mahepa

Modular Approach
to Hybrid Electric
Propulsion Architecture

Newsletter 2018/1

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 723368.

Get ready for take off!

GET READY FOR A GREEN TAKE OFF!

Aviation is the fastest-growing source of greenhouse gas emissions. As EU Commission has pointed out in their statement on reducing emissions from aviation: "If global aviation would be a country, it would rank in the top 10 emitters".

Besides CO2, airplanes emit particles and gases such as hydrocarbons, carbon monoxide, nitrogen oxides, sulphur oxides, lead, and black carbon which interact among themselves and with the atmosphere. Various technologies were and are currently designed to reduce the environmental impact from the aviation industry. As researchers have pointed out and the Air Transport Action Group (ATAG), aviation industry accounts for around 12% of all global CO2 transport emissions. Moreover, negative effects of aviation are engine noise and noise caused by airflow around the plane. Noise emissions are particularly expressive around airport.

But is it still possible to fly and cause minimal negative effects to environment and people?
YES, IT IS

With MAHEPA new generation of small hybrid-electric aircraft with low emissions, reduced noise and operating costs.

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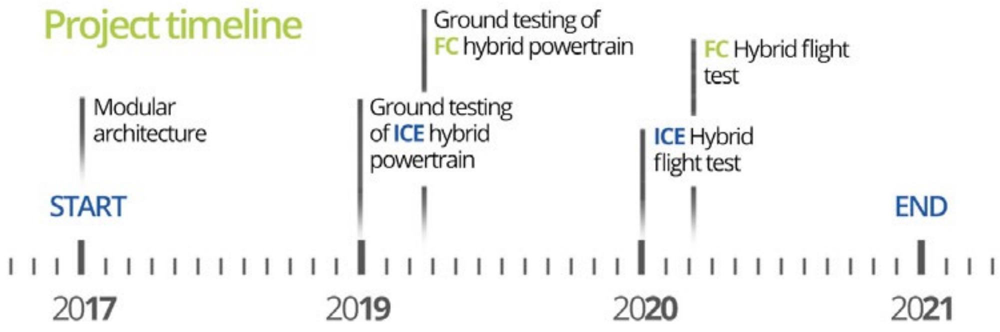

With modular approach to propulsion system components design, for the first time **two variants of a serial hybrid-electric powertrains** will be tested in flight: the first uses internal combustion engine (ICE) to charge the batteries and power the electric motor, while the second relies on fuel cells (FC) to produce power thus enabling zero-emission flight.

Due to a quiet and short take-off and landing capability with almost zero emissions, the hybrid aircraft could be used in the vicinity of city centres and **revitalise existing underexploited airports.** With the propulsion components developed in the project it is possible to build a larger hybrid-electric aircraft, for example a 19-seater, and offer a **new commercial transport service – micro feeder** that could connect small, grass airstrips airports with regional and international airports.

MAHEPA contributes to common European endeavours for clean and safe environment by developing hybrid-electric propulsion technology for a cleaner air transport.

Although there is still some time to year 2020, when the two MAHEPA hybrid-electric four-seater airplanes **Panthera and Hy4** will fly, notable achievements, such as the definition of ICE and FC powertrains, are bringing us closer to this milestone moment.

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HYBRID ELECTRIC POWERTRAINS ARE SHOWN TO BE VERY RELIABLE

With constant growth of air traffic, the pressure on environment is rising and the use of alternative fuels is a becoming necessity.

The hybrid-electric powertrain architecture has been used on serially produced automobiles for a couple of decades now.
In recent years, its proven advantages and the advancements of components characteristics have fostered intense studies and developments aimed at its application to different classes of ground, sea and air vehicles.

Since suitability of hybrid-electric powertrain architecture to aircraft has been thoroughly demonstrated by several successful projects, at present many diffe-rent endeavours are actively being pursued to develop a wide range of hybrid-electric aircraft, from single-seater ultralights to business airplanes including regional airliners.

