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Recent developments about hybrid propelled aircraft: a short review

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Abstract. Over the last decades, the rapid growth of the consumption of fossil fuel has generated an increased need for energy sustainability. The negative impact on the environment and now, as a global society, the dependence on fossil fuel have been questioned. For contrasting these adverse effects, NASA calls on the aeronautic industry to reduce aircraft fuel burn by 70% by 2025 in their N+3 concepts. Following high-profile government and industry studies, electric aircraft propulsion has emerged as an important research topic, this includes all-electric, hybrid electric, and turbo-electric architectures. The paper overviews the recent state-of-art about the innovative propulsion systems exploring the operating logic, their technological requirements, the ongoing research, and development in all the components necessary to make this technological change a feasible option for the future of passenger flight. It will be also reported the existing commercial products, prototypes, demonstrators for having a precise picture of the situation.

Introduction

Over the last decades, the economization of transportation has generated a sharp increase in fossil fuel consumption, causing a considerable increase in pollutant emissions. This increase in CO_2 emissions has prompted major industry companies and research institutions to develop new propulsion technologies for the aviation sector that are more efficient and have a reduced environmental impact. The new strong requirements about the emission pushed the academic and industrial researchers to investigates a new and sustainable type of engines for aerospace sector. Following the outcomes of these research Electric Propulsion Systems (EPS) and Hybrid Electric Propulsion System (HEPS) received a great emphasis and they have emerged as an important research topic and possible solution to satisfy the requirements imposed by NASA. In the next sections, the various innovative propulsion systems, identified in literature, will be discussed, labeling their advantages, disadvantages, and relative fields of application in relation to the type of aircraft that can accommodate them. Then the demonstrators will be reported that have been realize. In the end conclusion will be drawn.

Innovative Propulsion Systems

This section reports the main innovative propulsion systems identified in the literature. All the systems will briefly be introduced highlighting its advantages and disadvantages.

Sustainable Aviation Fuel SAF

Sustainable Aviation Fuel (SAF) can be defined as alternative fuel to conventional fossil-based jet fuel that is produced from either biological or non-biological sources. These fuels belong to the drop-in fuels class, characterized by having the same chemical and physical characteristics of the fuels used in aviation. This is a key aspect of its possible success because it allows the manufacturers do not make substantial modifications to the aircraft. The International Civil Aviation Organization (ICAO) reported that it would be physically possible to meet 100% of demand by 2050, which corresponds to a 63% reduction in emissions. So, it seems that SAF is a simple way to reduce CO_2 emission but there are also some disadvantages as the highly cost of production, that could be reduced only with a combination of policy incentives, capital investments, and time [1].

All Electric Propulsion Systems

All-electric aircraft configuration is the simplest of all the electric architectures in terms of layout, the power source, in this category is the rechargeable battery, connected directly to an electric motor through a power management system that drives a propeller. Globally this system is characterized by an higher efficiency compares with the classical propulsion system (83% vs 25% of the classical propulsion system). This category of aircraft has many advantages, including zero-local-emission, low noise, and operating cost reduction. The most critical disadvantage of this category of aircraft is the battery storage technology that has not achieved sufficient maturity to cover the same distances as jet fuel-driven aircraft [2].

An evolution of the classical battery storage system are the Fuel Cells propulsion system. This system is composed by three main components: the Fuel Cell, the hydrogen storage tank (gaseous or liquid), and a buffer battery. This category of aircraft is characterized by a much lower Maximum Take Off Weight (MTOW), as battery weight is almost eliminated, compared to an analogue battery storage aircraft and a similar refueling times and weights, comparable to the classical propulsion systems present on the market today. These systems are characterized by a great versatility since they do not require pre-storage of energy in batteries, but they only need to store a quantity of hydrogen required to accomplish the proposed mission. There are different types of F-Cells, a clever way to classified them is by the type of electrolyte used, the most common one used in the transport industry are the Proton Exchange Membrane (PEM) characterized by a low temperature of exercise, simplicity of manufacturing, reliability, and the competitive cost of production [3].

Hybrid-Electric Propulsion Systems HEPs

The implementation of full-electric propulsion systems, for classes of aircraft other than simple demonstrators, is critical because the technology of energy storage in batteries, as well as the realization of the various components associated with the distribution of energy on the aircraft, is still unsuitable for their realization, especially considering the deadlines imposed by the European Union. Instead, a more viable route is to go and complement the classical turbojet/turboprop systems with electric machines thus evaluating an additional propulsive methodology known as Hybrid Systems. This category includes 3 possible configurations examined: Hybrid Series configuration, Hybrid Parallel configuration, and Hybrid Series/Parallel configuration [4].

In a Series Hybrid configuration, the Electric Motor (EM) is the only component which drives the propeller, without any gearbox, this implies that the Internal Combustion Engine (ICE) can run always at its optimal regime. Due to this condition, fuel efficiency can remain high, and its lifespan can be lengthened. Another advantage is the flexibility of choosing the ICE location due to its the mechanical decoupling. The series configuration suffers of many disadvantages, such as massive power loss due the conversion system and an high cost of the components that have to be sizing to maximum power require during the mission.

In the Parallel Hybrid configuration type of system, the propeller is driven by both ICE and EM. From this configuration, multiply advantages are achieved. The most important advantage is that small ICE and small EM can be selected because all the main components of the system do not need to be sized to cope with maximum power requirements. Also, this configuration has some disadvantages, the main one is that it needs an efficiency energy management strategy, because it must optimize the power contribution of the ICE and the EM, to make them always work under the most efficient conditions.

