the aircraft continuously to detect any anomalies, an aircraft monitoring system is implemented on the demonstrator to improve logistics and asset management at the airport. This information is of value for both the airport authority as for airport maintenance.

The following data will be sent to the monitoring system:

- State of charge (SoC)
- State of health (SoH)
- Charging power
- Error messages from aircraft after activation of automatic response system

It will be possible for airports to assess the (real-time) utilisation and availability of the charging infrastructure at the airport. This makes allocation of electric aircraft to specific aircraft stands and charging infrastructure possible. Next to that, it also gives insights into the remaining charging time and the next possibility to charge another electric aircraft.

Asset utilisation, the number of times that a charger has been used for instance, is valuable information besides the real-time information that can be provided. This information will give airport maintenance personnel insights into the state of their assets. Communication protocols like the Open Charge Point Protocol (OCPP) are good examples of standardised communication protocols between electric chargers and vehicles. These standards are interoperable and have been applied by multiple different manufacturers of charging equipment. The aviation industry can learn from this standard development and the amount of data and the type of data that is exchanged between the charger, the vehicle and a back-end software platform. Next to that, it also allows transactions to take place which could benefit the business for airports.

Electric charger data can be utilized by many stakeholders, ranging from the user of the charger to airport operators. Figure … below presents an overview of different data sources that could derived from the charger (and indirectly the aircraft) and for which stakeholder this data could be of value.

Table 3 – Overview of different data and stakeholders

Data	Aircraft user	Airport Operations	Airport fire brigade	Airport maintenance	Charger manufacturer
State of charge	X	X			
State of health	X			x	
Charging Power	X	X			
Internal temperatures					X
Battery voltage					X
Battery anomalies	x	x	x	x	
Charger anomalies	X	X	X	X	X
Charger availability	X	X		X	X
Charger utilisation		X		X	X

4.4 Communication architecture

The most important automatic response from the system is to stop charging and disconnect the battery. If an anomaly is detected by one of the internal system of the Pipistrel Velis Electro, the safety measures currently implemented in the BMS of the battery pack will already do this. However, if the remote surveillance system detects an anomaly which requires an emergency stop – or if the airport authority decides to stop charging – this abort charging signal needs to be sent to the aircraft.

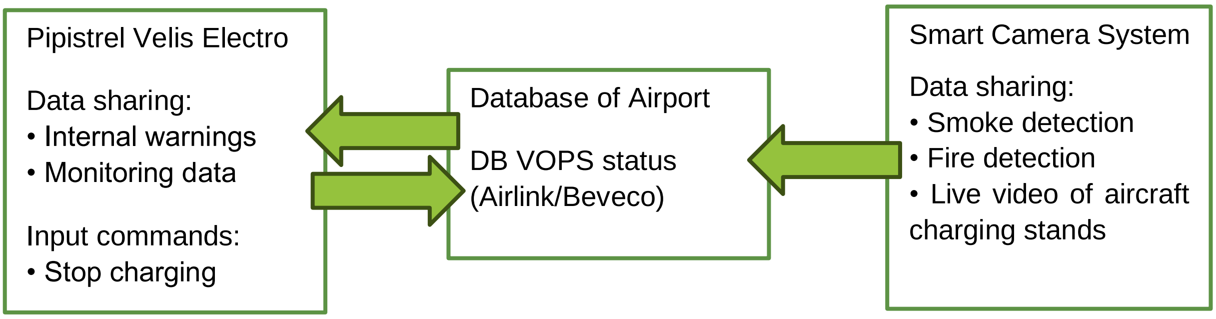

Figure 3 – Overview of communication architecture

The Bosch Smart Camera system will provide data to the Airport database regarding fire and smoke detection and can also provide a live video of the aircraft charging stands for airport authority.

The communication between Airport database and the Pipistrel Velis Electro is bidirectional; the aircraft provides data regarding its internal status but can also receive a command to stop charging.

5 Proof of function

The objective of Task 2.2 is to define the alternative means to enable unattended charging. These alternative means have been described in the previous chapters of this document, and this chapter provides a description of how the proof of function will be performed. Below an overview of the tests intended to be performed for validation of the system described in section 4.2 is provided, followed by a brief description of the test location. The test plans for the actual demonstrator, part of Task 2.5, can be found in Appendix D: Test plan for demonstrator.

