EVALUATING THE IMPACT OF FLEET SWITCHING TO HYBRID-ELECTRIC AIRCRAFT ON AIRPORT INFRASTRUCTURES

L. Trainelli, C.E.D. Riboldi, A. Rolando, F.Salucci
Department of Aerospace Science and Technology, Politecnico di Milano
Via La Masa, 34, 20156 Milano - lorenzo.trainelli@polimi.it

Abstract

While aircraft manufacturers have achieved the required capabilities to design and build electric aircraft, little attention has been addressed to date to the impact that the adoption of these new aircraft types will have on airport operations. Compared to the automotive case, it seems that aviation is lagging in this regard. The objective of the present work is to evaluate the impact on ground infrastructure, in terms of facilities and capacities, of the progressive transition to the fleet to hybrid-electric aircraft. Investigations have been carried out on battery-charging related requirements. In particular, the recharging facility sizing problem, id est the identification of the number and type of charging points and their related electrical consumption in terms of energy and power, as well as the number of spare batteries needed to guarantee smooth operations. Two alternative charging strategies were identified and compared: plug-in recharge and battery swapping. Results on the case study of Athens airport are presented.

Introduction

The European Commission invited key stakeholders of European aviation to come together in a high-level group to develop a vision for Europe's aviation system and industry: Flightpath 2050 [1]. Among the other goals, in 2050 technologies and procedures available will allow a 75% reduction in CO_2 emissions per passenger kilometre and a 90% reduction in NO_x emissions, and the perceived noise emission of flying aircraft will be also reduced by 65% with respect to the capabilities of typical new aircraft in 2000. EU targets are considered as being on an equal footing with those announced by ICAO, IATA, and the U.S. National Aeronautics and Space Administration (NASA) [2–4].

To fulfil these long-term emission goals, it is not possible to rely on conventional thermal propulsion: current technology has already been pushed to the limit. Indeed, a radical innovation is required. Among new aircraft concepts or systems, hybrid-to-full electric or hydrogen powered aircraft promise to lower emissions and noise pollution.

However, the existing airport framework was not designed for this new type of aircraft. Infrastructural enhancements will be necessary for the operations of pure-electric and hybrid-electric aircraft. An upgrade of the current electric grid is necessary to allow the energy supply, storage and distribution. Aircraft batteries will need to be recharged and an appropriate sizing of the recharging facility must be addressed to estimate the number and type of charging points and their related electrical consumption in terms of energy and power.

The problem has already been studied for terrestrial applications: due to maturity of the battery technology and public incentives, Electric Vehicles (EVs) are gaining popularity among drivers. However, the biggest obstacle to wider adoption of EVs is (im)maturity of battery technology [5]. Recharging batteries may take more time than refueling, which might be inconvenient. Various fast charging schemes are being developed and implemented, in order to reduce waiting times at public charging stations [6–8]. An alternative to a Battery Charging Station (BCS) is a Battery Swapping Station (BSS), where discharged EV batteries can be quickly swapped for a fully charged ones, thus eliminating long waiting times normally needed for charging [9–11].

A similar approach is here investigated and applied to air transport. The adoption of this new technology is bounded to its cost-effectiveness. Indeed, large investments are expected for these novel aviation technologies [12]. The transition to hybrid-electric aircraft is subjected to the price of new elements: batteries, chargers, and electricity. If their cost is paid back by the lower fuel consumption, aircraft owners will be pushed towards this ground-breaking technology. Additionally, possible full-electric take-off and landing can eradicate gaseous emissions and dramatically decrease noise at airport level. This positive environmental impact could bring a saving in airport emission and noise charges for airlines and foster the acceptance of this new technology.

Methodology

An adequate charging facility is needed to ensure smooth operations of an electric or hybrid-electric fleet. A sizing framework is here presented, where, throughout an optimization process, infrastructural costs and operational expenses are minimized. To provide a fair comparison, the two charging strategies, i.e. plug in chargers and BSS, are competitively evaluated.

