RESEARCH REPORT INTEROPERABILITY IN AIRCRAFT CHARGING

Student: Styn Vermetten
Student number: 500799663

HVA supervisor: Margriet Klompstra

Company: ElaadNL
Elaad supervisor: Baerte de Brey

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Preface

For the third-year internship, I did research for ElaadNL on interoperability within electrical aviation, with the goal of getting the first results on the implementation of interoperability in aviation.

For this research I used a qualitative research method where interviews were conducted with various experts within the sector to gain knowledge and opinions about interoperability and electric flying. With desk research I gained knowledge about this topic to be the best possible discussion partner during the interviews. With this I hope to have delivered a complete and well-founded final product.

Finally, I would like to thank everyone who has helped me during this research. First of all, my supervisor from the HVA during this internship Margriet Klompstra. I would also like to thank ElaadNL for the opportunity to do this research and I would like to thank all employees who helped with this research. I would also like to thank all the experts who made time for me to interview them. Matthijs Collard (E-flight school), Matthijs de Haan (Teuge), Luc Picard (ABB), Laura Leoncini (Greenmotion SA/EATON), Denise Pronk (Schiphol) and Jan-Willem Heinen (Venturi).

Last but certainly not least, I would like to thank Baerte de Brey for the help during this research and the work experience it has allowed me to gain.

Management summary

This report has been commissioned by ElaadNL to analyze interoperability in electric aircraft charging. The aim of this research was to find out why there should be interoperability in electric aircraft charging and what it takes to integrate this interoperability. To achieve this goal the following main question was formulated; Why should there be interoperability in aircraft charging and what does it take at an airport, in terms of hardware and software, to implement this?

The research conducted for this report consists of desk research and field research. The desk research consisted mainly of literature review, the purpose of this desk research was to obtain information about existing communication protocols and standards from the automotive sector and gain more knowledge about the electric flying and in particular the charging system for the electric aircraft. Nevertheless, it is not possible to complete this research with only desk research, therefore field research was also done. The field research consists of seven interviews with different specialists from different stakeholders. Such as respondents from the aircraft developers, charging system manufacturers and airports.

The most striking findings from the desk and field research are as follows, everyone believes interoperability is necessary in the future of aircraft charging. This is partly because with interoperability, different systems can communicate with each other and be monitored. This leads to cost and operational efficiency, it enables smart charging, and provides safety. To integrate this at an airport and in the charging systems, communication protocols and standards will need to be implemented in the aircraft charging systems. For the software, it is possible to adopt these protocols and standards directly from the automotive sector. For the hardware, it is more difficult; various standards from the automotive sector, such as the plugs, cannot cope with the larger amount of electricity required for the aircraft. However, we are looking at the larger electric aircraft that are still in development, the smaller electric aircraft already use a standard from the automotive sector. For the larger amounts of electricity, there is already a new standard in the automotive sector under development, the MCS standard, it is not fully in use yet. But a standard that allows charging is needed within the aviation sector, as it provides major operational and financial benefits. So, it will be waiting for the further development of the MCS standard, or a standard will have to be developed within aviation itself for aircraft charging.

Furthermore, the airports will have to ensure that their infrastructure is adapted in a way that the various systems can be implemented, such as making space available and installing electricity facilities. In the case of electricity facilities, this concerns the installation of green power facilities to be able to charge the aircraft.

The conclusion of this research is that interoperability in aircraft charging will be necessary in the future. Because eventually this leads to cost and operational efficiency, it enables smart charging, and provides safety. To implement this at an airport it requires adjustments to both the software and the hardware, whereby the software, looking at the communication protocols, can be adopted from the automotive sector. The hardware will need more adjustments, especially in the area of power capacity. Where standards still need to be (further) developed before they can be implemented in aviation.

Abbreviations

AC	Alternating Current
CPO	Charge Point Operator
DC	Direct Current
DSO	Distribution System Operator
eMSP	e-Mobility Service Provider
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
kWh	Kilowatt hour
MCS	Megawatt Charging System
OCA	Open Charge Alliance
OCPP	Open Charge Point Protocol
OSCP	Open Smart Charge Protocol
V2G	Vehicle-to-grid

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1: Introduction

This chapter will briefly explain ElaadNL and what they do. After which the issue for ElaadNL on the topic will be introduced and the final research question will be revealed.

1.1 ElaadNL

ElaadNL is the knowledge and innovation center in the field of Smart Charging and charging infrastructure in the Netherland and is an initiative of the Dutch grid operator. (ElaadNL, 2021) With the rising number of electric vehicles sold and the increase in the number of models coming onto the market, there will be more and more electric vehicles operating worldwide. (Weerd, 2021) This is good news for sustainability but also an important development for the electricity grid because more and larger users can cause problems on the grid. Through ElaadNL, studies and projects are being conducted to ensure that grid operators understand the measures that need to be taken to keep the grid reliable and affordable while enabling the development of E-mobility. Within the studies and projects of ElaadNL, innovative solutions such as Smart Charging are being explored, which ultimately deliver major social benefits.

The "exploration" of these solutions takes place in the Testlab where all types of charging stations are present that are also used in public areas in the Netherlands. All stations are able to Charge Smart and the energy flows will be managed by a central and controllable system. In the test site several high frequency power quality meters are implemented, which monitor the effect electric vehicles have on the electricity grid.
The tests can be carried out for both charging stations and electric cars and are performed to make sure customers can charge as efficiently, cost effective and smoothly as possible. The tests mainly take place on three themes: Smart Charging, Power Quality, and interoperability. (ElaadNL, 2021)

In addition to the technical aspects of charging electric cars, ElaadNL is also conducting research in the social field. It looks at the users of electric cars and their behavior in terms of charging. In this way more insight can be gained into power consumption and better predictions made for the future. Ultimately, as with the technical studies, the results will enable grid operators to see what measures are needed to guarantee the quality and reliability of the electricity grid.

1.2 Problem analysis

Because of the climate targets that have been set, it is important that the aviation industry looks for sustainable alternatives to fly. (IATA, 2016) One of these sustainable alternatives is flying electric, which requires a lot of adaptations at an airport. Looking at the hardware, the adjustments at the airport will mainly be to install charging stations and power supplies for these. On the software side, the adaptations at the airport will mainly focus on installing charging systems and protocols for charging. At the moment, most electric aircraft are still charged without the use of protocols, which means that the charging systems cannot "communicate" with each other and thus the charging process cannot be "smart". Due to this the impact on the electricity grid could increase significantly once more and larger electric aircraft become available, which could cause problems for energy suppliers and households who will be unable to supply and use more electricity. So, to avoid this, it is important that the charging systems can communicate with each other, this is also called interoperability. Also, at this time there is no known standard that will be used within aviation, which may cause many different systems to come to market. At the moment not much is clear about this in aviation, but as indicated earlier several sectors are already much further ahead in the field of electric transport, including the automotive sector. For possible solutions within the aviation sector, it may therefore not be necessary to reinvent everything, but another sector such as the automotive sector may be looked at first. Now ElaadNL is asking itself the question if the protocols and standards they developed for charging can also be used for electric aircraft or if there are still adjustments to be made for this. The research therefore focuses on the automotive sector and the various protocols and standards who creates interoperability in this sector. To find out what needs to be adapted at an airport to enable electric flying and what protocols and standards can be used to create interoperability in charging, the following research question was developed.

Why should there be interoperability in aircraft charging and what does it take at an airport, in terms of hardware and software, to implement this?

In order to answer the main question, several sub-questions have been drawn up and will be finished in chronological order. The following sub-questions were prepared:

1. What protocols for electric vehicle charging (EV-Charging) are there now and why are they used?

2. What is the impact of (smart) chargers, standards, and protocols on the electrical grid when they are used in the Electric Vehicle (EV) industry and in aviation?

3. Are fast chargers going to be applicable to every airport, and will they then be used for multiple purposes especially on regional airports?

4. Who will provide the facilities for charging, on regional and international airports, and what do the facilities look like in terms of safety and available space?

5. What differences are there between charging systems by aircraft type?

2: Research method

In order to clarify how this research was conducted, this chapter will explain the research methods used during this study. After which it will be explained how these methods were conducted and how the results were finally processed.

2.1 Methodology

This research is mainly about something that is still in the development phase, namely aircraft charging systems. To learn more about the charging systems and any associated protocols and standards and why they are used, desk research was conducted. Because aircraft charging systems are not yet fully developed, there has been looked at another sector in which more development has already taken place in the field of charging, the automotive sector. Within the automotive sector there are already several protocols in use and several systems have already been tested, which gives a better picture of why certain protocols and standards have been developed and how they work. With the knowledge gained from the desk research it was then determined with which parties' interviews can be held to find out more about the charging systems within the aviation sector. In chapter 2.2 more will be explained about the interviews. Ultimately, the results of both desk research and field research will be brought together into an outcome that will answer the main question of this research.

2.2 Interviews

Because this research has as its subject something that does not yet exist or is in initial stages of development, it was clear from the beginning that many answers would have to come from interviews with experts. Within a development process, different parties work together to ultimately achieve the common goal of developing a new product. Within the process of developing aircraft charging systems this is no different, here aircraft manufacturers, aircraft users, companies specialized in charging systems and airports work together. All these parties have an interest in the development of new charging systems and are therefore so-called stakeholders. For this research it was therefore important to talk to these different stakeholders in order to get a better picture of their vision on this development.

