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Battery power for propulsion and electricity supply

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Abstract

The use of batteries in aviation has evolved over time. This paper analyses the main approaches to battery application in aircraft, with a particular focus on battery-powered aircraft. Within this group, a distinction is made between all-electric aircraft and hybrid-electric systems, in which the batteries work in collaboration with another propulsion source. The main ideas associated with each use of batteries in aviation are presented throughout this paper, contextualising them within the framework of the Environmentally Friendly Aviation for All Classes of Aircraft (EFACA) project's proposal for a source of sustainable propulsion for all classes of aircraft.

1. Introduction

A battery is defined as a collection of interconnected chemical cells that store and convert chemical energy directly into electrical energy. Batteries are indispensable in modern aviation. However, it is important to distinguish between different applications.

On the one hand, batteries play a fundamental role in providing continuous and back-up power in various situations. This is known as the use of batteries in conventionally-powered aircraft. These batteries must meet strict operational requirements to ensure the safety of air operations.

In addition, batteries also play a key role in the transition to the More Electric Aircraft (MEA) concept. This significant innovation in modern aviation seeks to improve the efficiency, reliability, and performance of aircraft systems.

As described above, batteries are essential for the uses mentioned, but they are not responsible for aircraft propulsion in either conventionally-powered aircraft or the MEA concept.

In recent years, especially since the 2010s, aircraft concepts using electrification for part or all of their propulsion system have attracted significant interest within the industry [1]. There are several ways to electrify aircraft. In order to develop the electric aircraft of the future, it will be necessary to innovate and develop new energy systems. This includes low-weight electric engines and battery systems for aircraft propulsion [2]. Within this concept of battery-powered aircraft, a distinction is made. The first category are the aircraft in which batteries are the fundamental source of propulsion: all-electric aircraft (AEA). Alternatively, batteries can work alongside other propulsion sources to form hybrid-electric systems. In the latter case, batteries provide additional power during phases of flight that require it.

This paper aims to analyse the four cases of battery application in aviation described above and differentiate the basic functions of batteries in each case.

The European Environmentally Friendly Aviation (EFACA) project is a Horizon Europe-funded project that began in 2023. One of its objectives is to reduce emissions near airports and en route. Several types of emissions are considered within this objective, including carbon dioxide, nitrous oxides, sulphur oxides, contrails and particles [3]. In line with this project objective, battery use is a promising option for reducing emissions. However, as will be analysed later, the technical characteristics of current batteries limit their use to small aircraft, particularly in urban air mobility (UAM) applications.

Within the framework of the EFACA project, analysing the role of batteries in battery-powered aircraft is of particular interest. Furthermore, existing projects and prototypes should be analysed to draw lessons and define recommendations for the future. This paper aims to present the EFACA project's sustainable propulsion proposal, outline the use of batteries within it, and identify use cases for battery-powered aircraft within the project framework.

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The rest of the paper is structured to address the above objectives. It is divided into two distinct parts. The first part presents the four cases of battery application in aviation. Section 2 presents the main uses of batteries in conventionally-powered aircraft. Section 3 discusses the role of batteries in the MEA aircraft concept and its advantages. Section 4 discusses the AEA aircraft concept, associated technologies, and interesting concepts and designs. Section 5 provides an equivalent analysis for hybrid-electric aircraft. The second part of the paper seeks to contextualise the above concepts within the EFACA framework. This analysis is described in Section 6. Finally, Section 7 presents the main conclusions and key ideas drawn from the analysis.

2. Use of batteries in conventional aircraft

Before considering concepts in which batteries play a fundamental role in the electrification of aircraft systems, it is necessary to analyse the role of batteries in conventionally-powered aircraft.
This analysis provides a basis for identifying the advantages and potential challenges of more modern and innovative aircraft concepts. The main applications of batteries in conventionally-powered aircraft are represented in Figure 1.