To approach the concept of modular architecture for hybrid-electric propulsion of aircraft, seven main architectures were studied with aiming to provide a univer-sally applicable approach for architecture modelling.

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The emphasis was put on two tailored serial hybrid propulsion architecture implementations **- one utilising an ICE/ battery** and the second utilising a **FC/ battery technology**.

The serial architecture allows the **best efficiency versus range compromise in the light aviation segment,** and it is more scalable towards distributed propulsion compared to the parallel one.

Using reliability data from similar components, a general reliability overview of hybrid-propulsion system exposes some crucial factors. The main outcomes on system reliability analysis are:

- High temperatures and voltages highly affect electric and electronic systems.
- Distributed Electric Propulsion (DEP) architecture is more reliable having natural redundancies in the system.
- Redundancy in hybrid-electric aircraft is easily achievable due to the usage of smaller and lighter components than in the classical powertrains.
- Two redundant HMI modules with a lower Development Assurance Level (DAL) could highly increase the sy-stem reliability, reducing at the same time the module software complexity.

The general conclusion is that hybrid electric powertrains have many power flows enabling high reliabi-lity of the system also with non-re-liability optimized components.

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ICE BASED HYBRID-ELECTRIC AIRCRAFT PRODUCE LESS NOISE, HAVE LOWER OPERATING COSTS AND FUEL CONSUMPTION.

When defining the appropriate architecture and powertrain components, one of the most important aspect to be considered is the integration of the powertrain into the existing fuselage of the aircraft without major modifications to it.

To allow comparison between hybridelectric powertrain and classic internal combustion engines, the powertrain components have been designed following aerospace standards and regulations.

The aim was to design the powertrain in a way to be very efficient, low weight and highly reliable. Considering the aspects above, the decision to fit the ICE based hybrid-electric powertrain into the **Pipistrel Panthera** was taken.

HOW DOES AN ICE BASED HYBRID-ELECTRIC POWERTRAIN WORK?

The propeller is driven by an electric motor powered by a conventional turbocharged internal combustion engine combined with an electrical generator and a battery system consisting of two battery packs in parallel.

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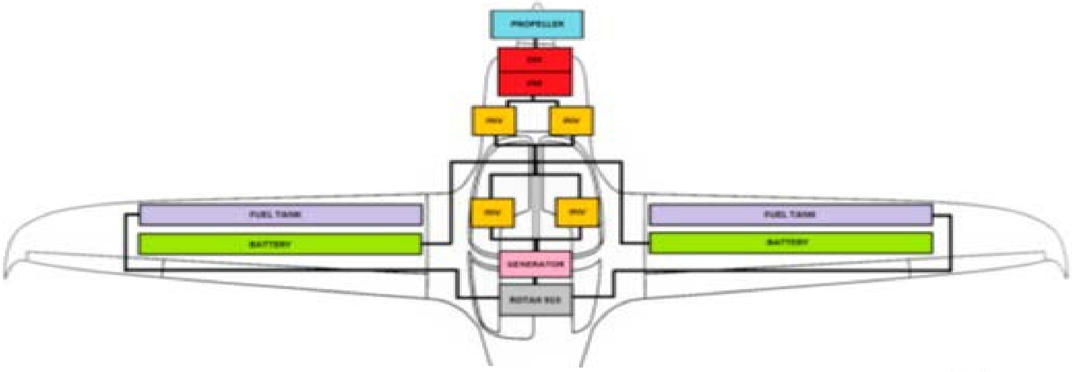

Figure 1: Powertrain’s simplified power links scheme

If a failure occurs in the ICE or in the battery system, the powertrain is still able to provide enough power for a safe continued flight and landing. The propulsion system is designed to allow an all-electric take-off, significantly reducing noise footprint and emissions of the aircraft close to the ground, making a hybrid electric aircraft more acceptable by the local communities.