After having looked at which stakeholders there are, choices were made with which companies and persons an interview could be held. Looking at the group of aircraft users in the Netherlands, it was soon clear which company could be approached, this was Eflight Academy which is so far the only full-electric flying school in the Netherlands and therefore works daily with electric aircraft. For the aircraft developers, the choice was more difficult because there are a lot of companies working on the development of electric aircraft, eventually they chose Venturi who are developing an electric aircraft for 44 passengers which fits well within the scope of this research. (*All electric Echelon1*, 2022)
The specialized companies in the field of charging systems exist within the automotive sector but not yet within the aviation sector, yet ABB stood out by having plans for the development of large megawatt chargers that will also be applicable in aviation. Further discussions were held with Green Motion, this company together with Pipistrel has

developed the first EASA approved charging system for aircraft. The choice of airports is based on the decision to interview a regional and an international airport. Teuge Airport was chosen as the regional airport from which Eflight Academy already operates with their electric aircraft and Schiphol Airport was chosen as the international airport partly because of the large variety of aircraft that operate there. Below is the list of all respondents.

Table 1: Respondents

Name	**Function**	**Company**
Laura Leoncini	Business Developer E-Aviation	Eaton / Greenmotion SA
Matthijs Collard	Co-founder	E-Flight Academy
Jan Willem Heinen	Co-founder	Venturi
Luc Picard	Global Solutions Development manager	ABB
Matthijs de Haan	Director	Teuge
Denise Pronk	Head of sustainability	Schiphol
Well informed source*	N/A	N/A

**Person did not want to be named in this report* ***All persons agreed to be named in this report*

2.3 Processing the results

In order to elaborate the results as well and clearly as possible, it was decided to treat the results of the desk research and those of the interviews separately. The desk research is discussed in chapter 3.1 and mainly contains information about the protocols and the operation of various systems as they are currently used. The interviews are discussed in chapter 3.2 where the interviews themselves are processed in the appendices by means of summaries. These summaries are divided by interview question to make it clearer which questions were answered in the interview. The interviews will be further elaborated within the chapter based on the interview questions and the respondents' answers. Finally, in Chapter 3.3, the results of the interviews will be made visual through a table.

3: Results

This chapter elaborates on both the results of the desk research and the interviews. First, the structure of the desk research will be explained, in order to get a better idea of which topics have been studied. Then, the interview results will be elaborated through different topics and finally processed into a visual.

3.1: Deskresearch results

Before the results of the desk research will be discussed, the definitions of the key concepts of this research will be briefly explained.

Interoperability (software)
Interoperability generally means that systems (or equipment) are capable of mutual exchange or/and communication. In other words, the systems can 'talk to each other' and are in a sense 'compatible'. To achieve interoperability, standards, protocols and procedures are very important." (CJSM, 2020)

Technical interoperability (hardware)
Technical interoperability concerns all issues that are important for the connection of the processes, services and systems involved. This includes issues such as interfaces, connection aspects, integration of data their middleware, presentation and exchange of data, accessibility, and security. (*Terminologie | Informatiebeheer*, 2021)

3.1.1 Charging chain

To first get a better idea of the different protocols that exist, there has been looked at the car charging chain. Within this car charging chain, it can be seen that there are one or more different protocols working between each link in the car charging chain. Figure 1 shows the car charging chain, every link of this chain will be explained:

- First there goes a current from EV to the Electric Vehicle Supply Equipment (EVSE) also called the charging station between which a protocol works.
- The second link is between the EVSE and the Charge Point Operator (CPO), who arrange the installation of the charging stations, a protocol also works to be able to pass on information and quickly notice and fix any defects.
- The third link is with the clearinghouse and the e-Mobility Service Provider (eMSP), this is about the charging cards as they are now used in the automotive sector where you have to hold a card in front of the charging station for charging after which you pay per kilowatt hour (kWh).
- Finally, there is a link between the CPO and the Distribution System Operator (DSO), also called the network operator, this is mainly about the power that is given to the charging systems and between them protocols work to detect, for example, any bottlenecks in the power grid.

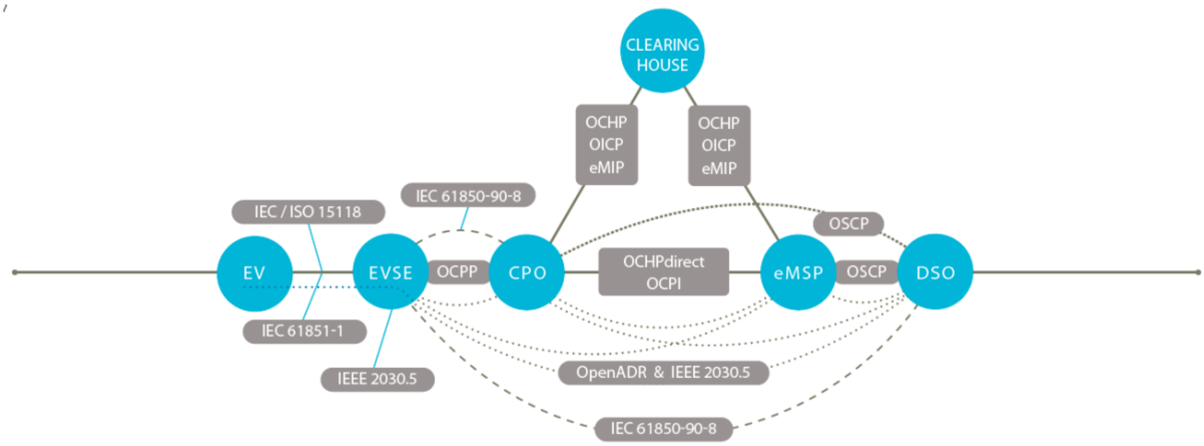

Figure 2: Charging chain (Klapwijk, 2017)

Looking at the functioning of each link in the car charging chain and what it is used for, one link emerges that is less important for this study, namely the third link. As indicated earlier, the third link is the one between the clearinghouse and the eMSP which ensures that through a charging card the payment for charging can be done. It was decided not to include this part in the study because the idea is that in aviation it is not convenient to work with charging cards. What is done now in aviation is to agree on a fixed price, currently for kerosene, and this is paid per agreed period. This is the most obvious solution to the many transactions for the airline. Therefore, the following charging chain showed in figure 2 was used within this study.

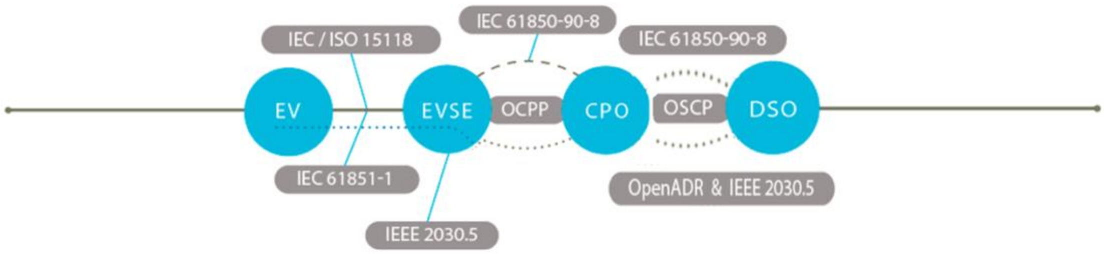

Figure 1: Charging chain used in this study

Now it is clear to see which protocols and standards might be used, these can be studied more closely to see why they are used and what their advantages are. This is covered in section 3.1.2.

3.1.2 Protocols and standards

Open charge point protocol (OCPP):

The OCPP is an application protocol for communication between electric vehicle charging stations and a central system and was developed by the Open Charge Alliance (OCA). The OCPP is designed and developed to standardize the communications between an EV charging station and a central system that’s used for operating and managing charging stations. It describes how communication between the EV charging station and the central system should take place. The OCPP is used to ensure that different systems can communicate with each other in a uniform way. In addition to the OCPP allowing different systems to communicate with each other, there are other benefits to OCPP as explained below:

- The OCPP is an open standard which ensures that the choice to purchase charging devices from multiple vendors and manufacturers is flexible. It also allows users to avoid vendor lock-in, which means that, users of this protocol can easily switch to other services or products from competitors and thus are not tied to a service provider or company. (EVBOX, 2021)
- The OCPP is not one protocol, but itself consists of a number of sub-protocols. (Aziz, 2021)
- Is independent of the charging technology, it works with all charging protocols.
- Ensures optimal distribution of power capacity between charging stations with dynamic load management. OCPP is only supportive for this, the party must otherwise arrange this themselves.
- Allows more charging stations to be installed in a place with limited power capacity without having to reinforce the grid.
- Enables companies to monitor their charging stations in real time. Initially this is mainly about charging session data but with OCPP2.0.1 it is possible to do real-time asset management for the stations themselves.
- Companies can offer dynamic pricing based on hours of the day, charging per kWh or duration.
- New features and improvements can be added relatively easily due to the openness of the protocol.
- On-site maintenance can be reduced by controlling charge points remotely. Software and firmware updates can be done remotely, hardware repairs do need to be done on site. (Aziz, 2021)

