



STRUCTURED ANALYSIS ESTIMATION FOR ELECTRICAL ENERGY DEMAND ON AIRPORT OPERATIONS FOR HYBRID REGIONAL AND ELECTRIC TOWING PARAMETERIZED BY MOVEMENT METRICS CONSIDERING UPCOMING ELECTRIC INTENSIVE TECHNOLOGIES AND EMISSION REDUCTIONS IN THE UPCOMING DECADE

Talitha Oliveira¹ & Adriano Carvalho¹

¹The Boeing Company

Abstract

The goal of this paper is to present a structured analysis for airport electrical energy consumption increase expected due to operations such as electric towing and hybrid regional implementation on the following years. The analysis is based upon movements and characteristics of Confins airport. The bench-marking airplanes used were A320neo, Boeing 737 Max 8 and Embraer 195 E2 to estimate the parameters to be accounted for on the analysis. Results have shown that electric towing would not heavily impact on the expected demand for electrical energy, accounting for around 1% increase, whilst hybrid operation could represent an increase from around 10% to 37%, depending on the amount of hybrid airplanes operating on the airport. Alongside these estimations, a study for reusing some of the energy spent on the descent phase of flight is also presented.

Keywords: airport operations, energy demand, electric towing, hybrid aircraft

1. Introduction

Airport infrastructure segment is constantly coping with the advances in aviation technology in order to provide the support needed. In the history of aviation, there has seldom been a substantial innovation that didn't exert pressure on airport infrastructure. Competitiveness factors that will influence Airports, considering Macroenvironment, Corporate, Market and internal scenarios, and an estimation of how the airport should act aiming to minimize the negative aspects and empower the positive aspects found in these competitive factors is paramount to assure their adequacy to these new challenges.

An overlook at the current state of Technology Readiness on more electrified systems together with the demand for more environmentally friendly solutions, especially on the transportation industry, push this industry to access the whole logistics supply chain, in which the infrastructure needed to operate these new systems is of special importance due to the level of investment and implementing time needed for these customizations to be set in place.

To assess what is expected for the following years in terms of airport electric consumption related to these new operation demands, an analysis was held for operations on Confins airport. It was found that 95% of its total operation is domestic and it was assumed that 3 airplanes are responsible for most of this operation: A320neo, Boeing 737 Max 8 and Embraer 195 E2.

Two analyses were made: one of them related to aircraft electric towing operation impact on the electric consumption for the airport and the other one related to regional hybrid operation impact.

2. Electric towing operation

For electric towing operation, it was considered that the goal is to decarbonize aircraft ground movements, so the assumption is that tow will be held from the gate until the runway. Figure 1 shows the view for Confins airport in scale. It was measured that the distance for this operation from gate to runway would encompass 2000 m.

