MAHEPA – A Milestone-Setting Project in Hybrid-Electric Aircraft Technology Development

Lorenzo Trainelli (1), Igor Perkon (2)
1 : Department of Aerospace Science and Technology, Politecnico di Milano, Via G. la Masa 34, 20156 Milano, Italy, lorenzo.trainelli@polimi.it 2 : Pipistrel Vertical Solutions, igor.perkon@pipistrel.si

Abstract

We present the MAHEPA project, an activity bringing together aeronautical enterprises, academia, and research centers to bridge the gap between the research and product stage of hybrid-electric (HE) propulsion technology for aviation. This project includes the complete development and flight testing of two serial HE General Aviation airplanes, one equipped with a thermal engine and the other with a fuel-cell system. This will provide a comprehensive knowledge base useful to validate performance, efficiency, and the emission reduction potential of HE propulsion. Concurrently, a research effort is ongoing on the investigation of HE aircraft design and analysis methodologies, powertrain model scalability, and impact prediction. This action shall profit from the availability of flight test data for the validation of design and analysis models, and shall allow reliable predictions for megawatt-scale applications, extending the picture of HE aircraft to the commuter and regional liner categories. Eventually, a scenario for the fleet switching from conventional to HE aircraft and its overall impact on aviation in Europe will be envisioned, in order to deliver indications for future actions towards sustainable air mobility.

Introduction

The present contribution introduces project MAHEPA (Modular Approach to Hybrid Electric Propulsion Architecture), an ongoing effort framed in the H2020 research programme within the MG-1.1-2016 “Reducing energy consumption and environmental impact of aviation” topic. This 48-month activity represents a major attempt to push habilitating technologies for hybrid-electric (HE) aircraft development, towards a future systemic implementation from General Aviation to regional transportation.

To this end, the project comprises two parallel lines of action. First, it provides advancement to TRL6 of two variants of serial HE propulsion fixed-wing aircraft models, by designing, developing, qualifying, and testing the relevant power-train systems. During the project, these powertrains will be fully integrated on board the two aircraft models and thoroughly flight-tested. Second, the project calls for a substantial research commitment in the investigation of HE aircraft design and analysis methodologies, powertrain model scalability, and impact prediction, which profits from close interaction with the industrial developments sketched above. In addition, this is completed with a visionary study considering the implementation of HE architectures for commercial category aircraft.

Based on this twofold approach, the MAHEPA consortium brings together industrial and academic partners. The lead is provided by Pipistrel Vertical Solutions, a renowned light aircraft manufacturer. Innovation-oriented companies Compact Dynamics and H2Fly provide the rest of the industrial capability needed for the project. Politecnico di Milano, Technical University of Delft, University of Ulm, and University of Maribor assure the academic research capability, together with the German Aerospace Center (DLR).

This presentation details the goals and structure of the work, illustrating the results obtained so far and the foreseen future development.

HE aircraft development and testing

Within the MAHEPA project, a modular approach in the implementation of two high efficiency, HE propulsion architectures is taken. In both cases, a “serial” powertrain is considered, i.e. a propulsive system in which the propeller is driven by an electric motor, receiving power by a primary source that does not consist in batteries only (which would lead to a pure-electric architecture).

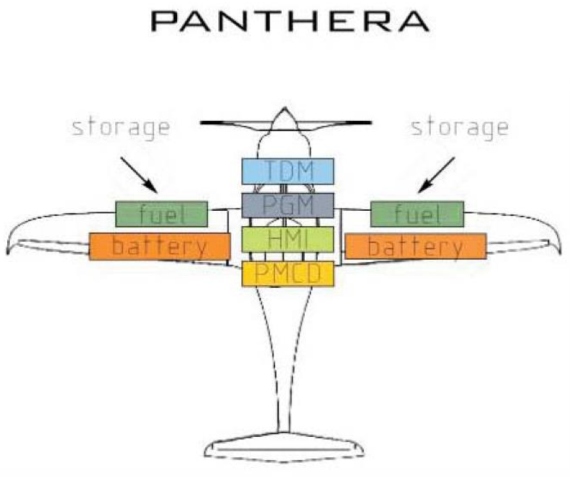

Fig. 1: HE-Panthera powertrain functional elements.