IEC/ISO 15118:

This is the communication standard that enables communication between your electric car and the charging station. It is also the standard that can ensure that the charging infrastructure of all car brands are on the same level through Plug & Charge. Plug & Charge means that it is possible to just plug the connected charging cable from the charging station into your electric or hybrid car and charging will start immediately. (Driivz, 2021a)
The main advantage of this Plug & Charge system is that it makes charging very easy. This simplicity is partly due to the fact that a (charging) card is no longer required to be able to charge. Instead of having to use a credit card, present a tag, using a mobile app, all they need to do is connect their vehicle to the charge point via cable or Wi-Fi for wireless charging. Each vehicle is linked to an individual billing account, whether personal, family, corporate, or other EV owner. Authentication standards allow the EV to automatically identify itself to the charging network and then begin the charge. The transaction will be accurately documented to reflect the energy that was supplied to the EV. (Redactie e-Drivers, 2020)

ISO 15118 further promotes performance in the following areas:

- Smart charging of EVs: Among other things, the smart charging mechanism in this standard perfectly matches the capacity of electricity grid with the cars that are charging at, for example, a charging station. This ensures a balance in the distribution of energy between the various charging points at a location and the electricity grid, and as a result the electricity grid is subjected to less load when there is a greater demand for energy. (Driivz, 2021b)

- Vehicle-to-grid charging (V2G): This is a technology that allows energy to be delivered back to the grid from a battery of an EV. Thus, it is a two-way energy transfer between the EV and the grid and better balances the grid. V2G further reduces demand on the electrical grid by using the vehicles' own energy to charge the grid and feeding energy back into the vehicle's battery during times of low demand or when the vehicle needs it. The latter is related to smart charging where the amount of energy going to the EV can be regulated based on when charging needs to be finished. (Driivz, 2021b)

IEC 61851-1:

The IEC 61851-1 is an international standard where the general requirements for EVs conductive charging systems are presented. According to IEC 61851-1 standard, the charging of EV's can be done in four ways, called mode 1-4.

- Mode 1: In this case the EV is connected to the residences standard socket outlets and the charging is realized without communication.
- Mode 2: In this mode the EV is connected to the domestic power grid via a particular cable with in-cable or in-plug control pilot, which is a device that assumes the safety and communication functions of the charging station, and a protection device.
- Mode 3: Here the EV is connected via specific socket on a dedicated charging station that had permanently installed the control and the protection functions.
- Mode 4: The EV is connected in the same way as in mode 3, however one big difference is that in mode 4 there will be charged with direct current (DC) instead of alternating current (AC) and charging with DC makes it possible to fast charge the EV. (Rata et al., 2019)

IEC 61851-1 is currently the standard for EV charging in Europe. This means that many thousands of charge points and every EV supports this standard. This standard is publicly available at limited costs, so the openness of this standard is very high. (Klapwijk, 2017)

IEEE 2030.5:

This protocol defines an application profile which provides an interface, which is an interface through which two systems communicate, between the smart grid and users. This standard is the mechanism for exchanging application messages, error messages and the security features used to protect the application messages. This communication can be between service providers and consumers, but also within a building or home network and between service providers and the aggregator with which again different programs can be read. Furthermore, with this protocol it is possible to manage the energy environment, which includes demand response, load regulation, price communication and energy storage. (*P2030.5 - Standard for Smart Energy Profile Protocol*, 2018)

IEC 61850-90-8

The IEC 61850-90-8 document is not a protocol in itself. It is a technical report which describes an object model for electric mobility. However, IEC 61850-90-8 can be considered as a protocol to control a charge point for both AC as well as (high power) DC charging. It optimized charging with scheduling and makes it possible to manage the grid and to do reservations of power. The model is available as an IEC technical report, however, there is no existing real life charge point implementation based on the protocol. At this moment this protocol is not in use anymore. (Klapwijk, 2017)

Open Smart Charging Protocol (OSCP):

This protocol communicates predictions of available grid capacity to other systems. The name also contains the word smart, and this protocol is also related to smart charging and regulating power capacity. It is based on a budgeted system where customer systems can pass the customer requirements to a central system which, through budgets per cable, prevents over consumption of the power grid. When a system needs more power it can request it, if it needs less it can return some of the budget which then becomes available for other systems. OSCP can thus be used to allocate, among other things, power capacity from a high-level system to a lower-level system. Partly because of this, the interoperability of this protocol is high. (*OSCP*, 2021)

3.1.3 Hardware standards in EV-charging and Aviation

In addition to the communication protocols and standards used in the EV industry, there are also hardware standards such as charging plugs. These plugs are connected to the vehicle after which power from the charging station can be supplied to the vehicle and charging can take place. There are different types of standard plugs that can be distinguished from each other in different areas. There are AC charging plugs which work with alternating current and there are DC charging plugs which work with direct current. Differently per continent, or sometimes country, certain plugs are used as standard. The list of standards per country or continent can be found in appendix 1.

Besides the variation in current type, there are also differences in the current speed that can pass through a certain plug. Looking at the AC charging plugs this can vary from 7.4 kW (Type 1) to 43 kW (Type 2), with the DC charging plugs it can vary from 200 kW (CHAdeMO) to 300 kW (CCS 1/2). (Charluet, 2021) The DC charging plugs can handle much higher current speeds, this is because with DC charging the on-board charger is not used and with AC charging the on-board charger does all the work. This means that with AC charging, the on-board charger in the vehicle still has to convert all the current to DC, which is not necessary at all with DC charging. Therefore, with direct current (DC) charging it is possible to charge quickly. (H, 2019)

Now the question is what is currently used for charging electric aircraft. Looking at what charging stations are currently already available for aircraft, there is one type within Europe that is approved by the European Aviation Safety Agency (EASA). This is the charging station from Skycharge that is suitable for the electric 2 seats Pipistrel aircraft. The specifications of this charging station can be found in Appendix 2. If one then looks at the specifications, and first at the current input and output, it can be seen that the charging station has an AC input and a DC output. This means that the charging station converts the current from AC to DC by itself, making fast charging possible. The standard plug used for this is a GB/t DC charging plug, which means that this charge post can currently supply up to 237.5 kW of current as shown in the second table in Appendix 1. It is also possible to work with a CHAdeMO and CCS charging plug, where CCS2 is a standard in Europe and can provide up to 350 kW of power. (Charluet, 2021) Furthermore, this charging station not only works with a standard charging plug but also already uses various communication protocols. The protocols used for this are OCPP and IEC 61851-1, these make smart charging possible with this charging station which in turn provides various benefits as explained in chapter 3.1.2. (*SKYCHARGE | Green Motion*, 2021)

So, in conclusion, it is already possible to charge electric aircraft quickly with different standards for all over the world. And some communication protocols are already in use in electric aircraft charging for smart charging.

3.1.4 Megawatt Charging System (MCS)

In the coming years, more and more types of electric aircraft will be developed. Detailed plans have already been made for some of these planes, including the plane of the Delft-based start-up Venturi. They are developing an electric aircraft for 44 passengers, which is a huge change compared to the Pipistrel. (*All electric Echelon1*, 2022)
This will not only lead to a change in the number of passengers that can be accommodated in the aircraft, but also the power required will increase many times over.

If one then looks at the power that the Pipistrel currently requires for charging, it is 22 kW. This is then for a 2 person aircraft, and this will mean that for the larger aircraft of Venturi a power is needed that will come in the Megawatt values. For these large values there are no standards available, but there is a standard in development, the MCS. This standard will have to offer a solution for the large amount of power required. Because the MCS is currently not or only on a small scale used within the automotive sector, many specifications of this standard are not yet available. What is known is that this standard can be used for a maximum current of 3000 Ampere DC (ADC) and a voltage of 1250 Volt DC (VDC). With this information it can also be calculated that the maximum power of this standard is 3000 x 1250 = 3750 kW, which converts to 3.75 Megawatt. This is a power that is not only suitable for electric aircraft but will also be able to be used for several other large electric vehicles such as trucks. (CHARIN, 2022) Also, this standard works with the same communication protocols and standards used in the EV industry, including ISO 15118. So, it would eventually be theoretically possible for the different sectors, to use one and the same standard.

3.2 Interview results

In order to make the interviews as smooth as possible, a questionnaire was created in advance with all the questions that could help to ultimately answer the research question and sub-questions of this study. The list of interview questions can be found in Appendix 3. Because each respondent has a different field of expertise, not all questions were used in each interview. Therefore, a table was created indicating which questions were answered by each respondent, this table can be found in Appendix 4. For each interview, it was explained in advance what the research is and what the purpose of this study is. This way, the respondents knew about the topic and could prepare for it. The elaborations of the interviews have been organized in such a way that each question answered in the interview has been elaborated separately in order to get clear what the respondents think about certain subjects and what their answers to the questions were in the end.