5.1 Description test scenarios

Three potential safety issues were detected during the discussions and workshops of this project. The systems for the unattended charging should be able to detect each of these and take appropriate action to mitigate the risk. In addition, two more tests have been added to confirm proper data sharing between the system and relevant parties, so response time in case of an anomaly can be minimised. In the table below is provided a list of these tests and the desired subsequent response from the system:

Test	Description	Data source	Desired response
1	Charging cables/power supply interruption test.	Aircraft	Stop charging, inform airport authority.
2	Safety issues inside battery pack (overvoltage, overtemperature, etc).	BMS	Stop charging, inform airport authority and (depending on priority) fire brigade.
3	Automatic detection of smoke/fire.	Smart camera	Stop charging, inform fire brigade and airport authority.
4	Sharing of charging data and other analytical data over the air via an internet connection to relevant parties	NA	Inform airport authority
5	Sharing of detected abnormalities in an open data environment.	NA	Inform airport authority and fire brigade

5.2 Test location

The unattended charging demonstration will be performed on Rotterdam The Hague Airport. The location at the airport will be at the Rotterdamsche Aeroclub, one of the flight schools at the airport. This location has been chosen as the flight school is already operating the Pipistrel Velis Electro and because electric aviation will initially impact general aviation and specifically trainers.

The Rotterdamsche Aeroclub is hosted at Platform Quebec at the airport and has seven operational aircraft parking stands for code letter A aircraft with a maximum wingspan of 13.5 meter. The parking stand in the south-west corner of the platform, next to the flight school's clubhouse, will be used for the demonstration. Satellite and ground pictures of the parking stand have been added in Appendix C: Figures of RTHA platform Quebec

6 Conclusion

It is not allowed to leave the Pipistrel Velis Electro charging unattended unless alternative means are in place. The purpose of this task was to define these alternative means so electric aircraft can be charged unattended in the future, while ensuring the safety of the airport and people around it.

Although a technical solution was found that could detect and respond to anomalies, this will not be sufficient to enable unattended charging because current regulations do not cover these new types of propulsion systems sufficiently to allow unattended charging.

In chapter 3 these regulations are analysed, and it was found that:

- Electric aircraft should abide to the same regulations as hydrocarbon powered aircraft,
    - Some of the regulations are not applicable to electric aircraft and can be negotiated,
    - Some of the regulations are not applicable but still need to be followed,
    - Some regulations might be important for electric aircraft but are missing or insufficient because they are not applicable to hydrocarbon powered aircraft.
- For airport operations there are no clear regulations how this should be done from the applicable civil aviation authority.
    - Some airports are following national regulations regarding infrastructure and operation of (fast)charging stations in public spaces,
    - Some airports are setting up their own internal guidelines on how to operate electric vehicles and do their own safety assessments,
    - These internal guidelines can differ between airports.

This results in some hazards related to electric aircraft operations not being properly assessed, increasing risks for people/personnel near the aircraft. In addition to missed risks, there is also regulations intended for hydrocarbon aircraft which do not make sense for electric aircraft and add unnecessary hurdles for introducing new electric aircraft, potentially slowing down the transition towards electric aviation and increasing the risks related to climate change.

This report has identified, analysed and proposed mitigation measures in the missing gaps in regulations to enable unattended charging of electric aircraft and to demonstrate that current technologies have reached the required level of maturity to safely charge an electric arcraft unattended.

Appendix A: LIST OF REFERENCES

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3. **EASA.** Easy Access Rules for Aerodromes. *EASA Pro.* [Online] June 2023. [Cited: 24 November 2023.] https://www.easa.europa.eu/en/document-library/easy-access-rules/easy-access-rules-aerodromes-regulation-eu-no-1392014.

Appendix B: VELIS ELECTRO TECHNICAL SPECIFICATIONS

MODEL	VELIS ELECTRO
ENGINE	Pipistrel E-811 EASA Type-Certified
max power	57.6 kW MTOP
PROPELLER	Pipistrel P-812-164-F3A Certified fixed-pitch composite three-blade, 1.64 m diameter

DIMENSIONS	
wingspan	10.71 m (35.1 ft)
length	6.47 m (21.3 ft)
height	1.90 m (6.23 ft)
wing area	9.51 m2 (102.4 sqft)
aspect ratio	12.04
positive flaps	0° (0), 8° (+1), 19° (+2)
centre of gravity	24% – 32.4% MAC

WEIGHTS	
basic empty weight – with batteries	428 kg (941 lb)
max take off weight, MTOW	600 kg (1,320 lb)
payload weight	172 kg (378 lb)

PERFORMANCE

Data published for 600 kg MTOW (1.323 lbs). All speeds in Knots

stall speed with flaps, VS0	45 KCAS
stall speed without flaps	51 KCAS
cruising speed (at 35 kW)	90 KCAS
maximum horizontal speed at sea level	98 KCAS
never exceed speed, VNE	108 KCAS
max speed with flaps (+2), VFE	65 KIAS
manoeuvring speed	100 KIAS
best climb speed, VY	75 KIAS
max climb rate	3.3 m/s (647 ft/min)
best glide ratio speed	64 KIAS
best glide ratio	15:01
takeoff run – grass/asphalt	246/241 m (807/791 ft)
takeoff over 50′ obstacle – grass/asphalt	453/409 m (1,486/1,342 ft)
service ceiling	3,660 m (12,000 ft)
endurance	up to 50 minutes (plus VFR reserve)
max load factor permitted @ (1.875)	+4g -2g
design safety factors & tested	minimum 1.875

Note: Data is for ISA sea-level conditions. Pipistrel reserves the right to revise this data sheet whenever occasioned by product improvement, government/authority regulations or other good cause.