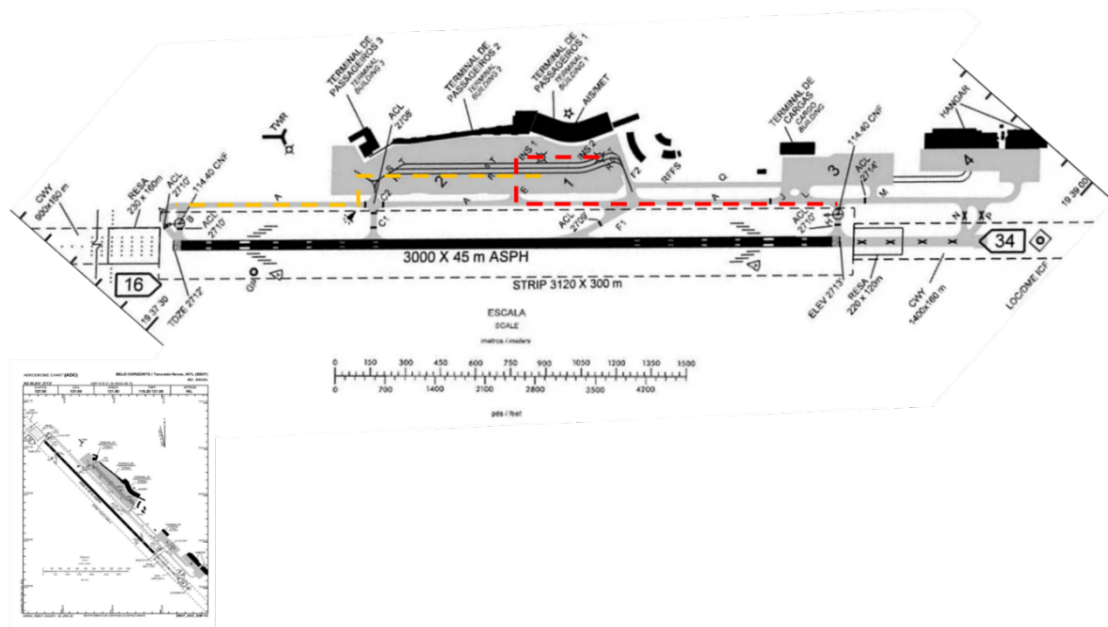


Figure 1 – Scaled view for Confins airport

Total energy demand is calculated based on the work needed to move the airplane plus tow equipment on this distance. To estimate this work, rolling resistance force is calculated [1]:

$$\tau_t = F_{rr} \times d \quad (1)$$

$$F_{rr} = f \times m \times g \quad (2)$$

$$m = m_t + m_a \quad (3)$$

In which:

τ_t is the work for each tow operation;

F_{rr} is rolling resistance force;

$d = 2000 \text{ m}$ is the distance for the ground operation;

$f = 0.011$ is the rolling resistance coefficient, for pneumatic tires on concrete [1];

$g = 9.81 \text{ m/s}^2$ is the gravitational acceleration;

$m_t = 14500 \text{ kg}$ is the tow equipment mass [2];

m_a is the airplane mass.

Airplane properties are shown in Table 1 [3], [4], [5], [6], [7], [8]:

An operation is considered as:

- Tow engaged on the airplane and moving it from gate to runway for take-off;
- Tow disengaged from airplane getting back from runway to gate;
- Tow disengaged from airplane getting from gate to runway;

Table 1 – Airplane properties summarized

Airplane Model	A320neo	Boeing 737 Max 8	Embraer 195 E2
Capacity (Passengers)	180	189	146
Maximum take-off weight (kg)	73500	82645	62500
Maximum landing weight (kg)	64500	69308	54000
Maximum operating altitude (m)	11918	12497	12497
Engine fan radius (m)	0.976	0.863	0.913
Engine fan rotational speed (rad/s)	404	460	370

- Tow engaged on the airplane and moving it from runway to gate after landing.

Total movements (take-off and landing) for CNF airport per year is show in Figure 2 [9] [10].