Interoperability

During the interviews it became clear that the respondents all thought the same about one thing, namely that interoperability will be needed in the future when charging aircraft. They looked at both software interoperability, where protocols play a role, and hardware interoperability, where standards for the same connection to the charging system will play a role. Luc Picard argues that interoperability is necessary because it is not economically feasible for the manufacturers of charging systems to make a charging system that only works with a certain brand or type. (Picard, appendix 7, 2022) To this, Jan-Willem Heinen adds that it takes a lot of time to create a new standard and that a good option is to adopt standards and protocols from other sectors, including the automotive sector. He does not see any problems in the short term; the interoperability from the automotive sector can be adopted by the aviation sector. To ensure that pre-existing plugs can be used, we look at the number of inputs on the aircraft. Suppose there are 4 inputs on an aircraft then there can be 4 plugs in the aircraft, if then the 9 Mw is needed you need 2.25 Mw per plug. This is still under the maximum of the megawatt plugs used for trucks (MCS) for example which means that for such an aircraft a plug from the automotive sector can be used. (Heinen, appendix 10, 2022)

From the perspective of the aircraft manufacturer there is another important point because interoperability is needed as soon as the chargers can be used by multiple aircraft types, the development of the chargers and ultimately the optimization thereof will go faster. This has to do with the software in the systems, when there are different protocols and standards in the charging system, the system can communicate information. This allows defects to be detected more quickly and the charging process to be optimized. It should be noted, however, that the focus at the moment is mainly on bringing an electric aircraft to market and the interoperability of the chargers is not a requirement in the short term. It is therefore possible that aircraft manufacturers will soon bring their own charging systems to market that are suitable for their aircraft. (Source, appendix 11, 2022)

Infrastructure

On infrastructure, opinions are a bit more divided, first of all on the procurement of charging infrastructure. Matthijs Collard says that at the moment airports, especially smaller regional airports, find it difficult to invest in new things like charging infrastructure. (Collard, appendix 5, 2022) This confirms Matthijs de Haan who adds that every airport would like to have its own charging infrastructure in the future but that it is currently not profitable to purchase, especially not for small airports, due to the small number of users and flights per day. Because of this, it will be a better investment for larger airports at this time, with more possible users and more flights per day. It could also be a solution for smaller airports to be able to use the chargers multifunctionally, for example by having the vehicles on airside also charge at these chargers. (De Haan, appendix 6, 2022) Laura Leoncini agrees and says that there are possibilities to use a charging system in a multifunctional way, these charging systems will have to use standards from the EV-sector. However, this is more suitable for smaller airports because at larger airports there is almost constant use of the chargers by aircraft themselves. (Leoncini, appendix 8, 2022) Also, the multifunctional use of the chargers will not be very profitable in commercial aviation because these aircraft need to fly as much as possible and therefore need to be charged as quickly as possible. Because of this, it will not be operationally possible at all to plan everything so that every electric vehicle can charge at the same chargers. (Picard, appendix 7, 2022)

In addition to the charging stations, systems are also needed to ensure that the charging systems continue to function properly. For example, cooling and heating systems are needed to ensure that the temperature remains optimal, and the charging systems can function properly. (Leoncini, appendix 8, 2022)

Bottlenecks

Looking at the bottlenecks that may arise when electric flying becomes more and more possible at airports, one bottleneck is often mentioned: the required electricity. According to Jan-Willem Heinen, the electricity needed for electric flying is the biggest bottleneck because, when compared to kerosene, it is about Gigawatt values, which is equivalent to a nuclear power plant in terms of power, and this is currently not available at airports. (Heinen, appendix 10, 2022) The disadvantage of this large, required amount of electricity is that at some point there will be a maximum of electricity that can be generated by for example solar and wind energy, says Matthijs Collard. On top of this, there will soon be fewer subsidies available for installing other ways of generating energy, so it will all come down to investors, who are currently hard to find. (Collard, appendix 5, 2022)
According to Jan-Willem Heinen, the possibility of removing old batteries from electric planes and using them as batteries to charge planes and store electricity is being considered. This is possible because the state of health of stationary devices, such as the shipping container, does not really have a minimum and the state of health in aviation is 90%. So, what happens to the old battery is that it is placed in a sea container at the airport, and it will act as a buffer for the power. (Heinen, appendix 10, 2022) As an airport, Schiphol too has already looked at whether there are possibilities to relieve the electricity grid. According to Denise Pronk, discussions have been held with aircraft manufacturers and plans have been put forward, such as an exchangeable battery. In addition to relieving the electricity grid, this

will ensure that more is possible operationally because the planning will be much easier because the battery can be recharged without the aircraft being present. However, aircraft manufacturers do not yet know exactly how this could be made possible and this solution brings with it other bottlenecks.

In addition to the electricity capacity, Denise Pronk states that operationally, a number of bottlenecks may arise. These include both the operation of the airport and the flying itself. This is an operational and financial bottleneck because a flight will be less profitable, and several existing routes may have to be adjusted to make it feasible for the electric planes. It is also true that the terminal will be used in a completely different way once small aircraft will arrive, the terminals are now equipped for hundreds of passengers but if soon aircraft with 20 passengers arrive at the gate, it will be so that a lot of space will not be used. (Pronk, appendix 9, 2022)

Safety

To ensure safety on the airfield and during operations, a number of safety measures will need to be taken. For example, according to Matthijs Collard, other protocols are needed at an airport for extinguishing electric aircraft, among other things. When a battery catches fire during charging or for other circumstances, it cannot simply be extinguished with water. The fire department at the airport must be aware of this and they must then know, through a protocol, what they can do. (Collard, appendix 5, 2022) In addition to such protocols, there should also be a way to immediately stop charging as soon as something goes wrong during charging. This could be done by means of a button on the charging station or in a central area where authorized people can enter. In addition to hardware safety regulations, a software system is also needed that can guarantee safety. For example, a system can be installed that monitors the charging process so that a malfunction is more quickly noticed, and accidents can therefore be prevented. These are examples of how it could be done at the moment, however, it is not the case that there is only one good way. The most important thing is that safety can be guaranteed and in what way this happens does not really matter. (Source, appendix 11, 2022)

Besides various hardware and software safety measurements, there is also another way to prevent accidents states Laura Leoncini. Training the staff is important to make sure they know exactly what to do, this prevents errors and at the same time makes sure the staff knows how to deal with problems. (Leoncini, appendix 8, 2022)
Here Luc Picard joins in and says that because of staff training, the safety measures for charging electric aircraft are much less compared to the safety measures for charging electric cars. This is because electric cars can be charged in public places, and anyone can connect the vehicle to a charging station. So, this needs to be handled much more carefully in terms of security because those charging stations are also used by non-specialist people. (Picard, appendix 7, 2022)

3.3 Interview result visual

In order to present the results from the interviews more clearly, there has been chosen to put the results in a table. Figure 3 shows the table, which categorizes the results from the interviews by topic. For each topic, the results were divided into software and hardware points. Finally, a distinction has also been made between the results in terms of efficiency (purple) and costs (red). The efficiency is about which points yield cost and operational efficiency for an airport and the costs are about which points cost the airport money.

This allows one conclusion to be drawn from the interview results, which is that; interoperability is mainly efficiency for the airport and the cost for this particular issue is low because it will be installed in the charging systems and thus add to the cost of the infrastructure. The infrastructure will be a big cost for airports because they will have to purchase both the charging systems and the associated equipment, which will ultimately provide efficiency in the operation though. But they will also need to be able to generate green energy at the airport to keep flying sustainable, so green energy facilities will need to be built. As with the infrastructure, the bottlenecks are a major cost item for the airport. It is not so much the bottlenecks themselves that are the cost item, but the adjustments to remove these bottlenecks that cost the airport money. Ultimately, for safety an investment must be made by the airport, such as staff training, in order to create efficiency and a safe working environment.

Interoperability	**Infrastructure**
Software: • Not a priority in the short term, but necessary in the future • Communication protocols and standards from the automotive sector can be directly adopted within aviation • Communication protocols will allow for faster improvement and optimization of the charging process due to monitoring ***Hardware:*** • Standards from the automotive sector will have to be adopted to handle the power demand or aircraft will have to be designed so that an existing standard is useable for the aircraft • Standard plug for each type of aircraft will be required	***Hardware:*** • Airports would like to have their own charging infrastructure in order to generate money with it • Green power facilities will to be built to provide power to aircraft charging systems • Now often still too large an investment for many (small) airports • The charging stations can be used multifunctionally, however, this is operationally a challenge for the airport • Cooling and heating systems for the charging stations are necessary to make them work optimally
Bottlenecks	**Safety**
Software/Hardware: • Enormously high electric capacity is required at an airport • There will be a maximum amount of green electricity to be generated, after which the electricity grid may have to be adapted ***Hardware:*** • In particular, the initial phase of electric flying, where there are still few charging stations at an airport, will lead to operational challenges • Spaces at airports cannot be optimally utilized due to lower numbers of passengers on planes	***Software:*** • Protocols for fire, for example, will need to be updated • Systems should be installed to monitor the charging process (OCCP) ***Hardware:*** • Training to eventually train people as specialists • Safety needs to be guaranteed, there is not only one good manner to do this • Emergency stop is necessary to stop the charging process and ensure safety

Figure 3: Interview results visual by topic

4: Conclusion

The conclusion of this research is the answer to the main question: Why should there be interoperability in aircraft charging and what does it take at an airport, in terms of hardware and software, to implement this?