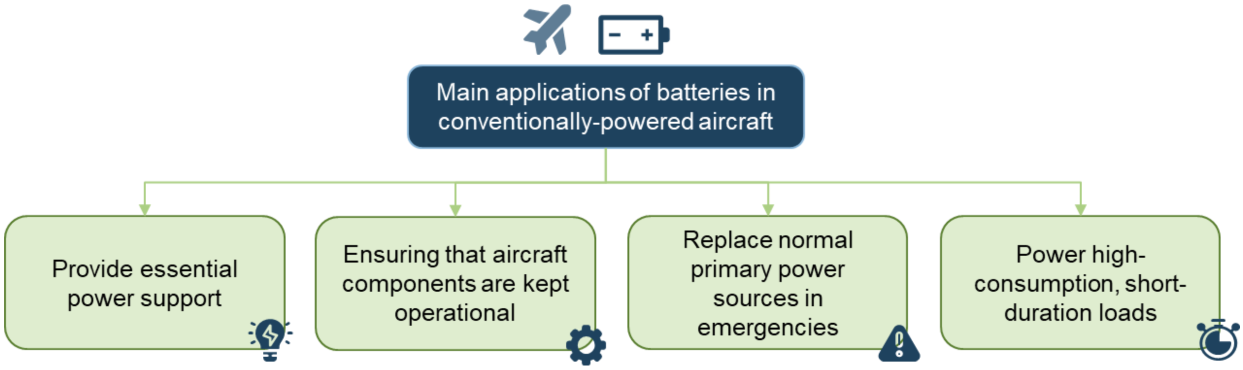

Figure 1: Main applications of batteries in conventionally-powered aircraft.

Batteries are indispensable in modern aviation with conventional propulsion. Traditionally, lead-acid or nickel-cadmium batteries have been used. However, in recent years, lithium-ion batteries have become increasingly common, with several key applications.
These batteries provide essential power support in a variety of situations. Batteries are also used to replace the main power sources in emergency situations. This ensures that critical systems function properly and the safety of the aircraft operation.
Batteries also serve as a back-up for primary power sources during periods of high power consumption, i.e. when large power consumers are switched on.
Furthermore, they provide independent power for loads that consume a lot of power for very short periods of time. Examples include auxiliary power unit (APU) starters, galleys and heating elements.
Batteries also serve as auxiliary or alternative power sources, ensuring that aircraft systems remain operational.
In summary, there are two main categories of batteries for conventionally-powered aircraft: main and emergency. Main batteries are used to start the engines and other systems, such as APUs. Emergency batteries are only used if the main electrical power system fails, for example during an emergency [4].
For these batteries to be used in aeronautical applications, they must meet a number of critical performance criteria. One of the main issues with batteries is the risk of thermal runaway. The batteries are installed in packs, each of which is made up of individual cells. Although battery failures are rare, the issue is that minor errors at cell level can, over time, lead to thermal runaway or catastrophic failures at the aircraft levels. To mitigate these effects, specific management systems must be developed and the batteries must be monitored in real time for early detection and diagnosis [5]. Similarly, precautions must be taken when installing batteries in aircraft. This is usually carried out in isolation from other electrical system equipment. Batteries must also be kept in a sturdy metal structure to absorb accelerations, vibrations and impacts.

3. More Electric Aircraft (MEA)

The term 'more electric aircraft' (MEA) refers to aircraft in which electric power is used for at least some of the on-board functions that were previously performed by other systems, such as hydraulic or pneumatic systems [6]. This concept can modify the nature of many traditional aircraft systems and processes. Another example of the increased use of electrical systems is the elimination of bleed air for environmental control systems. This is already a reality on

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aircraft such as the B-787 [7]. The MEA concept offers a number of notable benefits. The most important of these are illustrated in Figure 2.

