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Selecting figures of merit for a hybrid-electric 50-seat regional aircraft

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Abstract. In the course of the aircraft design process for a hybrid-electric aircraft, a number of configuration alternatives have to be assessed. In addition, novel propulsion concepts have to be compared to a conventional reference aircraft. These comparisons are carried out by means of suitable figures of merit, adapted to a reference mission. This work will give insight into the process of identifying suitable figures of merit for a 50-seat hybrid-electric regional aircraft, which was carried out in the Horizon 2020 project FUTPRINT50. Coming from a thorough perspective, a down-selection leads to a graspable number of parameters which are categorized in regard to the environment, to the airline desirability, and to the introduction of hybrid-electric aircraft. Those figures of merit, like emissions and operating costs, are gathered in an objective function which can support an overall evaluation of the aircraft design. This offers a detailed, yet transparent assessment of the various designs.

1. Introduction

As the impact of climate change is becoming more imminent, the aviation industry strives to engineer solutions for greener air travel. In order to drastically reduce emissions, new aircraft configurations and technologies like hybrid-electric aircraft concepts are investigated. The project FUTPRINT50 investigates such disruptive concepts and forms the scope of the work presented in this paper. This research project is funded by the European Commission through the research and innovation programme Horizon 2020. Its goal is to accelerate the development of a hybrid-electric regional aircraft with a seat capacity of fifty passengers. This is executed on the basis of a bottoms-up approach where the hybrid-electric architecture is developed on its own and serves as the main driver of the overall aircraft design.

The aircraft configuration is confined by the following top-level aircraft requirements: The design range is set to 400 km with a seat capacity for 50 passengers. Furthermore, the propulsion system must feature a hybrid-electric architecture and the planned entry-into-service lies between the years 2035 and 2040. The environmental goals of the project result from the European innovation strategy Flightpath 2050. This action paper calls for a 75 % reduction of the CO₂ emissions per passenger kilometer by the year 2050. Furthermore, it proclaims a reduction of NO_x emissions by 90 % and a noise emission reduction of 65 %. All of these values are measured in comparison to a typical aircraft from the year 2000. [1]

In the conceptual aircraft design process, many different configurations are investigated. In order to assess those designs, they are rated by the method of the figure of merit. It must be noted that there are two usages of the term figure of merit: A parametric figure of merit describes a single parameter which can relate to almost any characteristic of an aircraft. On the other



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hand, the top-level figure of merit relates to a combination of separate figures of merit. While the top-level aircraft requirements establish the framework of the aircraft design, the figure of merit quantifies how well the design matches the evaluation criteria. This generates a sorted list that can be used to prioritize further analyses into the various designs. However, almost any parameter given out in the aircraft design process can serve as a figure of merit. That is why this work provides a selection of meaningful figures of merit specifically for a hybrid-electric regional aircraft. This can serve as basis for the assessment of future concepts in this aircraft category.

In this work, parameters from the aircraft design process are presented which serve as input data for the figure of merit. Furthermore, an extensive down-selection of potential figures of merit is done by analyzing their significance to the aircraft design and the given requirements. At the end, a calculation method is presented and a conclusion including an outlook is given.

2. Input Parameters

The figures of merit are fed by parameters from the conceptual aircraft design that serve as input data. These data are normally imported from automated design tools which calculate numerous design alternatives at once. The input parameters are divided into the following three categories: Aircraft characteristics, hybrid-electric architectures, and energy management strategies.

The first category offers input data of the selected aircraft configuration which gives information e. g. about the placement of wing, tail, and landing gear. Furthermore, all dimensions of the main components are collected to describe the geometry of the aircraft in detail. This geometric data is used to generate the component and overall masses which also play a major role within the evaluation of the aircraft design.

The hybrid-electric architecture accumulates data about the propulsion systems of the investigated designs. One important item is the degree of hybridization which states the percentage of the electric power in regard to the total output power. Therefore, it serves as a figure which defines the architecture of the power train. [2] Moreover, the installation of different technologies is also described in this category. This may refer to various types of primary movers, fuels, and other technologies.

The final input data needed are the energy management strategies. Those strategies define ways to split the different energy sources like the usage of the gas turbine and battery.

3. Down-Selection

Every quantifiable parameter which characterizes the aircraft design can serve as a figure of merit. The more design parameters are incorporated, the better the assessment of the aircraft design might be. However, this also brings up some challenges as the calculation of the figure of merit becomes more complex and intransparent.

