

Testbed for evaluation of Electric propulsion Architectures

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Abstract

For some years now, the use of electrical energy for aircraft propulsion has been one of the ways to be explored to reduce the environmental impact of aviation. The total or partial electrification of propulsion systems means the introduction of additional electrical loads of much greater power than the non-propulsive electrical loads carried on board until now, on the order of a hundred kilowatts for a light aircraft and a megawatt for a commuter. The implementation of these high electrical powers, via a rise in voltage and current in an extremely constrained environment, questions current electrical architecture solutions and their installation rules. At the same time, the electrification of propulsion opens the way to new, more aerodynamically efficient distributed propulsion configurations, offering new reconfiguration capabilities for energy management and safety. ONERA's various conceptual studies on distributed electric propulsion (DEP) [1] [2] [3] have shown the need to master the integration of these electric propulsion chains, firstly from a functional point of view (static and dynamic), but also in terms of integration at aircraft level. This article describes the specifications of our new testbed, named TROPHEA (Testbed for Research On PHysics of Electrical Architectures), which will enable us to better understand the various physical phenomena associated with this type of architecture.

Introduction

Since 2013, ONERA engineers have described and validated several all electrical aircraft (AEA) concepts, based on distributed electric propulsion (DEP), for a small business aircraft (AMPERE concept) corresponding to the societal need for On-Demand Mobility [1] [2] (Fig. 1), for a medium range business aircraft (DRAGON research concept) [3][4] and most recently for a VTOL concept (HERMIONE concept) (Fig. 2) which has 12 propellers including 4 tilt propeller engines.



Fig. 1: Illustration of the AMPERE concept.

One of the key points of these concepts is the integration of the electric propulsion architecture. Indeed, this one will have to comply with the safety regulations (current and future) issued by the various CS23 [5], SC-VTOL [6]...

In early 2021, ONERA decided to design a testbed representative of a distributed electric propulsion

architecture, including both motorization benches and the integration of the electric wiring interconnection system (EWIS) of the electric chain.

In the first part of this paper, the main specifications associated to our new test bench are presented. The second part is a focus on the main component characteristics constituting our test bench.

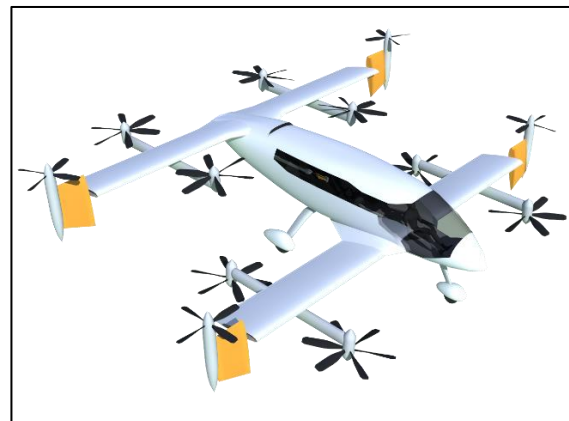


Fig. 2: Illustration of the HERMIONE concept.

1. Main specifications of TROPHEA

Based on our previous conceptual studies, it has been identified that the most mature framework for the development of new rules adapted to the specific features of new electrical architectures is to be found around light aircraft: on the one hand, because of their size and missions; on the other hand, the recent

revision of CS-23 introduces a new certification approach based on safety objectives ("performance-based"), which makes it possible to define the means of complying the right need, and thus facilitating the introduction of new technologies. And let us not forget the booming drone sector (pax and/or logistics), which is looking at embedding electric propulsion chains. It should be noted that the latest safety considerations for VTOL aircraft recommend retaining the loss of two thrusters, which translates into at least 8 propulsion systems in terms of performance.

To obtain a good redundancy of our aircraft, it is also necessary to distribute the source and the EWIS. Based on these considerations, we have defined the following distributed electrical architecture (Fig. 3) for our test bench TROPHEA. These include 8 motorization benches (electrical motor, inverter and propeller), 4 equivalent sources that can emulate different types of source (battery, generator, fuel cell, etc.), and an EWIS providing redundancy for power cable harnesses, distribution and protection cores (Fig. 4).

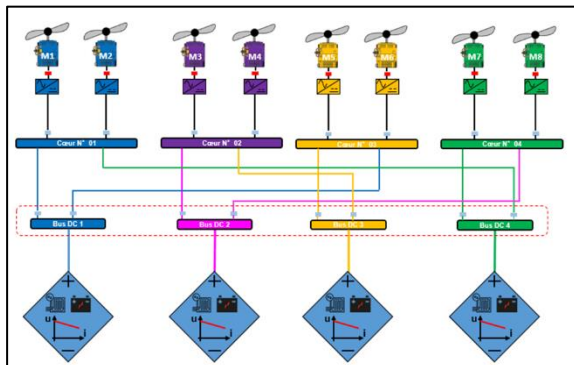


Fig. 3: Illustration of the TROPHEA electrical architecture.



Fig. 4: Illustration of TROPHEA.

2. The main component characteristics of TROPHEA

The main features of our test bench components are now described.

2.1 Composition fuselage section with EWIS integration

The fuselage section mock-up (Fig. 5) is made up of CFRP with bronze mesh, with metallic end plates. CFRP frames and cross beams are set in the mock up to be fully representative of a fuselage section. Moreover, metallic strips have been added on one over two frames and crosspieces, and additional protection elements (raceways, T protections, shields) are also considered. Its dimensions are a diameter of 2.3 m and a length of 4.6 m.



Fig. 5: Internal view of fuselage section mock-up.