Within this study, we looked at two types of interoperability. The first is hardware interoperability, which includes the charging plugs and other physical infrastructure. The second is software interoperability, which includes the various (communication) protocols and charging systems.

To answer the main question, the sub-questions were answered first:

1. *What protocols for electric vehicle charging (EV-Charging) are there now and why are they used?*

Several (communication) protocols and standards are currently used within the EV industry. These include the OCPP, OSCP and ISO 15118. These are used to ensure that smart charging becomes possible, which brings various benefits. The benefits include optimal distribution of power capacity between charging stations, allow monitoring charging stations in real time and plug and charge.

2. *What is the impact of (smart) chargers, standards, and protocols on the electrical grid when they are used in the Electric Vehicle (EV) industry and in aviation?*

Charging infrastructure has a major impact on the electricity grid. In the EV sector, it is already clear that the load on the electricity grid is very high and also has to deal with various peak moments. It is expected that the aviation sector will have an even greater impact on the grid because aircraft are larger electricity consumers and airports constantly need a lot of electricity from the grid to charge their aircraft.

3. *Are fast chargers going to be applicable to every airport, and will they then be used for multiple purposes especially on regional airports?*

Fast chargers will ultimately be the best thing for any airport to purchase. Looking at it from a commercial point of view, it is important that the aircraft can fly again quickly after arrival in order to fly as much as possible and thus generate revenue. Furthermore, fast chargers can charge both fast and slower, other charging stations can only charge at one speed. This will allow for multifunctional use where other vehicles can also charge at the fast chargers. However, fast chargers are more expensive to purchase and in some cases, this may mean that other charging stations than fast chargers are chosen because this may not be strictly necessary at these locations, such as small regional airports.

4. *Who will provide the facilities for charging, on regional and international airports, and what do the facilities look like in terms of safety and available space?*

For the airport the charging stations are also one of their sources of income, therefore airports will prefer to purchase and manage the charging infrastructure themselves. However, it is important that it is a universal interoperable charging system, to avoid having to purchase different charging systems, which increases the costs. Interoperability is also important, as it requires the use of a standard plug and systems, including communication protocols, that can be used on multiple aircraft. This ultimately brings operational benefits in addition to financial benefits

5. *What differences are there between charging systems by aircraft type?*

The differences that currently exist in aircraft charging systems relate primarily to power. The only charging station currently in use in Europe has an output power of 22 kW; for the larger aircraft this will be in the direction of Megawatt values. Furthermore, OCPP is currently being used in the charging stations and this will later be extended to other charging stations.

This research has shown that interoperability is definitely needed in the future when charging electric aircraft. In addition to the hardware interoperability that is important to ensure universal interoperable charging stations, as mentioned in point 3, there is also the software interoperability. This software consists of the different communication protocols and is important because with the help of these protocols the impact on the electricity grid can be reduced. This is because through the use of (communication) protocols it becomes possible for the different connected systems, such as the aircraft and the charging station, to communicate with each other. This makes smart charging possible which brings several advantages including optimal distribution of power capacity between charging stations, monitoring charging stations in real time and Plug and Charge. Which in turn are benefits that are essential for an airport, which will be home to large electricity users in the future, to run its operations as efficiently and safely as possible and to use power capacity as optimally as possible. Ultimately, hardware and software interoperability lead to major operational and financial benefits, as it allows one and the same system to be used which has a positive effect on operation planning and the production cost of the charging systems, which in turn reduces procurement costs.

In order to implement interoperability at an airport, a number of points are crucial in terms of hardware. In addition to having a charging station installed at the airport, cooling and heating systems for the charging station are also required and space will have to be made available for this. Green power facilities will also need to be placed at the airport to ensure that the planes can charge with green power. Furthermore, a standard will have to be used that can handle the amount of power, of which currently only the Megawatt plug (MCS) for trucks is suitable for some specific aircraft and space will have to be made available to give the larger non-moveable charging system a fixed place at the airport. In terms of software, the systems used in the automotive sector could be used. In this regard, each airport will have to consider which protocols will give them the greatest advantages in operations.

5: Recommendation

From this research no solutions can be given directly, this study shows what it takes at an airport to implement charging infrastructure and interoperability at this moment. Therefore, an advice can be given to the airport how they can proceed. This is then a step in the right direction to eventually implement electric flying.

As indicated in the conclusion, it is important to work with a standard that works for each aircraft, in order to create operational and financial benefits. However, the standard which so far is only possible for higher power ratings, MCS, is only applicable to a few aircraft and will therefore have to be further developed before it can be applied to more aircraft. Therefore, it is important for an airport to keep a close eye on the market and the developments around electric aviation. Hereby persons will have to be appointed who look at the further developments of the aircraft and the charging systems in order to take the first steps perhaps already towards charging systems for various aircraft. Since these developments are in some cases already at a further stage, it is important that a report is written annually on the developments with any recommendations for the airport as a result of the findings.

Following these reports, the airport will also have to make a strategic plan. This should include which types of aircraft and loading systems they will have to deal with the most. A plan will also have to be made describing how the power will be facilitated, which protocols will be used and how the space will be divided to implement the charging infrastructure. This will vary by type of airport, regional or international. This research has shown that the software interoperability, the communication protocols, can be adopted from the automotive sector. To help airports implement these protocols, organizations such as ElaadNL could play a supporting role. They will be able to rewrite an existing protocol for the aviation sector in order to give a clearer picture of what the system will look like.

Ultimately, not all of the answers are yet available, and the intention is also to have discussions with various parties in the industry. This in turn will eventually lead to new developments and answers.

6: Discussion

During this research several parties within the aviation industry have been interviewed, however, no interview with a specialized company in the field of airport design could take place. This is because the company did not have time within the stipulated time of this investigation, and this may have led to less information on this subject.

Another discussion point is that at the time of the research there is a lot of information available on this subject which is not based on test results. Because electric flying is still in its early stages, many companies that are working on it prefer to keep their information to themselves until more is known. Also, because it is still in the early stages, there is a lot of uncertainty so much of the information obtained from interviews is based on the first test results and opinions of the respondents. Therefore, some of the outcomes of this study are based on the most positive and optimal scenario, which may later prove to be not all possible. Because of this, more research will have to be done after this study once more tests have been conducted and the results are available. As indicated in the recommendation, this will require airports, for example, to keep a close eye on developments and to make strategic plans for the future. Therefore, the ultimate goal of this research and internship is to organize a discussion within ElaadNL, in which different people from the aviation industry participate. In order to ultimately stimulate further research.

Finally, partly due to the covid-19 pandemic, it was not always possible to schedule interviews with everyone who wanted to be spoken to. This had to do with little time in the planning of the respondents or had other reasons concerning covid-19.

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Appendices

Appendix 1: EV charging plug types

Figure 4 shows the standard charging plugs showing the maximum power they can hold and in which parts of the world/countries they are used as a standard. The standards in Figure 4 are based on AC current. Figure 5 also shows the standard charging plugs with the same information as in figure 4 only these are the standards based on DC current.

AC charging plugs

Plug type	Design	Power output*	Locations
Type 1		Up to 7.4 kW	Japan and North America
Type 2		Up to 22 kW for private charging Up to 43 kW for public charging	Europe and the rest of the world
GB/T		Up to 7.4 kW	China

Figure 4: AC charging plugs (Charluet, 2021)

DC charging plugs

Plug Type	Design	Power output*	Locations
CCS1		Up to 350 kW	North America
CCS2		Up to 350 kW	Europe
CHAdeMO		Up to 200 kW	Japan
GB/T		Up to 237.5 kW	China

Figure 5: DC charging plugs (Charluet, 2021)

Appendix 2: Specifications Skycharge charging station

Below, in figure 6, is the table showing the specifications of the, so far, only aircraft charging station in use within Europe. The top two columns show the input and output current values of the charging station. In the output column you can also see that it concerns DC-current (55Adc). In addition to the current values, the output column also indicates the type of plug that is used, i.e., the GB/T connector or CCS/CHAdeMO. The regulation column also states which other protocols and standards are used, OCCP 1.6J and IEC61851-1.

Power input	SKYCHARGE
Input voltage	3 x 400V_{AC} 50Hz
Input current	3 x 32A_{rms} (22kW)
Power factor	> 0.99
Standby consumption	< 50W

Power output	
Output power	22kW
Output voltage	530V_{DC} (can be increased to 1000V_{DC})
Output current 22kW	55A_{DC}
Output type	GB/T connector (other connectors on request) optional CCS or CHAdeMO
Efficiency	> 96%
Simultaneous charging	1

User interface & control	
User interface	Button, charging status indicator, 10 inch touchscreen display
Control of access	RFID, SMS
Network interface	Ethernet cable; 3G,4G or 5G
Remote management	Software management system (eMobility Cockpit)

Environmental	
Operating temperature	-25°C to 45°C
Altitude	Up to 2,000m (6,500 ft.)
Installation	Column, indoor or outdoor
Humidity	< 95% relative humidity

Mechanical	
Dimensions	1705 x 475 x 222 mm
Weight	85kg
Housing material	Stainless steel
Cooling	Fan cooling
Cable length	8 meters; 27 ft (custom length on request)

Regulation	
Conformity	AS6968 pending; IEC 61851-1; Pipistrel approved charger
Protection rating	IP54
Communication protocol	OCPP 1.6J
Bidirectional	V2G
Protection	Protection against surge, over current, over voltage, short circuit, over temperature, ground faults, insulation monitoring device, galvanic insulation

Figure 6: specifications of the Skycharge aircraft charger (*SKYCHARGE | Green Motion*, 2021)

Appendix 3: Questionnaire

Below are the interview questions, these were prepared before the interviews began. Not all questions were used in each interview, because each respondent has a different field of expertise. More about the questions asked per interview is explained in Appendix 4.