The charging method is selected by a solver adding the capability to choose the best one in the sizing algorithm. The optimization model is described in Figure 1. It consists of a solver that, based on information about the technical properties of chargers and batteries and on airport traffic data, determines the minimum number of aircraft to employ, the number of batteries, the number of recharging stations, the peak

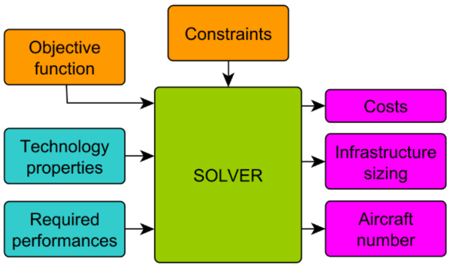

Figure 1: Model architecture.

electric power, infrastructural costs, operational costs, and the optimum battery recharging time schedule. Details of the architecture of the model developed are given in Figure 2.
First of all, we need to define the technology properties of the chargers and batteries. For convenience, two types of chargers are present: regular chargers and fast chargers. Chargers properties include: model, power, voltage, current, charger location (on-board or off-board), and cost. For fast chargers, a dedicated routine estimates the cost from the charging power. Battery properties are: model, technology, specific energy, energy density, and life cycles. Then, it is necessary to define data for aircraft considered within the simulation. Some of their properties depend on the battery and are recalled from the battery data. Other parameters are computed accordingly from the battery technology and capacity. The aircraft properties include: model, battery properties (capacity, energy density, specific energy, technology, cost, efficiency, life, charging power), cost, number of passengers and type of propulsion (electric or hybrid-electric). The data gathered are used to model the airport fleet. Afterwards, the airport under analysis is modelled.
The sizing problem requires to tune multiple parameters. Quantities like the number of batteries in the BSS, the number of plug-in stations, the peak power request and others design outputs are coupled and the variation of one of them affects the others. To be able to deal with different parameters at the same

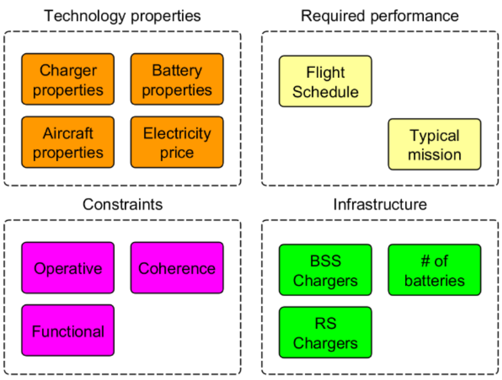

Figure 2: Elements considered in the model.

time, a Mixed Integer Linear Programming (MILP) formulation analogous to the one presented in [9] is introduced and discussed.

Case study

Athens international airport *Eleftherios Venizelos* is the primary international airport that serves the city of Athens and the region of Attica. It is Greece's busiest airport and it serves as the hub and main base of Aegean Airlines, as well as other Greek airlines. It has been selected as a test airport for the sizing procedure, since in 2016 it was the European airport with the highest number of propeller-driven regional aircraft movements. Concerning regional aircraft, Athens has been the busiest airport from 2014, with the number of movements constantly increasing from that year [13].
Regional aircraft are widely used to connect Greek islands to the mainland, thus Athens airport makes a good test case to assess the infrastructural needs of regional aircraft operation. To estimate the movements and to build up an average daily flight schedule, public available data have been used [14], since more specific information from the airport was not available. During a typical day, there are approximately 30 departures relevant for the analysis: 14 flights performed with a Bombardier Dash 8 Q400, 12 with an ATR 42 and 6 with an ATR 72. These aircraft carry, respectively, 78, 48 and 70 passengers. A conceptual design of hybrid electric regional airplanes corresponding to the aforementioned models was first carried out using dedicated tools [15], and subsequently employed to replace the conventional fleet of aircraft. Resulting data is shown in Table 1.
In Athens, flights are distributed during the day as reported in [15]. No operation takes place before 06:00 local time. For what concerns costs, a price tag for these hybrid-electric regional aircraft should be introduced in the model.
As the goal of this contribution is to provide a proof of concept and an illustration of the capabilities of the presented approach, the current price of the conventional versions of Bombardier Dash 8 Q400, ATR 42 and ATR 72 planes has been considered.
This should provide the correct order of magnitude of the aircraft acquisition costs. A more accurate, in-depth study would need further economic considerations. These prices are also given in Table 1. Current electricity prices in Greece are reported in Table 2.
Daytime charge refers to weekdays, from 7 AM to 23 PM. The particularity of these tariffs is their power

