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Infrastructure modeling for large-scale introduction of electric aviation

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Summary

This paper presents the results of the MODELflyg research project funded by the Swedish Transport Administration to gain more knowledge about ground charging infrastructure demand for the electrification of air traffic. An integrated simulation model was developed including flight traffic data processing, modelling of battery electric aircraft performance, and charging simulations. Several different options are available to select specific air traffic flows of interest, including scheduling algorithms for electric aviation adapted timetables. Furthermore, a smart-charging algorithm was developed to lower peak power demand at each airport from simultaneous charging of multiple electric aircraft.

Keywords: infrastructure, smart charging, electric vehicle, simulation, modeling

1 Introduction

The global aviation industry is targeting increased sustainability and a green recovery from the COVID-19 pandemic. Traditional improvements in fuel efficiency are not sufficient so revolutionary innovations are required, in the form of new aircraft technologies, sustainable aviation fuels, improved air traffic control, and economic measures. A general agreement is that there is no silver-bullet solution here, instead we must explore a mix of alternatives and apply each solution where it is most suited. Due to recent year's advancements in battery performance driven by the automotive industry, many aircraft developers are now looking for the next chapter of aviation technology. The idea is that battery electric aircraft could lead to both zero operational emissions, as well as attractive economics due to cheaper energy, less maintenance needs and less costly components, such as electric motors compared to jet engines. Electric motors could also mean more freedom in terms of aircraft design and propulsion configurations, such as distributed propulsion, which could enable more aerodynamically efficient aircraft combined with a highly efficient propulsion drivetrain.

Now, if we are to approach a future with an increasing share of battery powered aircraft, we must ensure that the airports are sufficiently equipped to allow for that to happen. One essential part of that is to implement a charging infrastructure network that can meet the demand from these aircraft. The first and most basic questions that arises here are threefold:

- how much energy the aircraft consume (i.e., how much they will need to recharge at the airport),
- how much time that is available for charging (i.e., how fast will they need to charge),
- and how many aircraft that will need to charge simultaneously.

Since there are currently no electric aircraft in commercial scheduled traffic, and thus no data or statistics regarding performance or operational properties, the first question is somewhat uncertain. The other two questions are highly dependent on the scheduling and airport logistics, which we do know for today's system, but whether this will be applicable to electric aviation or not is also uncertain to some degree.

Initially, when the technology is introduced on a smaller scale, many airports can probably be sufficiently equipped in terms of capacity to support a few of these aircraft. However, accelerated implementation can potentially result in extensive long-term challenges that require careful planning and preparation. Due to these uncertainties, the MODELflyg project was initiated to support airports by creating good estimations of what might become.

2 The simulation model

A simulation model was developed with the aim of increasing the general understanding as well as provide opportunities to easily test what the requirements for charging infrastructure at airports could become when transitioning to battery electric aviation. The model is developed in the programming language Python and contains several different approaches for testing electrification based on historical air traffic data, as well as the creation of new, non-existent air traffic schedules for electric aviation. Furthermore, an electric aircraft model was developed to allow for simulation of desired flight connections, resulting in estimates for energy consumption and flight duration.

A built-in charge curve limits how fast it is practically convenient for the aircraft's batteries to be charged. In addition, the charger itself can be limited to a certain maximum power and thus controls how fast energy can be delivered to the aircraft's batteries.

To enable sufficient range, the electric aircraft are expected to have large batteries which are also likely to be charged within short time intervals at the airports (turnaround-times). Thus, the need to install power capacity may be expected to increase drastically at the airports if several aircraft should be charged simultaneously. The project therefore places emphasis on developing smart algorithms for controlling charger power output over time with the ambition to balance the loads and lower power peaks at the airports.

The following chapters describe the modeling components in more detail – from data processing and logic to electric aircraft and charging simulations.

2.1 Data and model logic

The logic of the simulation model is to follow a complete chain of movements for each aircraft individual during a given period (typically one day), where charging required for each aircraft at each airport in the chain is given by what energy level the battery held at the start of flight, how much energy was consumed during the flight, time of arrival at destination, and when the next departure is due. Taxi-in and taxi-out times at the airports also affect how much time is available for charging.

To effectively follow said logic, it is essential to somehow include timetables for the air traffic, meaning time and place for departure and arrival of each aircraft in a defined system. The project was given access to historical flight plans for all domestic air traffic in Sweden during year 2019, which included data for roughly 100 000 unique flights. In addition to arrivals and departures, each flight contains information about aircraft identification number, aircraft type, callsign, flight distance, and more. Especially the identification number allowed for following the chain of movements associated to each specific aircraft, and thus enable continuous simulation of electrified flights and charging simulations throughout a full day for every aircraft.

2.1.1 Historical flight data processing

The project stored all historical flight data from 2019 in a relational database based on SQL (Static Query Language), which is a standardized programming language for retrieving and modifying data in a relational database. As the ambition was to create a generic model that allows the user to investigate electrification of any air traffic, this is an effective method to retrieve smaller, specific amounts of data from the database without having to keep all data in memory.