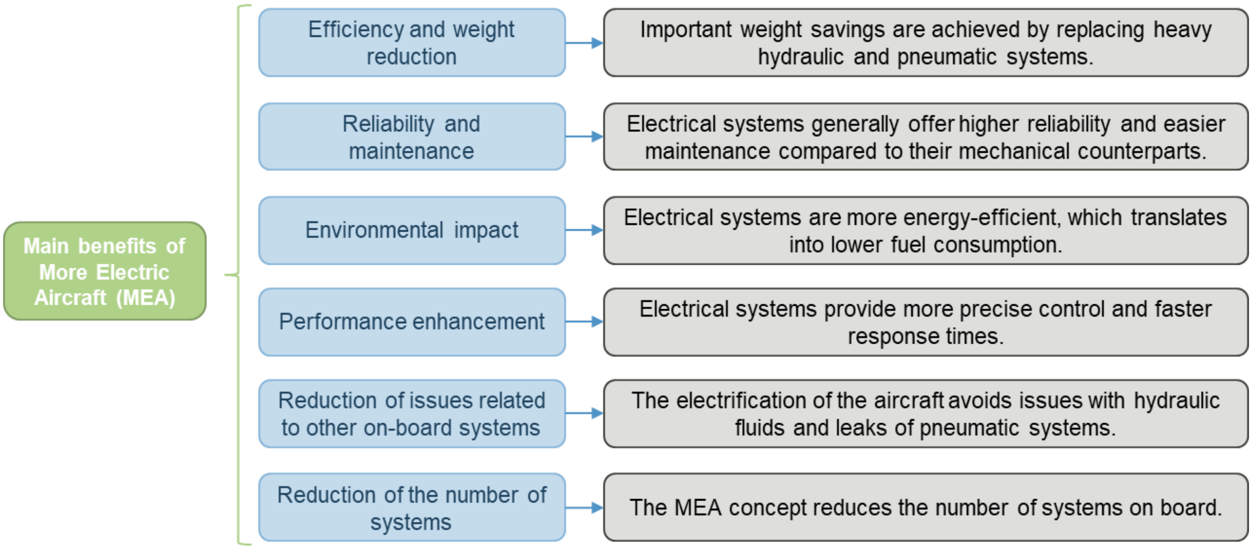

Figure 2: List of benefits of the MEA concept in aircraft.

One of the main benefits of the MEA concept is the reduction in aircraft weight. This contributes to reduced fuel consumption and operating costs.
Another advantage of using electrical components is a reduction in mechanical failures.
In terms of emissions, the MEA concept contributes to reducing greenhouse gas emissions. Electric systems offer significant efficiency advantages. This translates into a lower carbon footprint for the aircraft.
The greater control precision afforded by electric systems improves the aircraft's overall performance. In general, this more precise control improves flight stability.
The MEA concept also reduces the number of on-board systems and the associated incidents, as well as those related to other critical subsystems needed to keep them running.
The MEA concept focuses particularly on the electrification of certain on-board systems, which allows for the optimisation of non-powered systems such as flight control, landing gear, and other auxiliary systems.
However, despite the associated environmental improvements, this concept alone is insufficient to make a disruptive impact on reducing aircraft emissions. This requires the development of new aircraft concepts that focus on electrifying aircraft propulsion. These alternatives will be the subject of the following sections of the paper.

4. All-Electric Aircraft (AEA)

To meet the challenges of sustainable aviation, the first proposed concept for battery-powered aircraft is the all-electric aircraft (AEA) concept. This section begins by presenting ideas on the technical aspects of such aircraft. It then lists and discusses the main lessons learned from the analysis of relevant aircraft designs in this category.

4.1 Technical aspects of AEA

The all-electric configuration is the simplest electric architecture in terms of layout. It is based on the use of a rechargeable battery, also known as a secondary battery. This battery is connected directly to an electric motor via a power management system to drive a propeller [8]. For AEA aircraft, the battery must either be charged or replaced with a fully charged one on the ground.
Several requirements regarding battery parameters must be met to successfully design an AEA aircraft. One of the most important of these is specific energy, which is defined as the amount of energy that the battery can store per unit of mass. It also determines the battery's weight for a typical mission. For aircraft, it is desirable for this value to be as high as possible. Another important parameter is the number of cycles of the battery. This refers to the number of times a battery can be charged and discharged before it no longer meets certain standards. As with specific energy, for aircraft it is desirable for this parameter to be as high as possible. The challenge in battery design is that improving one key parameter can sometimes have negative implications for another.