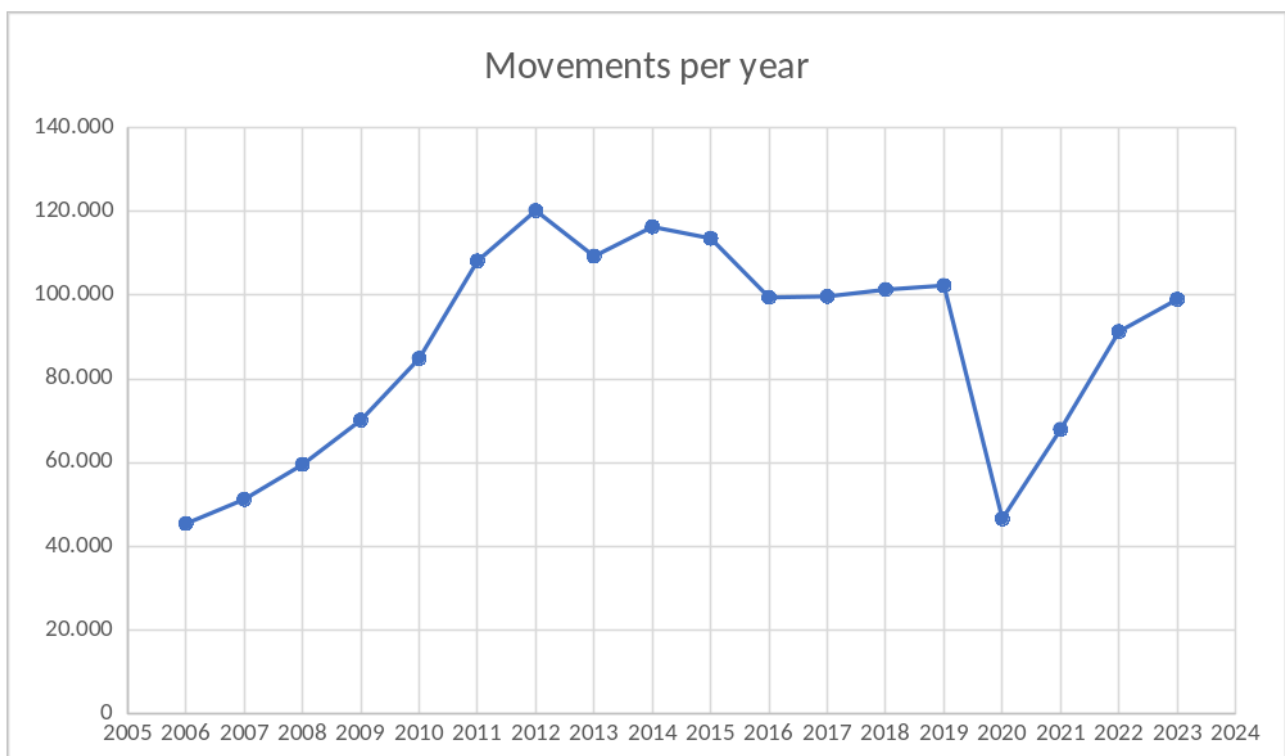


Figure 2 – Movements per year for Confins airport

Since 2011 movements have been varying from 90000 to 120000. Values of 2020 and 2021 are discharged due to the impact of COVID pandemics. Expectation for future is that the observed pattern will be maintained.

Considering that 95% of its operation is domestic and will be held by the airplanes according to the following distribution:

- 40% for Airbus A320neo;
- 40% for Boeing 737 Max 8;
- 15% for Embraer 195 E2.

Data regarding current electric energy consumption for CNF airport was not found, so to estimate its increase, data on Kansai airport was used as a benchmark analysis. For this airport, annual electric consumption was 360 TJ (terajoules) in 2015 [11]. Table 2 shows the results of this analysis.

Table 2 – Electric towing operation increase in airport electrical consumption estimation

Movements	90000	120000
Total energy for tow operation (TJ)	3.66	4.88
Total airport consumption (TJ)	363.66	364.88
Increase percentage	1.01%	1.34%

3. Regional hybrid operation

To analyze regional hybrid operation, it is expected that technology to recharge a part of the batteries using the energy from airplane movement while decelerating will be available, to optimize the operation on ground.

Using the data on Table 1, and assuming that the fan will be able to retrieve some of the energy from air to charge the battery while on the descent phase of flight (and thus would work as a wind turbine), it is possible to calculate the energy that would be converted in this situation [12]:

$$P = \frac{1}{2} \times \rho \times C_p \times A \times v_w^3 \quad (4)$$

$$C_p = c_1 \times \left(\frac{c_2}{\lambda_i} - c_3 \times \beta - c_4 \right) \times e^{\frac{-c_5}{\lambda_i}} + c_6 \times \lambda \quad (5)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08 \times \beta} - \frac{0.035}{(\beta^3 + 1)} \quad (6)$$

$$\lambda = \frac{r \times \Omega}{v_w} \quad (7)$$

In which:

P is the captured power;

ρ is air density;

C_p is the power coefficient;

A is the fan swept area;

$v_w = 139 \text{ m/s}$ is wind speed, in this case it is the same as the descent speed which was estimated;

Coefficients c_1 to c_6 are given [12]:

$c_1 = 0.5176$, $c_2 = 116$, $c_3 = 0.4$, $c_4 = 5$, $c_5 = 21$ and $c_6 = 0.0068$;

$\beta = 0.26 \text{ rad}$ is the blade pitch angle;

λ is the tip speed ratio;

r is the fan radius;

Ω is the fan rotational speed.

To calculate ρ , it is assumed that the highest altitude (top of descent) is the maximum operating altitude and the lowest altitude (airport zone) is assumed to be 457 m. The atmospheric model was used to calculate [13].

$$\rho = \frac{p}{0.2869 \times (T + 273.1)} \quad (8)$$

In which:

T is the air temperature;

ρ is the air pressure.

For top of descent:

$$T = -56.46 \quad (9)$$

$$p = 22.65 \times e^{1.73 - 0.000157 \times h_2} \quad (10)$$

For airport zone:

$$T = 15.04 - 0.00649 \times h_1 \quad (11)$$

$$p = 101.29 \times \left(\frac{T + 273.1}{288.08} \right)^{5.256} \quad (12)$$

To calculate the total energy that would be converted, it is considered a descent rate from top of descent to airport zone of 7.62 m/s and the two engines will be used on this operation.

$$E_g = n \times \Delta P \times t \quad (13)$$

In which:

E_g is the energy generated by the fans;

$n = 2$ is the number of engines;

ΔP is the power variation from top of descent to airport zone;

t is the descent time.