To simplify the data selection process, a user-interface (Figure 1) was developed built on earlier described logic, meaning that the user can select specific air traffic flows by choosing certain dates, adding airports, filter by airline, etcetera. As each flight is connected to an aircraft identification number (*AcReg* in Figure 1), the selection process makes sure to include only complete (unbroken) chains of movements for all aircraft involved.

For example, if the user is interested in examining the connection *Bromma Airport* (ESSB) to *Visby Airport* (ESSV) according to the setting in Figure 1 (see line "Current airport(s) selection"), there are likely aircraft individuals in that flight data which also operates another connection at some given time during the selected period. All additional connections that are included because of the movement patterns of the aircraft individuals can be seen in the boxes for Primary connections (direct) and Secondary connections (indirect). If a particular direct or indirect connection is not of interest, these can be deleted from the data set, which means that charging will not be simulated at the airports that make up these connections. The consequence will then be that all aircraft individuals who operate to/from these airports at some point during the period are automatically removed from the data set. Otherwise, there would be gaps in the movement pattern of some aircraft where charging is not simulated, which in turn makes it impossible to calculate the need for charging during the rest of the period.

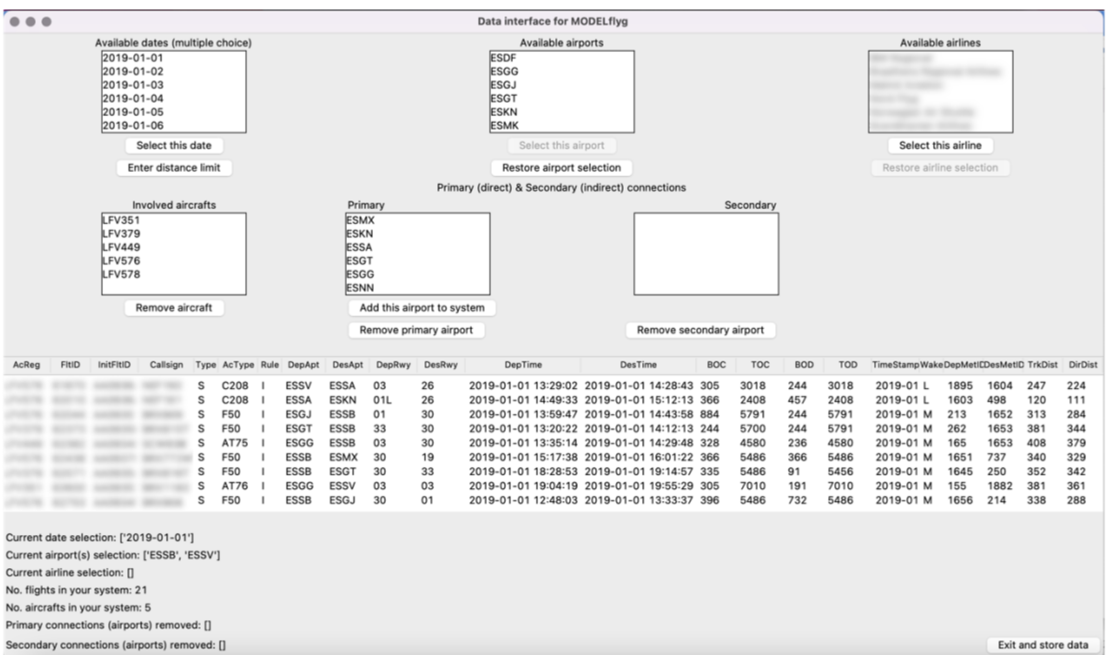

Figure 1: User-interface for selection and filtering of historical flight traffic data (sensitive parameters blurred).

When the user is satisfied with the selection, relevant data for the system is saved as further input to subsequent parts of the modelling process. The aircraft movements corresponding to the data selection made in Figure 1 can be visualized as shown in Figure 2. Here, each coloured line represents a specific aircraft individual. As seen, all involved aircraft operate to/from the airports ESSB or ESSV as specified, but also to other domestic airports. Consequently, flight and charging simulations are performed for all connections and at each airport on the y-axis.