Table 1: Aircraft characteristics.

Aircraft	Pax	Price [M€]	Estimated battery capacity [kWh] for HE variant
ATR42	48	12.2	1,000
ATR72	70	15.4	1,300
DH8D	78	21.9	1,400

Table 3: Greek electricity prices.

Item	Unit	Value
Constant fee Fixed charge	€/month	9.7085
Daytime energhy charge	€/kWh	0.05903
Nighttime energy charge	€/kWh	0.04614
Daytime power charge	€/kW/mo	8
Transport power charge	€/kW/mo	1.329
Distribution energy charge	€/kWh	0.0029
Distribution power charge	€/kW/mo	1.179
Other energy charge	€/kWh	0.01576

Table 2: Infrastructural sizing with 200 kW chargers.

Item	Unit	Const Energy Price	Nighttime Reduced Price
Total Batteries		26	31
Chargers		10	26
Aircraft		12	12
Peak Power	MW	1.8	5.2
Chargers total cost	M€	0.57	1.49
Battery replacement	Years	1.78	2.12

pricing. One tariff depends on the maximum power demand, while another one depends on the maximum daytime power demand. The nightly discount in the power price makes convenient to charge almost all the batteries during the night, as shown in Table 3, considering 200 kW chargers.

A sample of the output of the procedure is given in Figure 3. In this particular case, recharging all the batteries during the night is not necessarily the cheapest option, since it requires to increase the number of chargers and batteries. In fact, each charger would cost approximately 57 k€, and their expected life of 10 years corresponds to pay 157 €/day for 10 chargers and 409 €/day for 26 chargers. However, this power pricing policy makes the power price equal to 488 €/day for the night charge strategy, against 700 €/day for 10 chargers used all day long.

In both cases, the solver computed the same number of aircraft requested for the operations (assuming an aircraft performs a flight to another airport and comes back in 2.5 hours), but this number actually depends on how the airlines manages the fleet, and if all the aircraft departing from Athens are based in this airport.

In the constant energy price case, it is required to substitute a battery pack every 1 year and 9 months, while, in the nighttime discount case, the higher amount of batteries has to be substituted every 2 years and 2 months. However, in the long run the amount of purchased batteries will be the same, since what really matters is the number of charging cycles a battery can bear. Increasing the charger power to 400 kW, results are those illustrated in Figure 4 and Table 4.

The 400 kW chargers sizing shows the same trend of the 200 kW chargers sizing. While the charger number and their cost are strongly affected by the charging power, the variation of the other parameters is less relevant.