Total energy for the airplane on these conditions is calculated as the difference in potential energy (since it is assumed that there is no change in mass for this part of the flight for a hybrid airplane). It is assumed the mass corresponds to the maximum landing weight.

$$E = m_a \times g \times (h_2 - h_1) \quad (14)$$

$g = 9.81 \text{ m/s}^2$ is gravitational acceleration.

It is considered that battery energy density is 500 Wh/kg, 1 Wh = 3600 J and battery total weight is estimated based on the maximum take-off weight for each airplane [14]. Using this data, it is possible to find the results shown in Table 3.

Table 3 – Airplane energy retrieving estimation for descent phase

Airplane Model	A320neo	Boeing 737 Max 8	Embraer 195 E2
Total airplane energy (GJ)	7.25	8.19	6.38
Total saved energy (GJ)	0.42	0.38	0.25
Saved energy percentage	5.81%	4.68%	3.88%
Battery charged weight (KG)	234.05	212.77	137.5
Battery charged weight percentage	2.42%	1.97%	1.67%

From this analysis it is possible to note that only a small part of the battery would be recharged using the energy from airplane movement, most of the energy would need to come from airport installations.

Considering that regional operation encompasses from 5% to 20% of CNF airport operation, it is possible to find the boundaries for increase in energy to be provided for hybrid operation.

Using the following distribution for each airplane movements, it is possible to find the increase in energy demand for this operation, as presented in Table 4.

- 40% for Airbus A320neo;
- 40% for Boeing 737 Max 8;
- 20% for Embraer 195 E2.

Table 4 – Hybrid operation increase in airport electrical consumption estimation

Total battery amount	2250	12000
Total energy for hybrid operation (TJ)	39.07	208.36
Total airport consumption (TJ)	399.07	568.36
Increase percentage	9.79%	36.66%

The results of the analysis show that towing electrical operation would not have impact significantly on the electric consumption for the airport, whilst hybrid electric operation would heavily impact on the demand for electrical energy within airport, since for only 5% of regional hybrid operation there is an increase in almost 10% for the energy demand.

4. Discussion

The amount of energy to be feed for hybrid battery charging represents one of many challenges for the application of this technology, since airport infrastructure would need to be prepared to provide various charging installations and prepare a new logistics for dispatching the airplanes on a timely manner.

With regards to battery charging, there are two main ground recharging facilities in literature: a) Battery plug-in chargers (BPCs) and b) Battery Swapping Stations (BSSs). Some pure electric airplanes had been type-certified and use BPC technology, with charging times of around 15 minutes through an external 60 kW Direct Current (DC) charger [15]. However, a major concern regarding this technology is the increase expected on recharging time for larger airplanes, which would not suffice turnaround times for airline operations. On the other hand, BSSs allows battery charging unplugged from the vehicle, which would make it possible to swap batteries as part of operational preparation for take-off. The downside of this solution is the logistics related to batteries transportation and storage [16].

For the current energy consumption at airports aspect, it is noted that most of it already comes from electricity sources, but the major part is used to feed the terminal building, encompassing almost 80% of energy consumption. Nonetheless, an energy performance indicator benchmark that considers power consumption per passenger per year shows that there is no linear correlation between airport size and energy consumption, due to dependencies on multiple factors [17]. Whatsoever, both charging technologies needs to be evaluated in terms of the overall energy demand with regards to airport infrastructure, as well as other derived needs for the upcoming technologies which can heavily impact the current consumption, as shown by this analysis.

In conclusion, it was possible to estimate the increase in electric consumption for regional hybrid and electric towing operation based on movements for CNF airport and compare the results with the current electric consumption for a benchmark airport to understand the impact of these new technologies on the airport infrastructure. It was possible to visualize that electric towing can be easily

adopted since it would not cause a huge impact on the current operation, whilst hybrid operation would need to analysis especially regarding the logistics to be implemented, since it represents a huge impact on overall consumption.