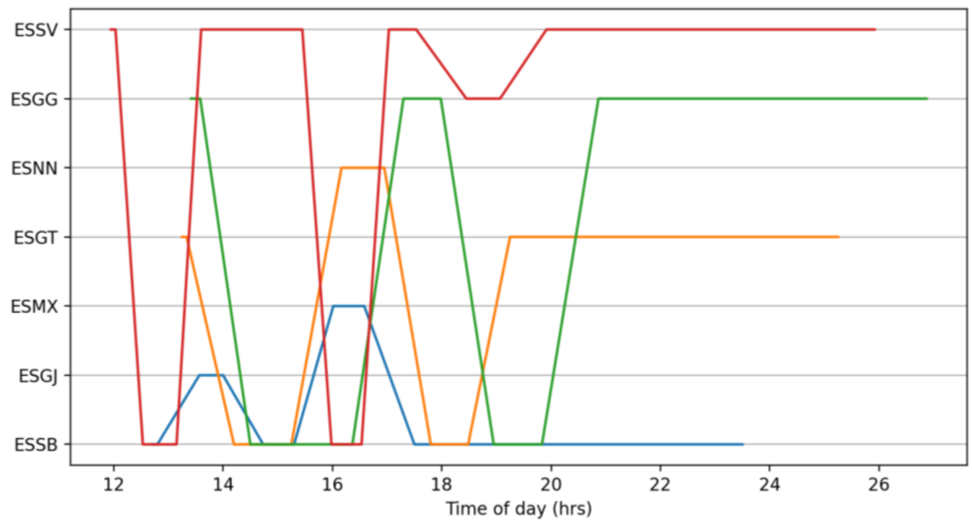

Figure 2: Aircraft movements over time for a chosen system. Time of the day is on the x-axis, airport code on the y-axis.

2.2 Electric flight simulations

Since there are no electric aircraft in commercial traffic to lean on in terms of operational characteristics and performance, the project has developed a simulation model for future electric aircraft. It consists of two parts: a manual "sizing" process for retrieving design and performance parameters, resulting in a configuration file for the aircraft itself. The second part deals with the routing of the aircraft on the desired flight route, first by defining the mission profile (how the aircraft moves in the airspace, at what altitudes, etc.), and then simulating the flight according to the mission profile, which produces the output parameters (energy consumption, flight time, etc.) required as input to simulate charging events.

Current limitations in terms of battery technology are steering towards smaller electric aircraft with limited range and payload in the short term. Therefore, the sizing process was carried out targeting a regional electric aircraft model parameterized according to the CS/FAR-23 certification limits, meaning MTOW (Maximum Take-Off Weight) of approximately 8600 kg, and maximum 19 passengers (excluding the pilot) [1].

With the described electric aircraft available, it is now possible to simulate flights on any given route. A route is defined as one departure-arrival airport pair. Given the geographic location (and altitude) of each airport, a mission profile is created based primarily on distance (great circle) and a maximum cruise altitude. If known, a detour factor can be manually set to simulate a flight distance longer than the calculated great circle distance. Some other settings are also available which affects the flight time and energy consumption of a given flight, like wind strength and direction, aircraft payload factor, as well as whether the flight should be energy optimised (decrease operational velocity to save energy) or time optimized (increase operational velocity at the cost of higher energy consumption). Eight different mission segments are simulated separately to create the complete profile, including *taxi-out* at departure airport*, take-off, climb, cruise, descent, holding, landing,* and *taxi-in* at destination.

Keeping the previous example, the figures below show the resulting mission profile (Figure 3), energy consumption and flight duration (Figure 4) for the route ESSB to ESSV.

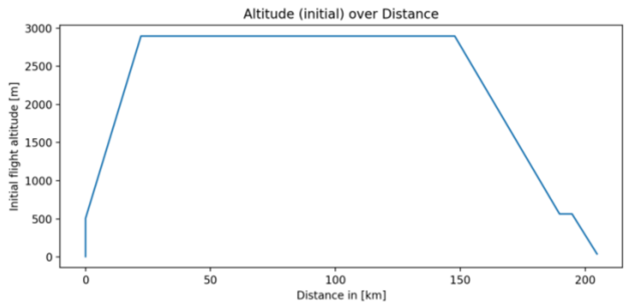

Figure 3: Mission profile as altitude over distance for a flight between airports ESSB and ESSV.

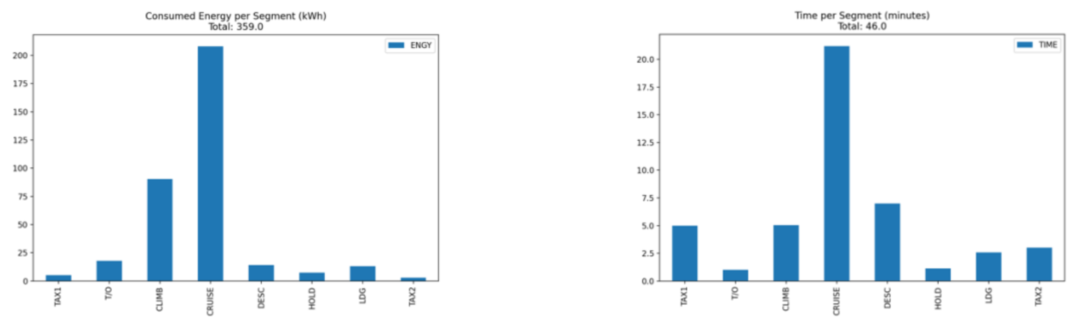

Figure 4: Energy consumed and flight duration for each of the eight mission segments for the route ESSB to ESSV.