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4.2 All-electric aircraft concepts and designs

In recent years, many designs for all-electric aircraft have been presented by various companies and research centres. In order to compare these concepts, it is important to understand the stage at which they are in the commercialisation process. While designs at various stages of development can inform future research, those that have progressed further in the certification process are more likely to reflect the market in the coming years. Table 1 presents some AEA models that have been deemed representative. Additional details for each of the models are provided below the table, along with certain lessons that can be drawn for future research based on the analysis carried out.

Table 1: Some relevant examples of all-electric aircraft.

Name and manufacturer	Number of passengers + Crew	Type of battery	Range [km] / Endurance [min]
S-4 (Joby Aviation)	4 + 1 [9]	Pouch cell battery [10]	161 km, including energy reserves [11]
Midnight (Archer Aviation)	4 + 1 [12]	Proprietary battery packs consisting of lithium-ion cells [13]	32-60 km [14]
Alice (Eviation) [15]	9 + 2	Li-ion pack	1 000 km
Velis Electro (Pipistrel) [16]	2	Liquid-cooled lithium batteries	50 min

The first two examples presented in the table correspond to electric vertical take-off and landing (eVTOL) aircraft. These two aircraft have been selected as they are examples of two of the aircraft closest to certification at present.
The first is the S-4, an aircraft designed by Joby Aviation. According to [9], the production prototype has a capacity for four passengers plus a pilot. It is an eVTOL aircraft powered by six electric motors. The aircraft's MTOW is 2 404 kg. Joby Aviation's business model for its aircraft is ridesharing, understood as a sustainable, aerial version of traditional car ridesharing business models.
The second aircraft in the above table is the Midnight eVTOL, designed by Archer Aviation. Like the S-4, it is currently undergoing certification under the supervision of the Federal Aviation Administration (FAA). According to [15], it is a high-wing aircraft with a payload capacity of around 450 kg, enabling it to carry up to four passengers and a pilot [12]. It has 12 engines, each of which is powered by an independent pair of batteries. The latest news from the manufacturer states that a new phase of the aircraft's test programme began in June 2025 [18], building on previous tests. The aircraft can cruise at an altitude of over 1 500 ft.
The third model to be considered is the Alice design, which was developed by Eviation. This project is considered to be representative of AEA more than just eVTOLs. According to [15], it is a battery-powered aircraft with a capacity for up to nine passengers. Additionally, given the modifications and difficulties encountered during development, this aircraft design is also representative of the challenges typically faced during the development and testing of electric aircraft. According to [19], this model is an example of an aircraft that underwent significant configuration changes during the design process. In Alice's case, the fuselage shape was modified to be more conventional, which the manufacturer claimed made it easier to produce. Although the manufacturer stated on its website that the model had received orders from several countries totalling over 600 [20], the latest news seems to indicate that production of the model has halted. One of the main problems faced by AEA manufacturers is securing financing. Once again, Alice can be considered a reference in this case. According to multiple sources and with official confirmation from the company [21], work on the Alice model was ceased during the first half of 2025 until other financing options could be found to allow the project to continue.
Finally, the last model referenced in the table is the Velis Electro concept by Pipistrel. According to [16], it is a light aircraft with a capacity for two people. It is a benchmark because its E-611 motor was the first electric motor to be certified by EASA in May 2020.

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Based on the information provided in this section, one of the most interesting markets for AEA aircraft applications has been identified as that of eVTOLs and associated business models. However, despite technological developments, the range of these aircraft remains limited, which restricts the scalability of their operations. Currently and in the coming years, the main batteries used in AEA aircraft will continue to be lithium-ion batteries, which are the most relevant type of insertion ion battery.