WHAT ARE THE MAIN BENEFITS OF AN ICE HYBRID-ELECTRIC POWERTRAIN?

When a hybrid-electric powertrain is paired to a classical ICE, several benefits arise, such as:

- Lower noise due to all electric take-off.
- Less fuel consumption and lower operating costs
- High power demands are handled by both power sources (ICE and batteries), allowing a smaller and more efficient ICE designed specifically for cruising performance.

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FUEL CELL (FC) HYBRID AIRCRAFT WILL CONTRIBUTE TO CLEANER SKY

ICE and FC powertrains provide very quiet take-off and the fuel cell (FC) based powertrain allows zero emission flights. From the development of fuel cells, which offer higher energy density; research on this technology is then essential to reach the goal of cleaner skies.

However, FC based hybrid-electric powertrains, despite many advantages, are still in a very early research stage.
At the moment, the only way to demonstrate that hydrogen technology could be used in aviation is extensive testing.

Fuel cells have been tested on the H2Fly Hy4 aircraft that, with its large volume, enabled to incorporate the fuel cell system and the hydrogen tanks in a very efficient way. The dual fuselage configuration allows for up to four seats, while the central nacelle allows for fuel cells and drive-train to be packed closely together for very high efficiency.

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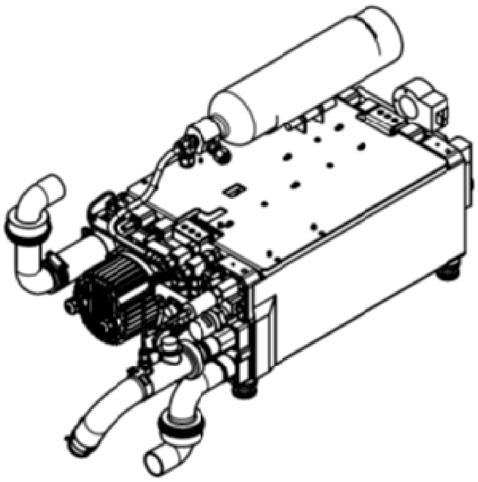

Figure 2: Fuel cell module

Even though the battery technology will probably prevail in the immediate future, especially in the automotive industry, due to the low energy density of batteries such technology will hardly expand to large airplanes.

Therefore, aviation industry could greatly benefit from the development of fuel cells that offer more energy density and so to explore this technology for future applications is more and more essential in our endeavour for cleaner sky.

HOW DOES A FC BASED HYBRID-ELECTRIC POWERTRAIN WORK?

The propeller is driven by both the fuel cell system and the batteries. These sources directly power the electric motor, hence there is no need to convert mechanical energy into electrical energy as in the case of an ICE based hybrid-electric powertrain.

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QUIETER AIRCRAFT – LESS FUEL CONSUMPTION

The preliminary performance study showed that the serial hybrid electric aircraft have the potential for less noise emissions together with less fuel consumption on short to medium range missions, typical missions for a regional micro-feeder.

The factors influencing the performance of a serial-hybrid aircraft have been investigated, considering various design constrains such as battery energy density, required reliability, required main-tenance and minimum cruise speed and altitude.

Following these criteria, the performance analysis aimed to identify the best cruise altitude for a desired mission range and cruise speed, minimi-zing the mission time and the fuel consumption.