Conclusion

An optimization algorithm able to size the airport infrastructure in support of a hybrid-electric fleet has been developed. Starting from battery, charger, aircraft properties and flight schedule the optimization finds infrastructural needs to perform smooth operations, minimizing the cost. Two charging strategies have been identified: BCS and BSS. This procedure has been tested on Athens international airport since it was the European airport with the highest number of propeller-driven regional aircraft movements in 2016 and because propeller-driven regional aircraft are considered the first step for the scalability of hybrid-electric propulsion from general aviation to airliners. Infrastructural requirements such as the number of necessary chargers, batteries, the number of aircraft

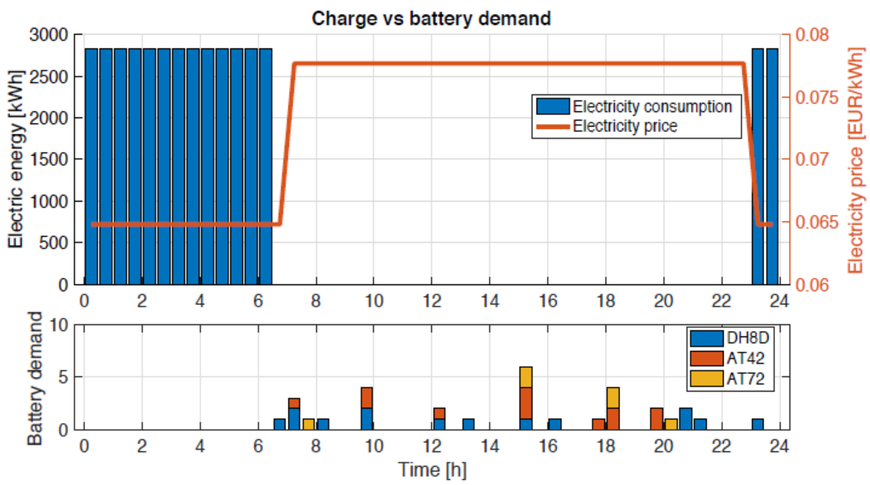

Figure 3: Airport sizing output with 200 kW chargers (nightime electricity discount case).

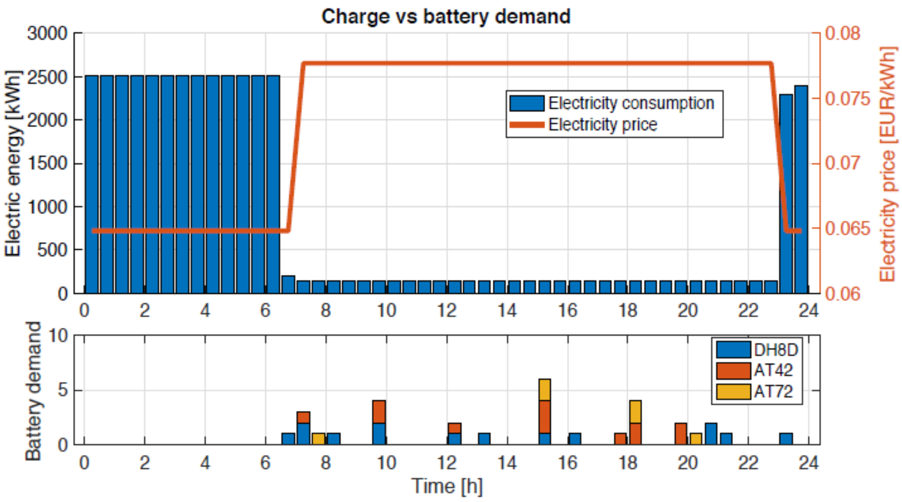

Figure 4: Airport sizing output with 400 kW chargers (nightime electricity discount case).

required to operate current flight schedule and electric peak power have been identified. An optimum recharge scheduled has also been assessed.

In the Athens case study, the plug-in solution was not deemed suitable for the big batteries required by regional airplanes. 200kW and 400kW chargers were considered. Greek electricity fares showed different optimum solutions involving a varying number of chargers/batteries.

Table 4: Infrastructural sizing with 400 kW chargers.

Item	Unit	Const Energy Price	Nighttime Reduced Price
Total Batteries		21	32
Chargers		6	16
Aircraft		12	12
Peak Power	MW	2.4	6.4
Chargers total cost	M€	0.41	1.08
Battery replacement	Years	1.42	2.19

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