Currently, obtaining sufficiently high energy density values remains one of the main challenges for this type of aircraft. However, according to [17], despite this limitation, there are several factors that can enhance the feasibility of these designs. These include the efficiency of electrical systems and growing traffic demand in short ranges (which means that these aircraft may not require overly large operating ranges to be operationally profitable).

As already presented in this section, developing AEA models is no easy task. In addition to technical constraints, financing is one of the main problems, and the time needed to progress from the initial design to certification testing can be lengthy — especially if major changes to the aircraft or a complete redesign are required.

5. Hybrid-Electric Aircraft

Although AEA aircraft offer significant benefits, such as reduced emissions and low operating noise, they are currently limited to small aircraft due to limitations in battery technology. Hybrid-electric propulsion aircraft could provide an alternative to all-electric aircraft. These aircraft combine battery power with other propulsion systems. This section focuses on analysing them. First, certain key technical aspects are described, followed by a presentation of some relevant hybrid-electric aircraft models and an analysis of the main advantages of using batteries in these configurations.

5.1 Technical aspects of hybrid-electric aircraft

The integration of hybrid electric propulsion in aviation is based on the success of this approach in the automotive industry. When it comes to aircraft, there are two fundamental technological approaches. The first involves combining batteries with gas turbines. The second approach involves combining batteries with hydrogen fuel cells. In the case of a hybrid architecture combining batteries and gas turbines, there are different alternatives, with the specific setup depending on the flight phase in order to achieve optimal performance [8]. Generally, there are two basic schemes: the series-hybrid configuration and the parallel-hybrid configuration.

In addition, it is possible to combine batteries with hydrogen fuel cells. This combination is known as a Fuel Cell and Battery Hybrid System (FBHS). The aim of this combination is to combine the advantages of both propulsion systems. It allows for the production of sustainable, efficient and reliable energy during various phases of flight, which is of particular interest during phases where power demand is highest. Two main configurations can also be distinguished in the case of FBHS: serial-hybrid and direct-hybrid configuration.

5.2 Lessons learned from hybrid-electric projects and prototypes

In recent years, many research centres, universities and companies have designed their own hybrid-electric aircraft.

Noteworthy among these designs developed by academic institutions is the e-Genius aircraft, developed by the University of Stuttgart. This is a 2-passenger aircraft with a serial architecture. In 2024, the University of Stuttgart announced that an important milestone had been reached after modifications were made to the aircraft [22]. Following over a year and a half of work, the e-Genius became one of only three battery-powered aircraft capable of towing sailplanes.

The DLR's HY4 is an example of a hybrid-electric propulsion aircraft developed by a research centre. According to [23], it is considered to be the world's first four-passenger aircraft powered solely by an FBHS. It uses lithium-ion batteries for battery propulsion.

After analysing these and many other hybrid-electric aircraft concepts in the EFACA project framework, a clear pattern has emerged regarding the usefulness of batteries in hybrid systems. Batteries play a particularly important role during the take-off and climb phases of flight. During these phases, the energy demand is significantly higher. Batteries provide additional thrust to assist the main engines. This improves both the aircraft's performance and fuel efficiency (in the case of turbines), while reducing emissions by alleviating the load on the aircraft's main propulsion source.

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6. EFACA proposal for the use of battery technology

The EFACA project is characterised by its ability to provide a sustainable propulsion solution for all aircraft types. This includes new forms of propulsion such as batteries, hydrogen fuel cells, liquid hydrogen and sustainable aviation fuels (SAFs).
Within this EFACA proposal, batteries would be the recommended propulsion solution for smaller aircraft. Figure 3 presents the main characteristics of these aircraft.