The code was developed to be very efficient and implementable on an on-board computer. This tool would allow

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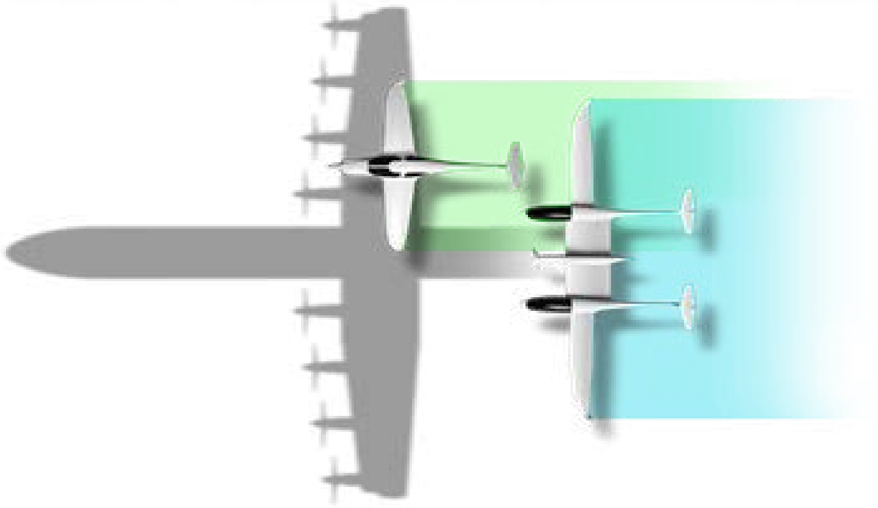

Figure 3: Panthera and Hy4 Airplanes

the pilot to easily plan the best flight profile in order to minimize the emissions and the flight duration increasing at the same time the overall powertrain efficiency.

Several flight dynamic models were used to simulate the aircraft performance, considering all the configuration changes that an aircraft is subjected to during the entire mission, from the landing gear retraction to the flap position and the loss of weight due to the fuel burnt. This enabled to demonstrate the possibility to fly also if one fuel cell stack fails, making the FC based hybrid-electric powertrain design very reliable.

Once the mission parameters are entered, the flight profile is uploaded to the main system controller, which will precisely follow the planned route reducing the crew workload that could focus on the system status.

The results obtained in this first design phase are positive. Fuel consumption is reduced as well as the noise footprint; all-electric take-off is possible, making the proposed aircraft much more acceptable by the local communities.

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THE POWER MANAGEMENT CONTROL AND DELIVERY MODULE MANAGES MORE POWER SOURCES WISELY

In a conventional aircraft, the pilot has direct control on the engine power. On a hybrid-electric aircraft this is much more complex, having different types of energy sources on-board possibly driving multiple electric motors.

To ease the power routing from the pilot input to the aircraft propeller(s), the Power Management, Control and Delivery (PMCD) module controls all the power flows, optimizing the amount of power drawn from each source considering their status, the flight phase, the aircraft configuration and, of course, the power requested by the pilotAirplanes

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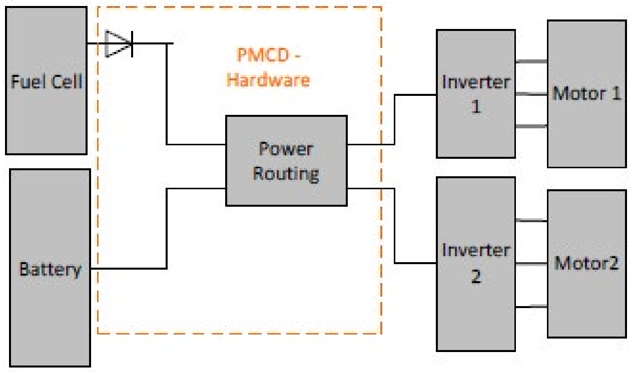

Figure 4: PMCD in FC powertrain

HOW DOES THE PMCD WORK?

- The PMCD-α is the intelligent unit which controls the power flows of the powertrain. Based on the inserted flight plan, the PMCD-α will have implemented logic that will predict the power needed for flight and then decide how to use the different power sources.
- The PMCD–β acts as a power delivery. Controlled by the PMCD-α, it contains various hardware that serves to route the power. Namely it is composed by several switches, relays, diodes and, in the case of the HY4 aircraft, a small DC/DC converter used to charge the batteries during recuperation.