2.3 Charging simulations

Charging is modelled in two consecutive steps. The first step is to charge according to independent fast charging (or denoted as "dumb charging"), where each electric aircraft connects to a charger and starts charging as soon as possible after arrival at destination (in other words, immediately after completing the taxi-in from the runway). Each electric aircraft is in this case permitted to get the power it requests from the charger. The requested power follows a maximum charging curve shown in Figure 5, defined as a C-rate (the number of times the full capacity of a battery could theoretically be recharged in an hour) as function of battery SoC (State-of-Charge). In general, the charge rate can be high at low SoC levels, but gradually decreases as SoC increases. It is uncertain what specific charge curve future electric aircraft will settle on, so for the specific shape of the curve used here, inspiration was taken from charging curves recorded when fast charging today's electric cars [2].

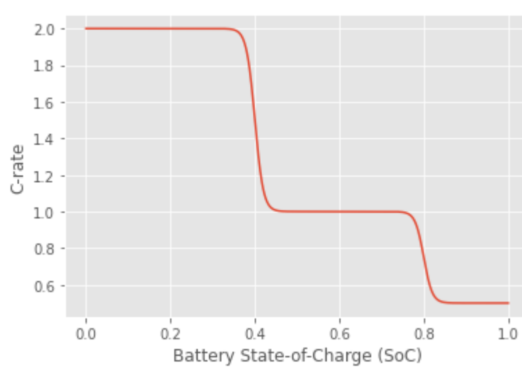

Figure 5: Maximum allowed charging curve for the aircraft battery.

In the case of dumb charging, each electric aircraft is thus allowed to follow the maximum allowed charging curve until fully charged (set to 90% in the model), starting from the SoC level that its batteries have at the start of charging (which depends on energy consumption from previous flights, SoC on departure from previous airport, and battery size). However, in the model's settings, it is possible to limit the maximum power that can be delivered by the chargers available at the airport, which can result in the aircraft receiving a lower C-rate than what is requested, depending on how this limit is set.

The second step in the charging simulation consists of a heuristic, “smart charging” algorithm. This algorithm redistributes how much power is given to each aircraft at each point of time, with the aim to lower peak power demand at the airport. Ideally, an airport would seek to minimize the installed peak capacity needed to meet the total energy demand of incoming aircraft, not least from a cost perspective. Simply described, as dumb charging has been previously simulated, the algorithm has prior knowledge of the dumb charging curves for each charging event at each airport. As each charging event is connected to a specific aircraft visit, the algorithm also knows whether charging was completed before time of departure, i.e., if there is any unutilized time. Based on this information, the algorithm strategically limits the power output from each charger at every point of time. Supply to aircraft with a lot of unutilized time (“rich”) can be limited more than those with little (or no) unutilized time (“poor”), meaning that rich charging events have more space to limit power peaks. The algorithm attempts to keep the total charging power at the airport below a certain target curve. If there is not enough time to achieve this target whilst still meeting the energy demand of each aircraft, the algorithm is however permitted to overstep the target curve.

To further build on the previous example, the selected flight traffic data from Figure 2 is used to exemplify the charging simulation results. All connections (flights) are first simulated using the described electric aircraft model to obtain resulting energy consumptions and flight durations. Secondly, the charging simulation steps are applied to each airport in the system. For this example, we focus on the results for airport ESSB, as shown in Figure 6. A couple of things can be noticed: the left plot shows start and end SoC-levels for aircraft visiting ESSB during this day, though some of them arrive with negative SoC. In practice, this indicates that these aircraft would not be possible to electrify with their present schedule. Moreover, the right plot shows that the smart charging algorithm could lower the power peak to some degree (blue vs. orange line), but not as low as the set target curve (green line).

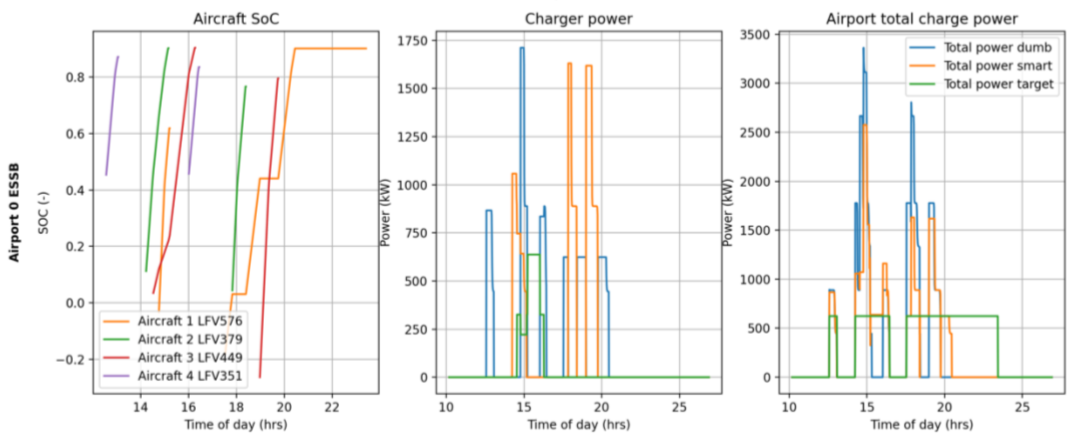

Figure 6: Simulation results for the selected system at airport ESSB. Start and end SoC-levels for visiting aircraft to the left. Power output from each charger in the middle. Summarized power output at each timestep to the right.