The last analyzed configuration is the Hybrid Series–Parallel system. It is a mixture of two architectures show before, the main part of this configuration is the planetary gearbox at which the propulsion components, such as propellers, engine, EM, and generator, are connected to it. All the advantages and disadvantages of this system belong to the power-split part. The main advantage of using this device is that all the engine, ICE and EM, work in their maximum efficiency region. Despite this important advantage this type of system suffers of a constate dissipation rate due to the permanent connection between the part. These configurations are the most used architectures in aerospace and automotive sectors. Among them, the series configuration enables the engine to operate at its ideal operating condition, but as cited before, its system efficiency is relatively low since large power losses exist in the energy conversion. The series–parallel is the most functional, but the most complicated configuration out of the three architectures. It is the least popular configuration concerning aircraft application due to high complexity. it can therefore be inferred that, given current levels of technology, the parallel hybrid configuration appears to be the most versatile.

Flight Demonstrators

The attention is now focused on the attempts made by universities and research institutions in moving from purely theoretical models to prototypes able to fly, all the models have been classified according to their geometrical dimensions. With this parameter three categories are identified: small, medium, and large scale. The small scale is convenient for demonstrating the feasibility of the hybrid electric technology, several attempts were made by industries and research group, the most interested one is the Drone develop by Harris Aerial which use a fuel cell system with a small high-pressure tank of Hydrogen [5].

The medium scale is interesting because there is the opportunity to ensure the transportation of people. The most innovative flying configuration is the conversion kit installed on an ATR 72 proposed by ZeroAvia [6]. The last class of aircraft is the most critical one due to the technological limit of the component available. One interesting possible configuration is the one proposed by ZEROe program developed by Airbus which use two hybrid-hydrogen turboprop engines installed on an A350 [7].

So, the small/mid-scale sector, both academic and industrial institutes presented the flying or flying-capable demos. Furthermore, the studies of large hybrid aircrafts are still at the stage of concept designs and analysis due to the limitation of electrical and other technologies.

In Figure 1, it is interesting to observe that there is an area, indicated with the red square, are confined most of the different configurations before cited. It is evident that the maximum distance that can be covered is about 350 nm (648 km) while as far as the transport of passengers is concerned from the datasheets it has been found that these aircraft carry at most 4 people.

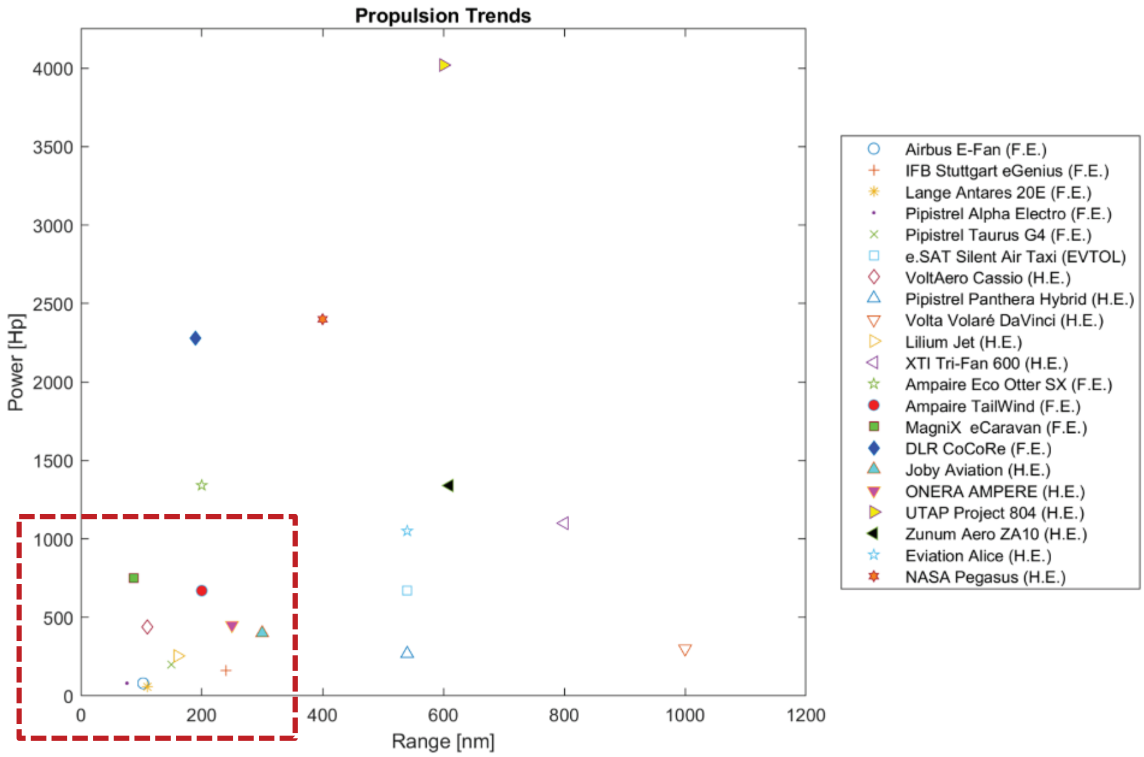

Figure 1 Propulsion Trends (F.E.: Full Electric; H.E.: Hybrid Electric)

Conclusion

The main purpose of this work is to quickly present the actual state of the art of new propulsion systems potentially adaptable to current aircraft configurations to achieve the CO_2 emission reduction targets set in 2050.

Without further technological development of batteries, it can be concluded that:

- Full-electric aircraft are implementable at most to the General Aviation category.
- Series/Parallel hybrid systems and fuel cells, characterized by a greater flexibility can be applied on a large scale of aircraft guaranteeing a partial abatement of CO_2.
- The main route remains SAF as they are solutions that can ideally be applied immediately since they do not require any modifications in the aircraft.

All the data reported in this short paper comes from a full paper under review [8].

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