In order to find a small but meaningful collection of figures of merit, a filter is put in place. The filter consists of four criteria:

- (1) Limitations that are defined by top-level aircraft requirements
- (2) Design parameters that are fixed
- (3) Parameters that do not change significantly between different designs
- (4) Parameters that are expressed through higher-level ones

The first criterion discards figures of merit that do not influence the assessment because of limitations by the top-level aircraft requirements. In the case of the regional aircraft from the FUTPRINT50 project, the requirements state a maximum cruise altitude of FL 250. Since aviation induced cloudiness is mainly expected to form in higher altitudes, this figure of merit is discarded. [3]

Fixed design parameters act as second criterion. Some parameters must remain unchanged during a design process. For example, the maximum range is a hard requirement stated by the airlines. Falling short of it is not an option. However, exceeding it will make the design not necessarily better either, as the design may become less efficient on shorter ranges.

The third criterion filters out parameters that do not change significantly. This may be valid for parameters that are estimated by engineers or parameters that only vary in case of a major technology change. Switching from conventional jet fuel to hydrogen will impact the ground handling and servicing for every aircraft design identically. This is why it can be neglected.

The last criterion discards any figure of merit that can be expressed by a higher-level one. As an example, cruise speed is normally defined as a figure of merit because it can have an influence on the number of possible dispatches. However, it is also interconnected with fuel consumption and many other characteristics. All of those aspects can be combined within the direct operating costs.

Table 1. Summary of selected figures of merit

Environmental Aspects	Airline Desirability	Introduction of Hybrid-Electric Aircraft
CO ₂ emissions	Direct operating costs	Development risks
NO _x emissions		Certification challenges
Noise emissions		Production aspects

In the case of the hybrid-electric regional aircraft developed within the FUTPRINT50 project, seven figures of merit persisted the described filtering process. Those are given in table 1 where they were divided into three categories. These figures of merit are explained in more detail in the following sections:

3.1. Environmental Aspects

The environmental aspects that were chosen for the figures of merit fully relate back to the Flightpath 2050 goals. CO₂ emissions strongly depend on fuel flow, therefore, the input data of the energy management strategies have a major influence on the figures of merit. The emission of NO_x is mainly dependent on the combustion characteristics in the engine. While its atmospheric effect is important to consider because of ozone forming, it is also a relevant pollutant in the vicinity of airports. [4]

The same issue corresponds to the noise emissions as well. Noise is a very important aspect in order to ensure the health and well-being of citizens living close to airports. Although noise is hard to analyze so early in the design process, engineers can roughly estimate it by the position of components like propellers on the wing or their potential shielding like a ducted fan.

Major contributions to these aspects can be provided by an optimum energy management strategy which has the potential of reducing emissions overall or just locally in more polluted or crowded areas.

3.2. Airline Desirability

As mainly airlines drive the specifications of an aircraft, pleasing them is a major aspect of every design. Since cost is an essential parameter in the airline industry, the direct operating costs are the main driver of this category.

The direct operating costs are divided into five portions which consist of capital costs, maintenance costs, fuel costs, crew costs, and navigation fees. Capital costs is expected to go up for a new hybrid-electric aircraft because of higher development efforts. On the other hand, fuel

and maintenance costs is expected to decrease because of lower energy costs for hybrid-electric aircraft and less complex maintenance in the long run. While crew costs are expected to remain the same, the navigation and landing fees might decrease because of environmental rewards. [2]

Beside operating costs, the potential of generating revenue is an important aspect for airlines as well. However in this case, it is assumed to stay the same as seat capacity and passenger comfort remain unchanged. Though, it may be included in further enhanced models.

3.3. Introduction of Hybrid-Electric Aircraft

The figures of merit in this category cover the risks in development as well as the challenging certification process and production aspects.

The first item represents the risks for the manufacturer developing the hybrid-electric aircraft. This includes challenges that might occur in the design process of not only the overall aircraft but also of all required components and subsystems. To address these topics, an estimation is made in relation to the technology readiness level of identified key technologies. Furthermore if required, infrastructure needs are also taken into account.

Certification is the second part within this category. Currently, CS-25 offers no guidelines how to certify hybrid-electric aircraft. By assessing the complexity of the system, an estimation can be made about the amount of testing required for certification. Furthermore, adding novel propulsion concepts like distributed electric propulsion will further increase complexity and therefore require verification.