2.4 Adapted flight data & new routes for electric aviation

As historical timetables are constructed for conventional, jet-engine propelled, aircraft, some challenges might arise when trying to perform the same tasks with electric aircraft:

1. Electric aircraft may have too short range for current connections.
2. Electric aircraft may need to charge longer than is currently available at the airport (turnaround-time).
3. Electric aircraft may fly slower than current aircraft.
4. Electric aircraft may have lower passenger capacity.

Insufficient range means that the route cannot be flown with electric aircraft and the connection can then either not be operated at all with electric aircraft or the logistics must be changed with shorter hops and intermediate charging. Longer flight time and/or downtime due to charging requirements means that all arrivals and departures in the future need to be postponed, and a lower passenger capacity per aircraft means that more flights need to be implemented if the same number of passengers are to be transported. In other words, current timetables may need to be adapted to electric aircraft, more departures may need to be deployed, and adapted or new routes may need to be considered.

As a response to these challenges, a couple of alternative methods for "adapting" historical timetables to electric aircraft, and to manually create new, non-existing, flight routes and schedules for electric aviation was developed.

Adapting historical timetables means rescheduling flights, but also to be able to change the number of flights to maintain the same transport capacity due to smaller electric aircraft. A mathematical optimization model was developed for this task, which produces a functional timetable for electric aviation. The goal of the optimization model is to minimize the number of electric aircraft needed to meet a certain travel demand, whilst considering both flight durations and minimum charging times for electric aircraft on involved routes. Running the earlier used example system from Figure 2 in the optimization model generates a new system visualized in Figure 7. Both the number of flights and aircraft have increased because of the electric aircraft being smaller.

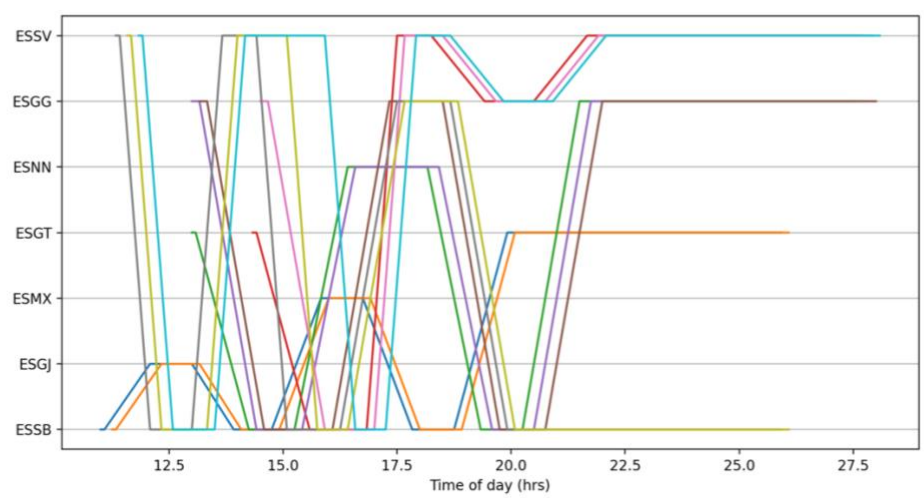

Figure 7: Flight connections over time for the adapted historical timetable. Time of the day on the x-axis, airport code on the y-axis

A continued simulation of all electric flights and charging at the airports in this adapted timetable show higher peak charging power (as more charging sessions overlap), but also a better result in terms of aircraft battery SoC-levels, where none of them is negative. This is because the timetable optimization makes sure that every aircraft has the time to complete charging before departing, which might not be the case with today's turnaround-times.

However, the length of some of the routes seems to be larger than what the aircraft can comfortably handle, since the SoC still drops dangerously low.