The usage of an automated power management strategy ensures, together with the optimization of the flight profile, an optimal control of the hybrid-electric powertrain performance. Moreover, turn around times are reduced by charging batteries during flight.

This enables the aircraft to be ready for another mission in a very short time and, at the same time, increases the safety margins: in fact, being the batteries fully charged prior to landing, in case of an ICE (or FC) failure during approach the batteries permit a safe goaround.

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YOUNG MINDS WITH FRESH IDEAS FOR MICRO-FEEDER MARKET

The idea of micro-feeder services is relatively new, and coupled with the new hybrid-electric technology it brings high novelty that needs a complete new perspective. This new market would reduce the door-to-door journey time together with the pollution created by the cars used to go to the airport.

The concept design of an all-electric or hybrid-electric micro-feeder aircraft that could connect the numerous grass airstrips to regular airports was proposed for a student Hackathon.

At MAHEPA Aircraft Design Marathon or Hackaton, 20 students from 7 different countries were envisioning the best hybrid powertrain architecture and design of the new generation of micro-feeder hybrid-electric aircraft.

Numerous topics, such as cockpit design, cabin layout and innovative aircraft configuration, were explored together with the market impact on micro feeder routes.

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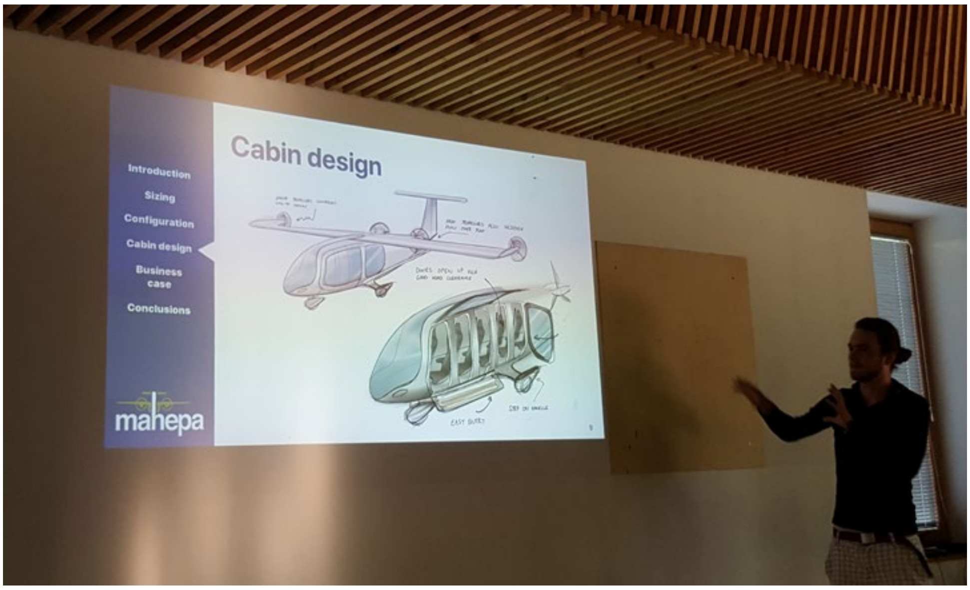

Figure 5: The winning team presenting the cabin design (Hackathon, 17th to 19th July 2017, Slovenia)

The winning team's proposal won over the technical committee with its innovative configuration definition, excellent layout solution and a balanced presentation of economic and technical aspects of the micro-feeder aircraft.

The participating students gained new knowledge and skills, while MAHEPA project was enriched with new and fresh perspective on future development of hybrid-electric aircraft designs and future potential micro-feeder services.

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PROJECT PARTNERS

- PIPISTREL VERTICAL SOLUTIONS
- DLR Deutsches Zentrum für Luft- und Raumfahrt
- Compact Dynamics
- ulm university universität uulm
- H2FLY
- TU Delft
- University of Maribor
- POLITECNICO MILANO 1863

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