Lastly, the selection of material and processes also imposes risks on different designs. Again, the newer and more complex the technology, the higher the overall risk for unforeseen difficulties.

All in all, these criteria are difficult to quantify. Oftentimes, the parameters for these figures of merit must be objectively estimated by the engineer.

4. Calculation

In this chapter, a work flow is presented which processes various input data into the overall figure of merit. The scheme of this method is shown in figure 1.

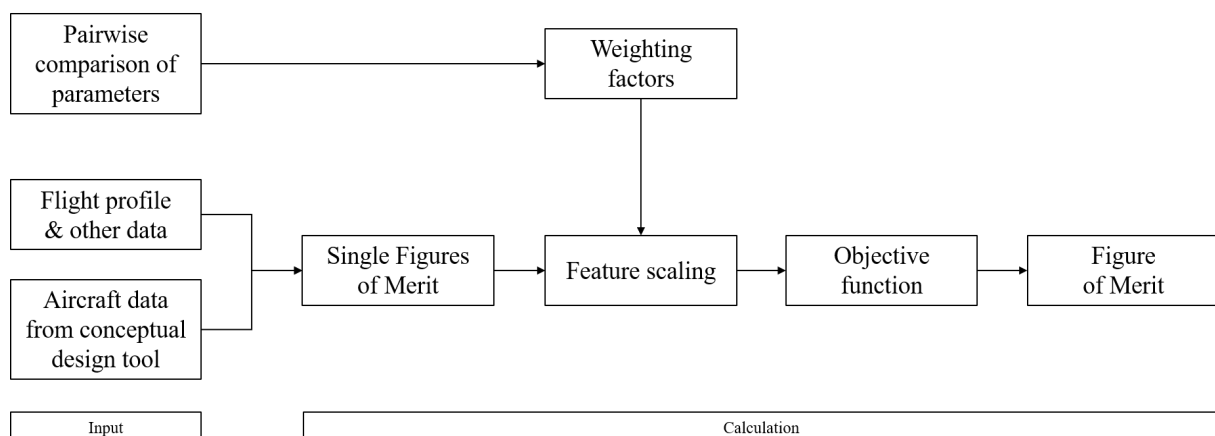


Figure 1. Calculation method for the figure of merit

The first step of the calculation method consists of combining the two major input data. The design tool gives out all the data that were previously described in section 2. The second input file contains data about the flight profile, ambient conditions, etc. The module *Single Figures of Merit* calculates the seven single figures of merit that were previously selected. Those separate figures of merit need to be feature scaled in order to be combined into one. Feature scaling is

a method which resizes all the different values of the figures of merit onto a scale between 0 and 1. Furthermore, the resulting equation consists of weighting factors. They are generated by a pairwise comparison in a table. The constructed equation forms the objective function. It consists of weighted, normalized parameters which are then combined into the aircraft-level figure of merit.

By dividing the parameters into different categories, the structure of the figures of merit is established in a modular way. The figure of merit CO₂ emissions merges into the figure of merit environmental aspects, and this merges into the overall figure of merit. This means that if any outcome of a figure of merit is unclear, it is always possible to go one level deeper to understand the characteristic of a specific figure of merit. This provides transparency, traceability, and plausibility. Another advantage of the modular approach is the simple implementation of modifications. When an additional figure of merit is identified, it can be added by changing only one module of the whole work flow.

5. Conclusion and Future Work

In conclusion, we presented a comprehensible selection of figures of merit for a hybrid-electric regional aircraft. We showed that a large amount of parameters can be summarized in a small, more graspable number of meaningful figures of merit. With the presented calculation method, these separate figures of merit can be consolidated into one single figure of merit. This defines the assessment of the entire aircraft configuration depending on selected weighting factors.

The set-up of the modular approach for the different levels of the figures of merit helps to enhance traceability and plausibility checks. Furthermore, this method allows separate modifications to every single level. Therefore, the calculation of the figure of merit supports further alterations to the requirements and evaluation criteria.

The results of this work will be integrated into the FUTPRINT50 project. During the development of a tool environment for the aircraft design process, the selected figures of merit shall be constantly improved. In order to examine the sensitivity, gradients of the figures of merit have to be investigated. This will help to locate parameters that have to be altered specifically in order to create an overall optimum.

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