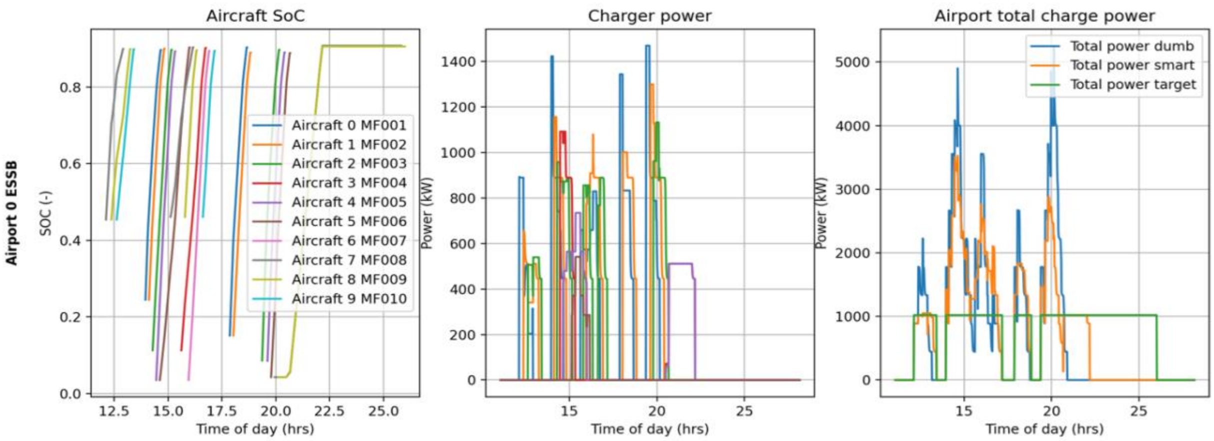

Figure 8: Simulation results for the adapted historical system at airport ESSB. Start and end SoC-levels for visiting aircraft to the left. Power output from each charger in the middle. Total power output at each timestep to the right.

Note that the plots and figures presented so far are merely examples to explain and show how our developed simulation model can be used and how the results look.

Next, creating new flight routes for electric aviation means no historical flight data or timetable is available, and thus it needs to be created. This can be done either by manually adding arrival times, departure times, number of flights etc. for each route of interest, *or* by giving information about expected travel demand and its distribution for each route to the timetable optimization model described earlier.

3 Case study: Regional hub for electric aviation

For several reasons, northern Sweden is an interesting area of application for future electric aviation. Among the reasons are deficiencies in alternative transport infrastructure and a potential for both increased accessibility and contributing to a more attractive region, for example with new electric flights between northern Sweden and Finland. [3]

To start investigating the possibilities from a charging infrastructure perspective, a small case study was carried out where four electric flight routes in northern Sweden, and one in Finland, are established to and from Umeå Airport (airport code: ESNU) acting as a regional transfer hub (Figure 9). Flight duration and energy consumption for each of the five routes were simulated using the 19-seat electric aircraft model described earlier. For simplicity, no wind and approximately 10% detour factor is assumed when defining the mission profiles for each route (in each direction). See Table 1 below for resulting figures.

Table 1: Key figures for the 5 routes established for this case study.

	Distance (km)	Duration (min)	Consumption (kWh)
ESNU-ESNZ	318	65	554
ESNU-ESNV	203	46	363
ESNU-ESNX	222	49	395
ESNU-ESPA	231	50	410
ESNU-EFVA	120	32	218

As the model currently support only one type of electric aircraft and one chosen battery size, the battery capacity for this case study is set to manage the longest route (ESNU-ESNZ, 554 kWh), plus extra margins. Some margin is added so that the battery does not need to be charged more than 90%, and some is added at the bottom so that there is at least 20% capacity left after arrival for the longest route. This means 30% extra capacity on top of 554 kWh, resulting in a total battery capacity of approximately 800 kWh.

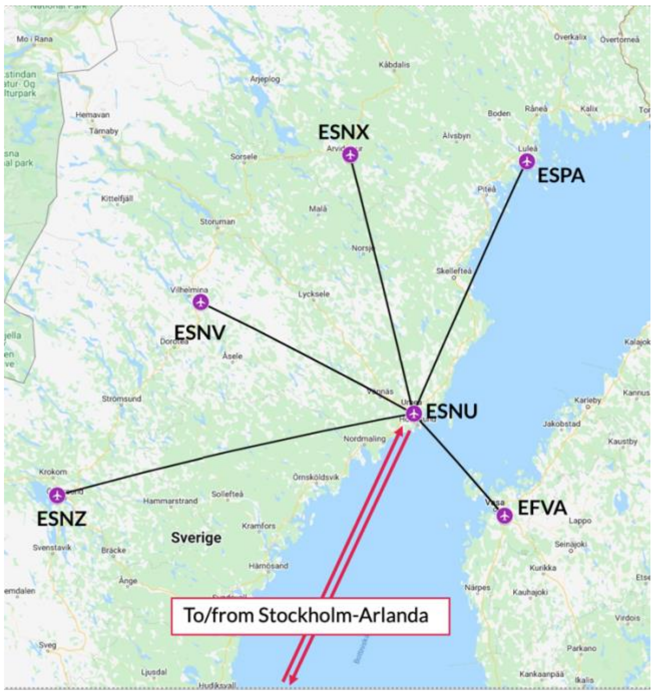

Figure 9: Electric flight routes used for the case study (not including to/from Stockholm-Arlanda).