Interview Questions:

1. Why do you think interoperability is needed, or not needed, in aircraft charging?
2. How do you think electric flying will impact the airport's power grid?
3. What is needed at an airport beyond charging stations to make electric flying possible?
4. Will fast chargers be the right facility at every airport, or will they not be needed in some cases?
5. Will these (fast) chargers then be used multi-functionally, looking at other electric vehicles at an airport?
6. What are the safety measures that should/could be taken with regard to charging and charging stations?
7. Are there any bottlenecks that may arise once more electric aircraft arrive?
8. Do you think much needs to change in regulations to eventually make electric flying possible?
9. What are the specifications of the batteries in the aircraft now and what is the expectation that it will be in about 10 years?
10. Some aircraft manufacturers have their own charging systems; do you think this could also become an option for airports? And if so who do you think will have to purchase the charging systems?
11. Looking at the smaller regional airports, have plans already been made to ensure that the charging infrastructure will be used in the most optimal way?

Appendix 4: Table answered questions per respondent

As indicated earlier, not all interview questions were asked of all respondents. In order to provide an overview of which questions were asked per interview, a table has been created indicating which interview question was asked per respondent.

Respondents →	Matthijs collard (EFlight)	Matthijs de Haan (Teuge)	Luc Picard (ABB)	Laura Leoncini (Greenmotion/ EATON)	Denise Pronk (Schiphol)	Jan-Willem Heinen (Venturi)	Well informed source
Question 1	x		x	x	x	x	x
Question 2	x		x	x	x		x
Question 3				x			x
Question 4	x			x	x		x
Question 5	x		x	x	x	x	x
Question 6			x	x			x
Question 7	x	x	x	x	x		x
Question 8	x		x				
Question 9	x					x	
Question 10	x	x	x	x	x		x
Question 11	x	x					

Appendix 5: Interview Matthijs Collard, Co-founder E-Flight academy, 3-12-21

- **Why do you think interoperability is needed, or not needed, for aircraft charging?**

Interoperability is not that important for a flight school because they operate from their own hangar and therefore just want to have a device with a fixed charging point. For any charging plazas eventually at an airport, it is more important that multiple people can charge at the same charging stations. This is partly because various subsidies will be granted and ultimately the most efficient way must be found because it is not possible for an airport to apply for subsidies four times for four different charging areas. However, for the coming years it is not very important that universal charging systems are introduced. Only when charging is as fast as refueling will it become attractive to have universal charging systems. Until then, the airlines that have electric planes will probably install their own systems at airports.

- **What are the specifications of the batteries in the aircraft now and what is the expectation that it will be in 10 years?**

In the coming years until 2024 fleet expansion is still possible with only the pipistrel, after that there will be other aircraft with larger batteries (75 kWh) that can fly for 4 hours, which ensures that, for example, as a flight school you can carry out the entire training electrically. Eventually the batteries will become bigger and bigger, allowing the aircraft to fly further. however, it is now a question of where large aircraft manufacturers will focus their efforts in the future, looking at hydrogen and electricity.

- **Looking at the smaller regional airports, are there any plans already made to ensure that the charging infrastructure is going to be used as optimally as possible?**

Eflight academy is currently working on a subsidy for a loading dock where the plan was first that the loading dock would be located on the grounds of Teuge airport, however, due to the many shareholders, this is not immediately possible at Teuge. It has now been said that the loading dock can be built on Eflight's land at Teuge Airport, which could later have a negative impact on Teuge because the loading dock would then be owned by Eflight and Teuge would not be able to generate any income from it. Especially small airports find it difficult to invest in something new like a charging infrastructure, but the use of the airport and its facilities is their source of income so they will have to look carefully at how best to deal with this. Larger airports find it a little less difficult because they employ strategists and other people with knowledge of these issues who can get to the bottom of it all and draw up a strategic plan for the airport.

- **Will fast chargers be the right facility at every airport or is this not necessary in some cases?**

Fast chargers are actually always the right solution for an airport, looking at the commercial flights they just need to be in the air as much as possible so they can charge as fast as possible. Looking at the flight school, it can be said that at the end of the day the aircraft can charge slower until the next day, but there is no need for a separate charging station because you can also just set the fast chargers a bit slower.

- **Will these fast chargers then be used multifunctionally, looking at other electric vehicles at an airport?**

At the moment we cannot say if it is possible that other vehicles will charge at the same charging station as the aircraft, it is also true that this charging station now only works for the aircraft and at the moment there is no other certified charging station for airports. It is also the case that the charging stations for aircraft have much higher specifications than the automotive chargers and so even though they may be the same plugs and work with the same protocols, it is still too expensive a charging station to use for different vehicles. The whole infrastructure behind the charging stations might be able to be combined with charging stations for other vehicles, think of the solar panels and other infrastructure that generates energy for the charging systems.

- **Some aircraft manufacturers are working with their own charging systems, do you think this could also become an option for airports? And if so who do you think will have to purchase the charging systems?**

What we are seeing now in particular is that the builders of new electric aircraft are also starting to develop their own charging infrastructure, such as Venturi. Right now, Pipistrel is using their own charging system that is based on greenmotion technology using OCCP 1.6. Now it is not really clear how it is going to be regulated at large airports regarding the charging of larger aircraft, but what certainly needs to be in place at an airport is a standard so that it will not be the case that Airbus aircraft cannot charge on Boeing's charging systems.

- **What do you think the impact of electric flying will be on the airport's power grid?**

The impact on an electricity network is high when airports start charging because at the moment in Teuge two charging posts is the maximum, another one will exceed 80A. One solution would be to generate our own power, like Groningen airport where there is a large solar panel field creating a sort of private grid from which we can "tap" power. Solar energy in particular is very suitable for this because there is a lot of space at an airport and solar panels pose no danger to aircraft because they can be placed low down on the ground.

- **Do you think much needs to change in the regulations to eventually make electric flying possible?**

At the moment, the regulations for charging are exactly the same as for refueling. This is quite impractical because, for example, rules such as not charging indoors and always being present at the aircraft during charging are set up without this being really necessary, of course. But this still needs to be adjusted and there are already exemptions granted to Eflight for certain rules regarding loading. In the field of flying there are also rules that may be adjusted such as A to B flights where now 30 minutes reserve must be left which ensures that you can only fly very short and therefore not efficient.

- **Are there any bottlenecks that may arise once more electric aircraft arrive?**

In terms of bottlenecks, at a certain point you reach a maximum of energy that you can generate by, for example, wind and sun. And subsidies will soon be less available, so it all comes down to whether there are investors. Also, in terms of noise it could be a bit less because at the moment it is still quite noisy during charging and as soon as more aircraft start charging this will only increase. Also, for the fire department at the airport it is still different than with kerosene aircraft because you can't just extinguish a battery, so this also requires other protocols at an airport.

Appendix 6: Interview Matthijs de Haan, Director Teuge Airport, 8-12-21

- **Some aircraft manufacturers are working with their own charging systems, do you think this could also become an option for airports? And if so, who do you think will have to purchase the charging systems?**

At the moment Teuge is not investing in the charging infrastructure for aircraft itself, as Matthijs Collard has already told us. However, it is not the case that Teuge as an airport does not want its own charging infrastructure for aircraft but at this moment it is simply not profitable for Teuge to invest in it because there are still too few users (Eflight). Eventually every airport will want its own charging infrastructure as this is a major source of revenue just like kerosene is.

- **Are there any bottlenecks that may arise once more electric airplanes arrive?**

One of the bottlenecks that currently exist at Teuge is the electricity grid, because at the moment more aircraft cannot be added because then recharging will no longer be possible. Plans have already been made to look into generating our own electricity by means of solar panels. This plan is already ready and will provide both the airport and surrounding houses with power from the solar panels. The latter has ensured that subsidies can be obtained more quickly because the local residents often agree more readily than if it were only beneficial to the airport. Other bottlenecks that are currently being encountered mainly have to do with regulations; roughly speaking this is because there are no regulations yet for electric flying. Examples of this are not charging indoors and keeping a certain amount of reserve. This means that, for example, a full pilot's license cannot yet be obtained electrically because certain flights still take too long. It is also true that in terms of fire safety some things are changing with electric flying, which ensures that adjustments must be made to the rules for example for extinguishing the aircraft.

- **Looking at the smaller regional airports, are there already plans in place to ensure that the charging infrastructure is used as optimally as possible?**

At the moment the charging stations are only for the aircraft but there is certainly a chance that later on the charging stations will also be used for vehicles at the airport that are slowly becoming all electric. To make this happen, a charging station will have to be created in a central location, because at the moment the vehicles are parked in a different place than the planes. As an airport, we are not only looking at the charging infrastructure for aircraft at the airport but also at the charging infrastructure for guests who come here with an electric car. In the plans as they are now with the solar panel field, the charging infrastructure for the guests will use the same power as the charging infrastructure for the aircraft, this will therefore come from the solar panels.