The integration of the various cable harnesses required the installation of around 300 m of aeronautical cables (DR04), over 1,000 aeronautical brackets and clamps, over 30 m of raceways or IPNs, and over 100 m of communication/signal cables for the operation of the engine test benches, the electrical cores and the DC bus core. The main choices for integrating cable harnesses that have been defined and implemented are as follows (Fig. 6):

- Raceway with removable partitions to create independent compartments. Inside each compartment, we find either a topology with 2 single cables spaced apart, or a twisted two-wire topology. Electrical continuity (metallization braid) is provided between each raceway and the mechanical structure

of the fuselage section. We mainly find two-compartment raceway inside the fuselage section and four-compartment raceway outside the fuselage section.

- An aluminum IPN beam is located in the center of the fuselage section. It includes two opposing compartments. Each compartment contains a topology of two spaced cables and a twisted pair. A spacing between the twisted pair and the other cables was considered. As before, electrical continuity has been maintained in relation to the model structure.
- The use of aeronautical brackets and clamps. The combination of the different references supplied enabled us to consider several choices for integration into the fuselage section. For example, simple or complex assemblies were created to route single or twisted two-wire cables.
- The use of power connectors, mainly from Staubli, but also a new power connector from Amphenol AirLB (HPAC - 800V / 125).

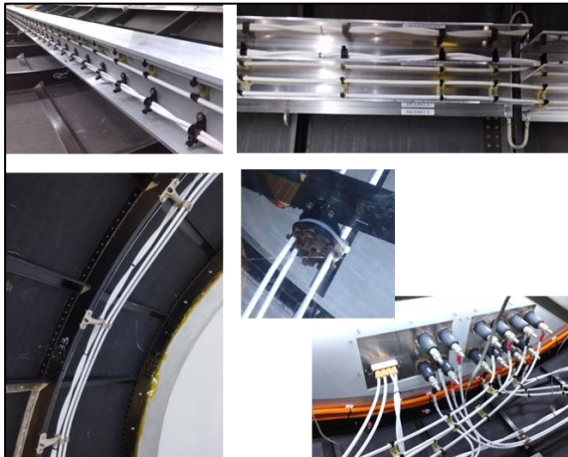


Fig. 6: Views of EWIS intégration.

As shown in figure 3, our electrical architecture is redundant in terms of cable bundle routing, but also protected by distribution cores: a main core (called the DC bus) and four secondary cores located in the fuselage section (Fig. 7). Each supply line is protected by a power contactor (in our case from the railway sector (SCHALTBAU)), a programmable overcurrent relay and also a fuse.



Fig. 7: Views of secondary cores.

2.2 Motorization benches

Each motorization bench is able to deliver a maximum mechanical power of 10 kW (with forced cooling positioned under each machine). A test bench (Fig. 8) consists of a two-stage mechanical structure made of aluminum sections:

- The lower stage supports two reversible inverters (automotive field) to convert DC bus voltage into AC and vice versa, enabling current to feed back into the electrical grid. This advantage makes it possible to have 80 kW of power available, while consuming only the system losses (approx. 16 kW) from the complete electrical grid.
- The upper stage consists of two axial-flux synchronous motors linked by a flexible mechanical coupling. Note that one of the machines is considered as an alternator, which in our case will allow us to emulate it as an equivalent propeller via an appropriate torque control law.

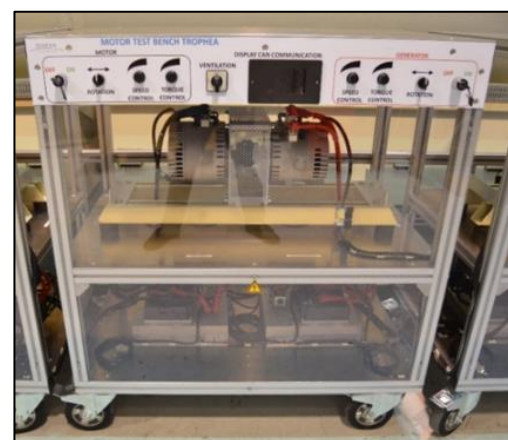


Fig. 8: Motorization bench.

Each motorization bench can be controlled either by analog commands or by digital commands via a CAN bus.

2.3 Power emulation bay

A power emulation bay (low voltage/high current) is used to supply TROPHEA's DC bus. This bay is made up of 4 sources of 15 kW each, with a maximum voltage of 80 V or a maximum current of 450 A. The emulation bay can be controlled via a number of software programs to simulate battery mode (charge/discharge mode), fuel cell mode or general mode (voltage/current). This bay can also be used in +/- DC mode (30 kW max in our case). It should be noted that we have also the same emulation bay at our disposal with a voltage of 500 V.

Conclusions

The TROPHEA test bench should be operational by the end of 2023. We will then be in a position to carry out various studies on the integration of distributed electrical architectures in order to:

- Analyze transient phenomena during power switching in network reconfigurations (failure during power line isolation).
- Emulate Airplane propeller resistive torques (quadratic function) to replicate realistic mission profiles.
- Analyze the network's electrical behavior (stability) during power reinjection phases linked to a wind milling state.
- Analyze different network security configurations, highlighting reaction times.
- Evaluate thermal phenomena associated with different types of attachment.
- Evaluate the influence of the spatial orientation of cables on heating for different types of raceways.
- Assess the impact of electromagnetic coupling on the closeness of electrical cables (Fig.9).
- Define a solution for detecting partial discharges (health monitoring).



Fig. 9: First EMC test with TROPHEA.

Acknowledgment

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