5. Contact Author Email Address

To contact the author. [mailto: talitha.oliveira@boeing.com](mailto:talitha.oliveira@boeing.com)

6. Copyright Statement

The authors confirm that they, and/or their company or organization, hold copyright on all of the original material included in this paper. The authors also confirm that they have obtained permission, from the copyright holder of any third party material included in this paper, to publish it as part of their paper. The authors confirm that they give permission, or have obtained permission from the copyright holder of this paper, for the publication and distribution of this paper as part of the ICAS proceedings or as individual off-prints from the proceedings.

References

- [1] *How to calculate rolling resistance*. (2024). Retrieved on May 30, 2024. From: <<https://x-engineer.org/rolling-resistance/googlevignette>>
- [2] *Eagle Tugs-Aircraft Tugs and Airport Tugs | Aircraft Tug Ground Support Equipment, Tow Tractors, Airplane Tugs, Industrial Tugs, More—Eagle Tugs*. (2024). Retrieved on May 30, 2024. From: <<https://eagletugs.com/aircraft-tugs/eagle-xm-series-aircraft-tugs-xm-30>>
- [3] *EASA.IM.A.120 - Boeing 737 Type certificate*. (2024). Retrieved on May 30, 2024. From: <<https://www.easa.europa.eu/en/document-library/type-certificates/aircraft-cs-25-cs-22-cs-23-cs-vla-cs-lsa/easaima120-boeing-737>>
- [4] *EASA.A.064 - Airbus A318, A319, A320, A321 Single Aisle Type certificate*. (2024). Retrieved on May 30, 2024. From: <<https://www.easa.europa.eu/en/document-library/type-certificates/aircraft-cs-25-cs-22-cs-23-cs-vla-cs-lsa/easaa064-airbus-a318>>
- [5] *EASA.IM.A.071 - Embraer ERJ 190 Type certificate*. (2024). Retrieved on May 30, 2024. From: <<https://www.easa.europa.eu/en/document-library/type-certificates/aircraft-cs-25-cs-22-cs-23-cs-vla-cs-lsa/easaima071-embraer-erj>>
- [6] *EASA.E.110 - LEAP-1A LEAP-1C series engines*. (2024). Retrieved on May 30, 2024. From: <<https://www.easa.europa.eu/en/document-library/type-certificates/engine-cs-e/easae110-leap-1a-leap-1c-series-engines>>
- [7] *EASA.E.115 - LEAP-1B series engines*. (2024). Retrieved on May 30, 2024. From: <<https://www.easa.europa.eu/en/document-library/type-certificates/engine-cs-e/easae115-leap-1b-series-engines>>
- [8] *EASA.IM.E.090 - Pratt Whitney PW1500G Series Engines*. (2024). Retrieved on May 30, 2024. From: <<https://www.easa.europa.eu/en/document-library/type-certificates/engine-cs-e/easaima090-pratt-whitney-pw1500g-series-engines>>
- [9] *Infraero aeroportos – Estatísticas*. (2024). Retrieved on May 30, 2024. From:<<https://transparencia.infraero.gov.br/estatisticas/>>
- [10] *BHAIRPORT – STATISTICS AND PUBLICATIONS*. (2024). Retrieved on May 30, 2024. From:<<https://site.bh-airport.com.br/SitePages/en/publicacoes/estatisticas.aspx>>
- [11] Baxter, G., Srisaeng, P., Wild, G. (2018). Sustainable airport energy management: The case of kansai international airport. *International Journal for Traffic Transport Engineering*, 8(3).
- [12] Xia, Y., Ahmed, K. H., Williams, B. W. (2012). Wind turbine power coefficient analysis of a new maximum power point tracking technique. *IEEE transactions on industrial electronics*, 60(3), 1122-1132.
- [13] *NASA Glenn Research Center – Earth Atmosphere Equation – Metric*. (2024). Retrieved on May 30, 2024. From: <<https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/earth-atmosphere-equation-metric/>>
- [14] Rossi, N. (2017). *Conceptual design of hybrid-electric aircraft*.
- [15] SARKER, M.R.; PANDŽIĆ, H.; ORTEGA-VAZQUEZ, M.A. Optimal operation and services scheduling for an electric vehicle battery swapping station. *IEEE Trans. Power Syst.* 2015, 30, 901–910.
- [16] ZHENG, Y. et al. Electric vehicle battery charging/swap stations in distribution systems: Comparison study and optimal planning. *IEEE Trans. Power Syst.* 2014, 29, 221–229.
- [17] ORTEGA, A. S., MANANA, M. (2016). Energy research in airports: A review. *Energies*, 9(5), 349.