In dialogue with Swedavia, who owns and operates Umeå Airport, it was decided that electric flights to/from the locations above should time the arrivals and departures of today's flights to/from Stockholm-Arlanda at Umeå Airport (Table 2). Umeå Airport thus becomes a regional commuter-node for electric flights, where each location has its "own" electric aircraft that commutes back and forth at appropriate hours to time incoming/outgoing flights from/to Stockholm-Arlanda.

Table 2: Arrivals from and departures to Stockholm-Arlanda to be timed.

Arrival times	09:25, 09:30, 18:25, 18:50
Departure times	09:50, 10:00, 18:55, 19:20

For scheduling of the electric flights, it was a prerequisite that all passengers arriving at Umeå with electric flights should have time to catch any of the departures toward Stockholm-Arlanda. And conversely, it was a prerequisite that all arriving travellers from Stockholm-Arlanda should have time to catch a departure by electric flight on any of the routes in Figure 9. An assumption was made that this requires a transfer time for changing aircraft of at least 45 minutes. Thus, the electric aircraft may depart from Umeå Airport no earlier than 45 minutes after the last arriving aircraft from Stockholm-Arlanda, and conversely, the electric aircraft may arrive at Umeå Airport no later than 45 minutes before the first departing flight to Stockholm-Arlanda. 45 minutes was assumed to be a reasonable time for changing aircraft, including luggage handling.

Furthermore, a separation between departures and arrivals at Umeå Airport was set to 5 minutes, meaning that the runway is used by a maximum of one electric aircraft per 5-minute interval. For all airports in the system, taxi-in and taxi-out times were set to 3 and 5 minutes, respectively. We define arrival and departure as "arrival at the gate" and "departure from the gate", respectively. In other words, the latest arrival of electric aircraft to Umeå Airport must land 45+3 minutes before departure towards Stockholm-Arlanda to include both taxi-in to the gate, plus allowing for 45 minutes to change aircraft.

Using above assumptions, arrival & departure times from Table 2, and simulated figures from Table 1, a proposal for an electric flight schedule was created shown in Table 3.

Table 3: A proposed flight schedule for the electric aviation routes in this case study.

From (ICAO)	To (ICAO)	Departure time (from gate)	Arrival time (to gate)
ESNZ	ESNU	08:00:00	09:05:00
ESNV	ESNU	08:04:00	08:50:00
ESNX	ESNU	08:06:00	08:55:00
ESPA	ESNU	08:10:00	09:00:00
EFVA	ESNU	08:13:00	08:45:00
ESNU	ESNZ	10:15:00	11:20:00
ESNU	ESPA	10:20:00	11:10:00
ESNU	ESNX	10:25:00	11:14:00
ESNU	ESNV	10:30:00	11:16:00
ESNU	EFVA	10:35:00	11:07:00
ESNZ	ESNU	17:05:00	18:10:00
ESNV	ESNU	17:09:00	17:55:00
ESNX	ESNU	17:11:00	18:00:00
ESPA	ESNU	17:15:00	18:05:00
EFVA	ESNU	17:18:00	17:50:00
ESNU	ESNZ	19:35:00	20:40:00
ESNU	ESPA	19:40:00	20:30:00
ESNU	ESNX	19:45:00	20:34:00
ESNU	ESNV	19:50:00	20:36:00
ESNU	EFVA	19:55:00	20:27:00

All flights are simulated with the electric aircraft model and charging simulations are then performed according to the proposed schedule. The results indicate that a charger that can deliver 550 kW (at Umeå Airport, ESNU) would be enough for all electric aircraft to be able to fully charge before the next departure (Figure 10). However, it is primarily the flights to/from airport ESNZ (Aircraft 0 in Figure 10) setting this limit because they must fly the longest and thus consume the most energy.

Since all electric aircraft arrive at Umeå Airport at about the same time, there are periods where all aircraft wants to charge simultaneously, i.e., 5 chargers are needed. If all aircraft apply dumb charging (take out the maximum power 550kW from the chargers), we get a total power peak of approximately 2 750 kW. With the application of the smart charging algorithm, it becomes obvious that most aircraft can do without using the maximum power of the chargers for most of the time. In the middle of the figure below, a power output in the range of 200–300 kW is sufficient for most aircraft a large part of the time, so these are reduced while the electric aircraft going to ESNZ is allowed to charge with the higher power for most of the time. The resulting power peak with smart charging is approximately 1 300 kW in the morning and 1 050 kW in the afternoon, about a 50-60% decrease.