Appendix C: FIGURES OF RTHA PLATFORM QUEBEC

Figure 4 – Satellite Overview of Rotterdam The Hague Airport and the location of the Rotterdamsche Aeroclub; Imagery ©2023 Aerodata International Surveys, Airbus, CNES / Airbus, Landsat / Copernicus, Maxar Technologies, Map data ©2023

Figure 5 – Close-up of platform Quebec including the demonstration location at the aircraft parking stand in the south-west corner of the platform; Imagery ©2023 Aerodata International Surveys, Airbus, Maxar Technologies, Map data ©2023

Figure 6 – Charging infrastructure at the demonstration parking stand at Platform Quebec

Appendix D: TEST PLAN FOR DEMONSTRATOR

The purpose of this test is to demonstrate how an unattended charging system could function. This is done by simulating different failure scenarios which should be detected by the system and automatically respond accordingly as described in Table 2 found in "System survey acceptance protocol: Concept of unattended charging with belonging test plans and technological solutions implemented on a Velis Electro aircraft."

1. Scope of test and test objectives

Features that will be tested:

- Detection of Smoke by smart camera.
- Automatic stop of charging due to power supply interruption.
- Data sharing of issues detected by BMS with airport authority.
- Remotely stop charging by airport authority.

Because the purpose of these tests is to show that the technical solutions work accordingly, rather than charging the aircraft unattended, there will always be at least one person from test crew and/or aircraft operations attending the aircraft while it is charging to minimise risks.

Most hazards will be simulated to test the system, for example by using a fog machine to test the smoke detection rather than having an actual fire on the airport.

The actual detection of issues by the BMS and appropriate action will not be covered during this test as this has already been proven during certification of the aircraft and could result in damage of the batteries. Instead, a computer will be used to simulate a digital battery pack which can send error messages to the aircraft to test the data sharing capabilities of the aircraft.

2. Timeline

All tests will be performed during a single week testing period.
Each testing cycle starts with preparation of the Pipistrel Velis Electro which has a battery SOC of less than 50%.
During each cycle one of the following safety hazards should be simulated to test the unattended charging system:

- Cycle 1: No hazard
- Cycle 2: Detection of smoke by smart camera.
- Cycle 3: No hazard
- Cycle 4: Automatic stop of charging due to power supply interruption and remote stop charging by airport authority.
- Cycle 5: No hazard
- Cycle 6: data sharing of issues/hazards detected by BMS with airport authority
- Cycle 7: No hazard

After each charging session the aircraft needs to be prepared for flight and deplete the battery by either flying or via an alternative method. Once SOC is below 50%, the next test cycle starts.

3. Preparation for test cycle

Before each test cycle can start a WIFI-CAN interface needs to be connected to the aircraft charging CAN-bus. The connector of this CAN-bus is found near the data logger USB host port, on the right side of the instrument panel.

WARNING: REMOVE WIFI-CAN INTERFACE BEFORE FLIGHT

Once WIFI-CAN interface has been connected to the aircraft and is connected to the dashboard via the WIFI network the regular charging procedures can be followed to start charging the aircraft.

4. Simulation of errors during test cycle

Below in Table 1 are provided the testing procedures to simulate the hazards for each test cycle:

Type of hazard	Explanation
No hazard	These tests are needed to quantify false positives
Detection of smoke by smart camera	A fog machine will be used to create smoke that should be detected by the smart camera
Automatic stop of charging due to power supply interruption	Power supply to charger will be interrupted via distribution board.
Remote stop of charging by airport authority	From the airport tower a command via the monitoring dashboard will be send to the aircraft to stop charging.
Data sharing of issues/hazards detected by BMS with Airport authority	A laptop connected to the aircraft will be used to simulate a digital battery pack. The laptop can send warning messages from the BMS stating the battery is outside operating limits such as over voltage.

5. Finishing test cycle

After the charging session has been completed the results of the test should be logged.

Remove the WIFI-CAN interface from the Charging CAN-bus and follow regular procedures to prepare aircraft for flight or discharge aircraft using an alternative method.

WARNING: REMOVE WIFI-CAN INTERFACE BEFORE FLIGHT

6. Pass/fail criteria

The test is successful if:

- All hazards have been detected
- The automatic response system acted appropriately on the hazards (stop charging, informing relevant parties etc).
- False positives are within reason.