The first uses a hydrocarbon-fuelled internal combustion engine (ICE) and an electric generator as primary power source. The target aircraft is a HE variant of the Pipistrel Panthera 4-seater. The functional scheme of the Hybrid Panthera powertrain is shown in Figure 1, where TDM stands for Thrust Delivery Module, PGM for Power Generation Module, HMI for Human-Machine Interface, and PMCD for Power Delivery and Control Module.

The second features a different concept, with a powertrain implementing a hydrogen fuel cell used to produce electric power. In this case, the target aircraft is an evolution of Pipistrel's Taurus G4 double-fuselage motorglider [1,2], the world's first fully electric 4-seat aircraft, which won the NASA Green Flight Challenge in 2011. The new incarnation, called the Hy4 (Figure 2), is equipped with four cell modules of the PEM (proton exchange membrane) type and two Li-Po battery packs.

Fig. 2: The Hy4 under preparation for testing.

The newly-developed elements that are common to both variants are the PMCD module, used to implement advanced power management methods to optimize mission, range and emissions; and the power electronic devices, namely a highly efficient, airborne qualified electric propulsion motor and next-generation technology inverters.

The MAHEPA project not only includes component design, qualification, and assembly into the two above-mentioned HE powertrains, but also the complete airframe integration of such powertrains and a subsequent comprehensive flight test campaign for the two airplanes. This shall demonstrate the capabilities of the developed technologies, validate prediction and design models, and provide an invaluable data set for the studies brought forward within MAHEPA and beyond.

HE aircraft design methodologies and case studies

Based on the technology development and its test and evaluation, the MAHEPA project directly tackles one of the main questions related to the future implementation of HE aircraft in substitution to conventional, purely ICE-driven models, seeking sustainability and eco-friendliness: will HE architectures and technologies be capable to empower heavier aircraft categories than light and General Aviation, reaching the regional transportation sector?

To this end, a general framework for the analysis and conceptual/preliminary design of HE aircraft is being developed, with the capability to consider a wide spectrum of aircraft categories and multiple configuration choices, including concentrated or distributed propulsion [3]. This framework includes ad-hoc procedures for aircraft preliminary sizing [4] and configuration definition, as well as the modelling of the powertrain, for accurate performance predictions.

A specific work package is devoted to the capability to scale powertrain component model properties in order to extend the design and analysis capability towards larger airplanes categories. To this end, the consolidation of the flight test data and their inclusion within the numerical prediction models will provide a strong validation and a reliable starting point for scaling up to megawatt-scale applications.

In particular, two target airplane types will be designed and evaluated:

1. A "micro-feeder", i.e. a small passenger airplane in the commuter (CS23) category devoted to a feeder service from small, scattered airfields to large hubs hosting typical commercial flights (a preliminary study of this concept is found in [5]).
2. A regional aircraft in the 70-seat category, which attracts much interest worldwide, in view of a technology leap enabling a wider diffusion and a higher profitability of this segment (an early investigation of a HE regional aircraft concept is found in [6]).

This shall deliver important information for a possible future implementation, adding to the results obtained for smaller aircraft categories.

HE aircraft implementation scenario

The final goal of the MAHEPA project is to provide a comprehensive, dependable knowledge base concerning HE aircraft implementation based on small-size, high-TRL, thorough experimental validation together with reliable prediction methodologies enabling the design of aircraft, operations, and implementation scenarios.

Therefore, a work package is dedicated to the different elements that contribute to setup adequate strategies for maximizing the impact of HE aircraft in the future. This includes studies geared towards the identification of the necessary ground infrastructures for HE fleet operations, the prediction of the operational impact, the environmental impact, and the "fleet switching costs". Preliminary results concerning different airport-level scenarios have already been achieved [7,8].

The studies shall be pushed to include near term (2025), medium term (2035) and long term (2050) scenarios, with the aim is to provide indications to regulators, airport operators, and investors where bigger pay-offs can be reached by introducing HE aircraft, including the potential implementation of regional transport fleets.

Conclusions

The overall objective of MAHEPA is to bridge the gap between the research and product stage of a low-emission propulsion technology to meet the environmental goals for aviation towards the year 2050. The core value of MAHEPA is to build-up technological know-how and use flight test data to validate performance, efficiency, and emission reduction capabilities of above technologies, and allow reliable predictions for megawatt-scale HE applications, in view of a future transition towards more sustainable short-range air transportation.

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