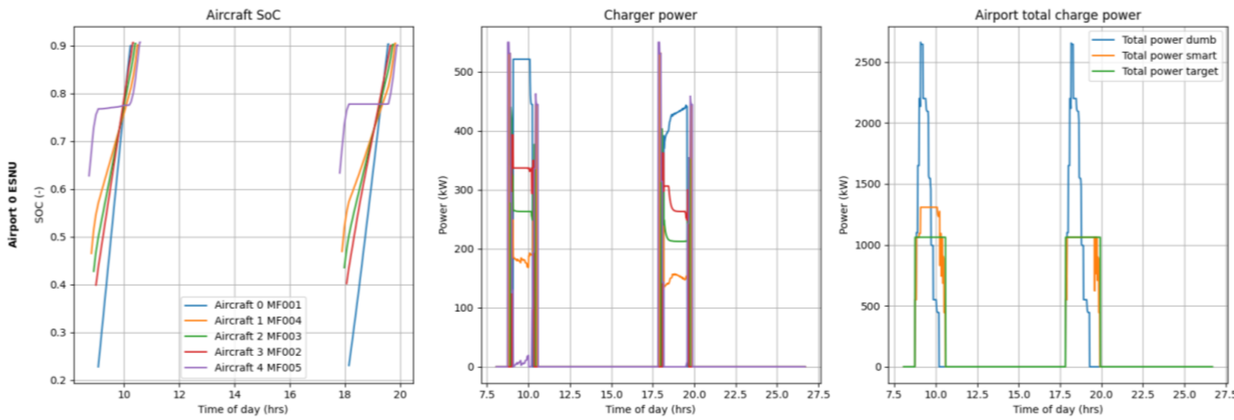

Figure 10: Charging simulation results at Umeå Airport (ESNU) with proposed electric flight schedule.

4 Discussions and outlook

The design of models and tools largely depends on the analyses and studies that are to be made, which questions that are desirable to answer, and what is given and not given. With the help of MODELflyg, insights were gained and many potential ideas for further development for both expanded and improved functionality as well as more application areas for the simulation model were identified.

Common to all parts of the model in this project is that costs are currently excluded. Only "physical" requirements for infrastructure were modelled, but several methods have nevertheless been developed with some form of cost-related idea. For instance, load balancing and lowering of power peaks with the smart charging algorithm should have a clear cost advantage where the airport reduces the requirement for installed capacity, and thus what investments need to be made. Moreover, in the method for timetable optimization, the aim is to minimize the number of electric aircraft required to meet a certain travel demand since new electric aircraft will be expensive to purchase and that the airlines will want as high utilization rates as possible for these. However, we eventually see that the development (and integration) of cost models is a necessity to really make recommendations to airports and other actors in the ecosystem regarding the systematic implementation of this sort of infrastructure. Things such as electricity prices, battery replacement as an alternative to fast charging, and the connection to other energy system components such as energy storage and local electricity production, can affect which system solution is preferable. How well different system solutions perform depends, of course, both on its ability to meet the needs that arise and how resilient they are to change, but also at what cost.

5 Conclusions

In the project described throughout this paper, we developed methods for simulating the charging of electric aircraft at airports, to be able to study what requirements it can place on the airport in terms of power demand, (in total and per individual charger) as well as the number of chargers to install.

As we have focused on developing a model that is generic and flexible, there are thus good opportunities to continue the development, bring in more perspectives and include more questions related to infrastructure for electric aviation. Since electric aviation is still in its infancy, there are many uncertainties about how it will turn out, which is why we considered it appropriate not to build something that is definitive, but instead something that can be tested, adapted, and further developed as we gain more knowledge over time.

Acknowledgments

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References

[1] EASA, "Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes - CS 23", https://www.easa.europa.eu/downloads/47173/en, accessed on 2022-04-27.

[2] Fastned, "Fast charging", https://support.fastned.nl/hc/en-gb/sections/4409800889105-Fast-charging, accessed on 2022-04-27.

[3] A. Mäenpää, H. Kalliomäk and V. Ampuja, "Potential Impacts of Electric Aviation in the Kvarken Region", Vaasan Yliopisto, Vaasa, 2021.

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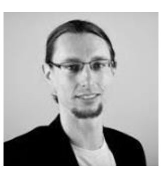
John Nilsson began his professional career in 2011 at the Swedish Transport Administration where he worked as a project leader on early phases of transport planning, with a focus on traffic analysis and complex road infrastructure. John works since 2018 at Swedavia, which owns and operates ten airports of strategic importance in Sweden. In his current role he is responsible for the coordination and strategic planning of electric- and hydrogen driven aviation, with a focus on its effects on Swedavia's airports, from an infrastructure as well as a passenger experience perspective.



Ingo Staack is employed as an assistant professor at Linköping University (LiU). He received his M.Sc. in Aeronautics in 2008 at Technical University Munich and gained his Ph.D. in 2016 at Linköping University with his research on aircraft systems conceptual design. He is currently working on future aircraft studies, dealing with Systems-of-systems research and system architecture modelling and simulation. Beside his teaching activities on conceptual aircraft design, Ingo is also highly involved in the Swedish Aeronautical Research Center (SARC), promoting graduate aeronautical education and national and international research collaborations.