Appendix 7: Interview Luc Picard, Global Solutions Development manager, ABB, 14-12-21

- **Why do you think interoperability is needed, or not needed, in aircraft charging?**

Looking at the pricing and the business case, it will certainly be important to have interoperability. There is no major industrial player that is going to build a charger that is going to be used only for certain brands. That's purely because it's just not economically feasible and takes a very long time. What can be seen now is that the planes that are being built now are similar to trucks. The planes are going to be charged with megawatt charging systems and initially it looks like the same standards as trucks like MCS are going to be usable one to one for aviation. Further research is being done to see if MCS is really possible within aviation and it certainly remains to be seen since MCS is not currently being used anywhere. More and more aircraft manufacturers are now also getting into CharIn to see how they can get the standards as close as possible to the standards from the EV sector. Making a standard that will be ideal for every sector is not possible now, so it is now a matter of compromise. This is because the designs of the aircraft now do not allow for testing one system today and another tomorrow, also different connectors on an aircraft are not an option as this adds more weight and thus high operational costs.

- **Some aircraft manufacturers are working with their own charging systems, do you think this could also become an option for airports? And if so, who do you think will have to purchase the charging systems?**

From the perspective of the aircraft manufacturer, the charging systems will be arranged by the aircraft manufacturer because this gives them a new market by making systems for only their aircraft. However, from the perspective of airports this is actually not feasible because it creates such high costs for an airport because one day an Airbus will land there and the next day a Boeing will arrive, which will cause problems because the airport will eventually provide the loading as a service. Protocols like OCPP will be the same purely because the services need to be billed. It is also important for the fleet management because it is impossible to charge everything at the same time and with the protocols the optimal use of the grid can be ensured.

- **How do you think flying electric will affect the airport's power grid?**

At the moment the grid cannot cope with the demand for charging aircraft at the same time and generating additional energy will not solve this problem immediately.
The most important point to solve this problem is the fleet management. If this is well organized and known in advance, the load on the grid will be much lower. The airports already have a "private" electricity grid, and it will certainly be the case that a separate grid for charging systems will be added for safety and to reduce the chance of failure.

- **What are the safety measures that should/could be taken regarding charging and charging stations?**

The safety measures for the systems and the charging stations are actually less than for autos because only trained personnel come to the aircraft and so certain precautions can already be omitted here. The loading stations are also no longer going to be mobile but a fixed loading area, the containers can be moved but that is not easily arranged. So, it will be the case that the loading stations will already be at the gates and stands.

- **Looking at the smaller regional airports, have plans already been made to ensure that the charging infrastructure will be used in the most optimal way?**

Multi-purpose use of charging stations is not very profitable in commercial aviation because those aircraft need to fly as much as possible and thus charge as fast as possible. Having other vehicles charge at the same stations is possible but not practical because it may prevent aircraft from charging if something goes wrong with a vehicle at the charging station. A better option will therefore be to create a separate charging station for vehicles, this will ultimately be cheaper because the charging systems for aircraft are much more expensive and the priority for this is the aircraft.

- **Are there any bottlenecks that may arise once more electric aircraft come on stream?**

In the technical perspective as I look at it there will not be any bottlenecks in the coming years outside of the high demand for power. Looking at the regulations and the fact that certain standards are still in the making, it may well be that these will bring obstacles with them to the integration of electric flying.

Appendix 8: Interview Laura Leoncini, Business Developer E-aviation, Eaton, 22-12-21

- **Why do you think interoperability is needed, or not needed, in aircraft charging?**

Looking at the past as it has gone in the EV, it is important that there is interoperability in the charging systems. As soon as the aircraft manufacturers all develop their own charging systems and incorporate their own protocols and standards, this will create a problem for the infrastructure at an airport. Especially large airports will have to purchase many different types of charging systems, which will result in very high costs and possibly a lower efficiency because some airlines will sometimes come with different aircraft. All in all, it is financially and operationally best to create interoperability, and thus a standard, for aircraft charging in the short term already.

- **Some aircraft manufacturers have their own charging systems; do you think this could also become an option for airports? And if so who do you think will have to purchase the charging systems?**

Currently, some aircraft manufacturers are trying to create their own charging systems in order to get their aircraft on the market. For the short term this may be a solution, but the most important thing is to reach the standardization level and thus create a standard. For this, builders and developers will have to start working together and it is not convenient that there will be many different types of charging systems. This is therefore not something for the future because airports, as already mentioned, will not purchase all kinds of different charging systems. Who will purchase charging systems once there is a standard is not yet known. It is true that those who now arrange everything for the infrastructure of refueling would prefer to also arrange everything for charging in order to expand and generate more revenue. But this is still a question because not every situation is the same and there will have to be a good look at the infrastructure per airport. And then a system will also have to be created that will regulate the payments for recharging, which could perhaps be the same as for EVs.

- **Will fast chargers be the right facility at every airport, or will they not be needed in some cases?**

There are 3 possibilities to charge, there are fast chargers, slow chargers and also chargers that charge "normally". Because it takes a lot of electricity during peak hours, it may be more convenient to not always charge at full power with fast chargers and to therefore purchase "normal" chargers. However, by means of smart charging it is possible to vary the power which ensures that the peak moments are perhaps less and that when it is not necessary, not much power is given.

- **Will these fast chargers then be used multi-functionally, looking at other electric vehicles at an airport?**

There are possibilities that a charging system will be used in a multifunctional way, these charging systems will have to use standards from the EV-sector. For airports it will be much more convenient that they can buy a system that can be used for both vehicles and planes, this is more suitable for the smaller regional airports. Looking at the larger airports, it is operationally more difficult. Looking at larger airports where the charging systems must be used constantly by aircraft, this will be difficult to plan. Also, the infrastructure behind this type of system is more difficult because it requires even more power capacity from the electricity grid and will therefore become even more complex.

- **What is needed at an airport beyond charging stations to make electric flying possible?**

In addition to the charging stations, systems are needed to ensure that the charging systems continue to function properly. For example, cool and heat systems are needed to ensure that the temperature remains optimal, and the charging systems can function properly. Backup systems are also needed to ensure that charging is monitored, and possible problems are identified so that the system can intervene by, for example, stopping the charging process.

- **What are the safety measures that should/could be taken with regard to charging and charging stations?**

To ensure that charging is safe, the people who connect the planes to the charging station must be trained in order to avoid mistakes. Also, the software systems mentioned earlier are important for safe charging, these systems are a kind of backup if something goes wrong during charging. Also, manufacturers of charging systems are required to demonstrate that their charging system can be quickly switched off and that charging is monitored in order to guarantee safety.

- **How do you think electric flying will impact the airport's power grid?**

There must be enough power available for the planes at the airport. The tricky thing is that there will not only be planes charging in the future but also cars, which will cause even more power to be needed. So, the impact on the power grid will only increase with more electric planes and more electric car users. To solve this, green energy such as from solar panels will have to be used as well as from the electricity grid. This will allow a lot of power to be available at the same time whereby it will sometimes happen that there is an excess, and this power will then have to be stored. The problem at the moment is that the systems and devices that can store power are still very expensive. To ensure that the power network maintains the same efficiency, use can be made of face and balance systems that ensure that unevenness caused by the high demand for power is absorbed.

- **Are there any bottlenecks that may arise once more electric aircraft arrive?**

In addition to the amount of power required, there will be other bottlenecks. Examples are the layout of airports and maintenance, both of which will change considerably. If we look at the systems in electric airplanes now, they need maintenance much faster, looking at the batteries that last about 1.5 years, which is in contrast to the layout of the maintenance now. So, you will have to take the battery out of an aircraft every 1.5 years and put in a new battery which is a pretty big job. The layout of the airports is not only related to the placement of the charging infrastructure, but also to the possibility of vertical take-offs. Some aircraft manufacturers are now working on this, and the aircraft will look more like helicopters when they take off. This will also have to be adjusted in the regulations.

Appendix 9: Interview Denise Pronk

- **Why do you think interoperability is needed, or not needed, in aircraft charging?**

Because aircraft from many different countries come to the airports and for these aircraft and their airlines it is important that they can charge on any system. This is looking at both the hardware and the software, so there will have to be a standard plug that fits every aircraft and there will also have to be systems that enable communication between the aircraft and the charging systems, for example, which will have to be the same for every aircraft.

- **Some aircraft manufacturers have their own charging systems; do you think this could also become an option for airports? And if so who do you think will have to purchase the charging systems?**

There will not be a loading system for each aircraft, because this will not be at all convenient for the operation. If we look at the current situation where the pipistrel has its own loading system with its aircraft, however, as more aircraft will soon arrive, it will not be convenient and profitable for airports to buy a separate loading system for each aircraft type. Ultimately, an airport will want to offer the facilities because they generate revenue from it, but as long as there is no standard, the investment will be far too large and not profitable.