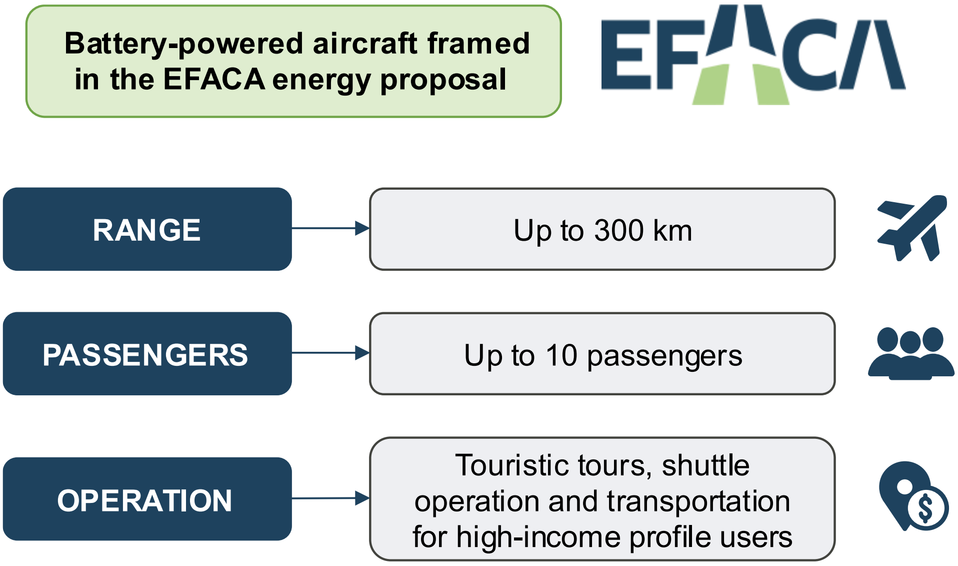

Figure 3: Battery-powered aircraft framed in the EFACA propulsion proposal for all classes of aircraft.

Within the EFACA project, battery-powered aircraft would be used for short-haul travel of a few hundred kilometres and for carrying a small number of passengers. Specifically, these aircraft would typically have a range of up to 300 km and the capacity to carry up to 10 passengers.
Following the analysis developed in the project, the business models for these aircraft would be framed within the urban air mobility market. Taking the aircraft's range into account, three application cases are proposed:

- Shuttle services between city centres and airports, in which battery-powered aircraft would replace helicopters. This could be a profitable case study, as it is one of the applications reported as being of the most interest to companies purchasing eVTOL aircraft.
- Development of tourist tours in cities: this is a viable option as most battery-powered aircraft described in previous sections offer large windows allowing panoramic views of important city monuments.
- Another main application of battery-powered aircraft would be transporting high-income passengers. This is because operating these aircraft would save time to users or companies with the capacity to invest more money in these services.

As stated above, the EFACA project proposal for battery-powered aircraft use is compatible with most of the ranges achieved by the AEA aircraft presented in this paper. Similarly, the use cases are aligned with some of the main case studies for eVTOL operations.

7. Conclusions

This paper has analysed the main applications of batteries for both electricity supply and propulsion in aircraft. First, the most common applications in conventionally-powered aircraft have been examined. Next, the MEA concept has been presented, along with the benefits of using batteries to electrify previously hydraulic or pneumatic systems. However, to achieve the sustainability goals of the aviation industry in the coming years, scaling up the use of battery-powered aircraft will be the real challenge. Two options have been considered: AEA aircraft and the use of batteries in combination with other propulsion systems to create hybrid-electric systems. The main technical concepts and relevant designs associated with each of these options have been presented. Based on the analysis of these designs, a series of general ideas regarding the battery-powered aircraft market have been defined. Finally, the use of battery-powered aircraft has been incorporated into the EFACA project. This project proposes a sustainable propulsion solution for all aircraft classes. Specifically, the project has selected batteries as the option for smaller aircraft, capable of reaching ranges of up to 300 km and transporting up to 10 passengers. The EFACA project identifies the eVTOL

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aircraft market as one of the first commercial applications of these aircraft. The most likely use cases for these aircraft include developing tourist tours and implementing shuttle services for passengers between city centres and airports.

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