- **How do you think electric flying will impact the airport's power grid?**

Schiphol currently uses power from various wind farms, which is regulated to meet the demand and there is little or no excess. If electric flights are to be launched from Schiphol in the near future, it will be necessary to look at branching the power grid in order to meet the additional demand for power without inconveniencing other locations at Schiphol. However, at this moment Schiphol's strategy is based more on sustainable fuels and hydrogen because looking at the flights that are currently made from Schiphol and the flights that are possible with these new forms of energy they come closest. It is also not the case that Schiphol is not looking at electric possibilities at all, but it is expected that this will have a much smaller share at Schiphol than the other energy sources and that the construction of electric facilities will be a much lesser problem.

- **Will these fast chargers then be used multi-functionally, looking at other electric vehicles at an airport?**

Making a loading system multifunctional is a good idea, but operationally it is not possible to do this at a large airport like Schiphol. The planes are only allowed to stand at a certain spot, they are actually used almost every moment of the day and if another vehicle is going to load there, this will cause a problem as soon as an aircraft arrives. For regional airports this may be an option, look at a Maastricht where only 3 flights per day are, it will be operationally quite easy to plan.

- **Will fast chargers be the right facility at every airport, or will they not be needed in some cases?**

When electric aircraft became more popular, there were discussions with larger aircraft manufacturers including Airbus. They discussed the charging systems and whether this would be a fast charger or an exchangeable battery. In particular, the latter will be operationally the best because in terms of planning it is the best to carry out and less stressful for the grid. However, the aircraft manufacturers do not know this yet and neither do the airports, because in this situation you will need a person who is purely responsible for charging the batteries and also a person who is responsible for changing the batteries. This will then cause adjustments to the turn Around process as it is now.

- **Are there any bottlenecks that may arise once more electric aircraft arrive?**

Apart from the large power demand there will also be other bottlenecks. For example, the electric aircraft can fly shorter distances with fewer passengers. This is an operational and financial bottleneck because a flight will be less profitable, and several existing routes may have to be adjusted to make it feasible for the electric aircraft. It is also true that the terminal will be used in a very different way once small aircraft will arrive, the terminals are now equipped for hundreds of passengers but if soon aircraft with 20 passengers arrive at the gate, it will be so that a lot of space will not be used.

Appendix 10: Interview Jan-Willem Heinen, Co-founder Venturi, 21-12-21

- **Why do you think interoperability is needed, or not needed, in aircraft charging?**

Interoperability is needed in aircraft charging because otherwise you get a situation where one type of plug fits one type of aircraft. Even though the effect will be much less than in the automotive world where you are talking about much larger quantities. In aviation we are also not looking to build a new standard, rather we take over from another sector such as the automotive sector. In the short term it is true that interoperability is not a priority but even if an aircraft manufacturer chooses to make its own charging system you will see that they will use the plugs from the automotive sector.

- **What are the specifications of the batteries in the aircraft now and what is the expectation that it will be in 10 years?**

What's interesting about Venturi's plans is that the aircraft will last about 20 years, but the battery will only last 2000 cycles which converts to 1.5 years. This means that every 1.5 years a battery pack will need to be replaced so the range of aircraft will increase due to improvements in the batteries over the years. The old battery is no longer suitable for aviation because within aviation a state of health of 90% is required, however, the battery is still perfectly usable for other purposes. So, what happens to the old battery is that it is placed in a sea container at the airport, and it will act as a buffer for the power. This is possible because the state of health of stationary devices, such as the shipping container, does not really have a minimum. If we then look at the amount of power needed we see that 9 Mega Watt (Mw) is needed, which is equivalent to 9000 Kw. To ensure that pre-existing plugs can be used, we look at the number of inputs on the aircraft. Suppose there are 4 inputs on an aircraft then there can be 4 plugs in the aircraft, if then the 9 Mw is needed you need 2.25 Mw per plug. This is still under the maximum of the megawatt plugs used for trucks for example which means that for such an aircraft a plug from the automotive sector can be used.

- **Will these fast chargers then be used multifunctionally, looking at other electric vehicles on an airport?**

Because of the many plugs and the amount of power the system can have, eventually the charging system will be able to act as a public charging point. For example, smaller aircraft with only 1 plug will be able to charge at a reduced power level. Ultimately, this will make the investment more attractive to smaller airports because it will make it a multi-purpose charger.

- **Are there any bottlenecks that may arise once more electric aircraft arrive?**

The biggest bottleneck for electric flying is the amount of power needed for the operation. If it is compared to the operation with kerosene, it is about GigaWatt values, which amounts to a power supply comparable to a whole nuclear power plant needed for the operation. The airport building is dwarfed in terms of consumption by what the total operation of charging aircraft will consume.

Appendix 11: Interview well informed source, 17-12-21

- **Why do you think interoperability is needed, or not needed, in aircraft charging?**

From the position of the manufacturer of aircraft (ev-tal), we are primarily working toward the launch of electric aviation. The focus from that side is to put electric flying on the map as soon as possible and interoperability is not really a requirement yet. It is also the case that at the moment builders would prefer to be able to use their own systems and continue to develop this until it is properly optimized. However, having a standard for charging is preferable because then a wider industry of chargers can be chosen. It is important for a manufacturer of aircraft that there is a broad industry of chargers so that there is a choice, and more types can be charged. In the short term, interoperability is not so important yet because right now it is about getting a product to market as soon as possible. In the longer term, however, it is important because it allows production to increase and therefore to be cheaper, as interoperability increases the use of charging systems. It also gives a quality boost because as soon as a system is used more often, there will be faster development and optimization of the system. And it will be easier for aircraft manufacturers to sell their products to airports if they can be used by multiple parties by working with standards. In short, interoperability is not a critical issue in the short term, but it is in the long term in order to be able to run the operation properly everywhere.

- **Some aircraft manufacturers are working with their own charging systems; do you think this could also become an option for airports? And if so, who do you think will have to purchase the charging systems?**

On a large scale, looking at the operational side, it may not be very convenient to have each aircraft manufacturer build their own charging system. However, it is true that aviation cannot be compared to the automotive industry, aviation is much better planned. So, if a situation arises that at Schiphol Airport, for example, charging is only possible with Airbus charging systems, other aircraft manufacturers and airlines will plan flights to airports where they can charge. This would not be convenient for either the airport or the airline, as the airport would lose income and the airlines might not be able to land at the desired airport. In the short term the charging systems will be purchased by their users, this is due to the fact that the charging system is not yet (fully) interoperable. An airport is not going to buy a charging system for each type of aircraft to meet everyone's needs. As soon as a standard is made and a system is available that is (almost) fully interoperable, an airport will make the investment to be able to offer a service and generate income from it.

- **Will fast chargers be the right facility at every airport or is this not necessary in some cases?**

A megawatt charger would also allow you to charge at a slower rate when it is not needed, which is better for the battery and the grid load. So, looking at the technical side it would not be necessary to buy another charging station as a smaller airport being. However, it is much more advantageous in purchase, a fast charger for aircraft will be a much more expensive system as a "normal" charger so in that respect it might be better for smaller regional airports to invest in "normal" chargers.

- **Will these fast chargers then be used multi-functionally, looking at other electric vehicles at an airport?**

It will be possible that charging stations will be used multifunctionally, however, the question is whether a certain one size fits all system should be made. Now, the charging systems that are made are optimized for charging an aircraft and have a plug that fits the aircraft and not for a bus that takes people to the terminal. So, it is not likely that different vehicles will be charging on the same charger.

- **What is needed at an airport besides charging stations to make electric flying possible?**

Outside of charging systems, the only thing that will need to be in place in terms of hardware is a cooling system to ensure that the chargers do not overheat. On the regulatory side and the operation, itself, more will have to change. For example, rules will have to be drawn up on how to deal with the chargers and safety regulations will have to be introduced. An example of a safety regulation could be that a person no longer needs to be present during loading but that there is a central button that can be pressed as soon as something goes wrong and thus stop the loading.

- **Are there any bottlenecks that may arise once more electric planes arrive?**

In the short term, we are mainly looking at a closed system where we look at an area where a particular aircraft is operating and in terms of optimizing the operation it is quite easy looking at the schedule. As soon as there are more aircraft, and they all load on the same system then a maximum will have to be set for the operators in order to optimize the planning. But looking at bottlenecks it will then be the case that many parties will have to be considered and that will be difficult to get a good optimization.

- **What do you think the impact of electric flying will be on the airport's electricity network?**

The impact on the electricity grid will be very large as more users will come to an airport. Especially the tricky thing about this is that so much power will be needed at one time that there has to be some point, like solar panels, where it will have to come from because power obviously cannot be stored. Another thing that can be done is not to separate the power grids of the main building and the charging systems and then as soon as there is less use on one side tap the remaining power to make the best use of the power. Also, smart charging is very important to ensure that there is no overload because this allows the power to be distributed optimally. But whether all this is enough to be able to charge all the aircraft remains to be seen.

- **What are the safety measures that should/could be taken regarding charging and charging stations?**

Outside of hardware safety regulations, there are also systems that can and should ensure safety. For example, there are various systems that can monitor charging so that a malfunction is more quickly noticed and thus accidents can be prevented. When looking at hardware such as a red button to stop charging there are several ways to do this, for example it can be on the charging station, but it can also be a button that someone has to carry with them. This is actually a good example of how things are done now. It's not that there is only one right side, it's that safety can be guaranteed and if that can be done it doesn't really matter which way it is.