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DRAGON: hybrid electrical architecture for distributed fans propulsion

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Abstract

Starting from the knowledge acquired on various electrical distributed propulsion system concepts, ONERA explored the viability of a hybrid electrical aircraft configuration on the basis of a transonic transport aircraft and more particularly on the inclusion of the single aisle segment (A320 or B737): the DRAGON (Distributed fans Research Aircraft with electric Generators by ONERA) concept was born in 2017. The design of this advanced power architecture required the multi-physics integration of different domains such as flight performances, safety and environmental requirements (thermal, electric, electromagnetic). This paper describes the last trade-off analysis which has been performed on the hybrid electrical architecture to assess the electrical power chain characteristics while considering failure scenarios. An analysis of the Electrical Wiring Interconnection System (EWIS) has been done to evaluate the influence of technology characteristics of electrical components on the aircraft performances.

Introduction

Since 2013, ONERA engineers have described and validated an all electrical aircraft (AEA) concept, based on distributed electric propulsion (DEP), for a small business aircraft (AMPERE concept) corresponding to the societal need for On-Demand Mobility [1] [2]. In 2017 within the European Program Clean Sky 2 (CS2-LPA-IADP), ONERA decided to explore the implementation of DEP on a transport aircraft carrying 150 passengers at a cruise Mach number of 0.78 over a range of 2750 NM. The DRAGON research concept (Fig. 1) has been defined [3][4] to meet this challenge. To design an efficient hybrid electrical aircraft, a multi-disciplinary approach has been adopted taking into account all integration aspects (aerodynamics, structure, aero elasticity, electrical propulsive chain), flight performances, safety and environmental requirements that have been included into ONERA's MYSTIC (Multidisciplinary Sizing Tool for Integrated Concepts)[5].

In the first part of this paper, the main elements associated to the selected distributed-propulsion aircraft are presented. The second part is a focus on the hybrid electric architecture and more particularly on the effects of electric component characteristics on the aircraft design.



Fig. 1: Illustration of the DRAGON concept (configuration including 40 electric motors).

Main characteristics of the DRAGON concept

Previous analysis [2] of flight performances showed that the propulsive force of DEP architecture should be controlled symmetrically to control yaw and roll effects. Consequently, Electric Ducted Fans (EDF) clusters have been proposed by symmetrically distributing them on both sides of the wing.

To take into account certification constraints, we decided to extrapolate CS-25 failure cases. Specifically, the "One Engine Inoperative condition" (OEI), which is requested in the CS-25.121, must be replaced by the "One Turboshaft Inoperative" (OTI) condition. This requires at least two turboshaft engines for the aircraft to be able to maintain the required slope.

Next, on each turbo-shaft, an electric generator is positioned which allows converting the mechanical power in electrical power. Another failure condition can thereby be considered as the "One Generator Inoperative" (OGI) condition.

In addition to the OTI and OGI conditions, the "One Core Inoperative" (OCI) condition must be addressed as a failure condition. In this configuration, there is no loss of power and the total amount of power could be distributed over a reduced number of electric components if required.

Concerning the "One Engine Inoperative" condition (OEI), in terms of propulsion, it could be renamed "One Electric Engine Inoperative" (OEEI) condition to include the electric propulsion aspects.

As described previously, we imposed the requirement of a symmetric distribution of EDF clusters on both wing sides. Therefore, if one EDF is lost then the symmetric EDF must be stopped. During the AMPERE Project [1][2], it has been demonstrated the possibility to lose roughly 45% of EDF to still respect the failure cases (gradient of climb). Presently, we

have done the hypothesis that the OCI condition must cover the OEI condition through this proposed electrical architecture.

This means that the OTI, OGI and OCI cases are likely to be the most significant sizing conditions in terms of power for all the electric components.

Starting from these hypotheses, a hybrid electrical propulsive architecture can be defined. In this paper, the configuration proposed (Fig. 2) is based on:

- Twenty four EDFs located on the lower surface of the wing in the vicinity of the trailing edge and split into four clusters of six EDFs.
- Two turboshaft engines mounted at the rear burning regular kerosene. Note that the kerosene tanks are localised in the rear cargo hold area of the fuselage to respect an appropriate gravity center.

The OTI condition is considered equivalent to the OEI condition mimicking the OEI requirements in the CS-25 document associated to 2 engines (gradient of climb of 2.4 % at 400 ft).

Note that a turboshaft is designed for Mid Cruise (MC) conditions (i.e. Mach=0.78 for an altitude of 10000 m) with atmospheric conditions at ISA +15°C. Therefore, its equivalent power for a sea level condition will be more important.

- Two embedded electric generators driven by one turboshaft engine have been considered to reduce the power of each element but also to reduce the size of the electric generator versus the turboshaft diameter.

The OGI condition is considered as mimicking the OEI requirements in the CS-25 document associated to 4 engines (gradient of climb of 3 % at 400 ft).

- Four electric cores, located in the cargo zone (pressurized area), which allow distributing, controlling, protecting and reconfiguring the propulsive power chain and more particularly the four EDFs clusters.

The OCI condition is considered as mimicking the OEI requirements in the CS-25 document associated to 4 engines (gradient of climb of 3 % at 400 ft).

- Starting from the previous characteristics, an electrical wiring interconnection system (EWIS) has been defined considering the necessary redundancies at the integration level and to respond to safety aspects (Fig. 3).

Thus, each electric generator provides High Voltage Alternating Current (HVAC) up to a converter which dispatches High Voltage Direct Current (HVDC) up to two electrical cores via a DC bus and electrical harnesses. Finally, each electric core provides HVDC voltage to all converters of one EDFs cluster.

Note that, in order to protect the power cable

harnesses, Fault Current Limiters (FCL) and HVAC & HVDC Breakers have been introduced to inverters/converters levels and electric cores.

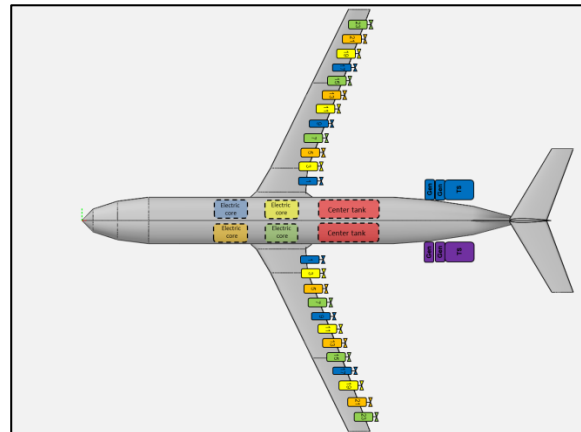


Fig. 2: Illustration of the layout for DRAGON

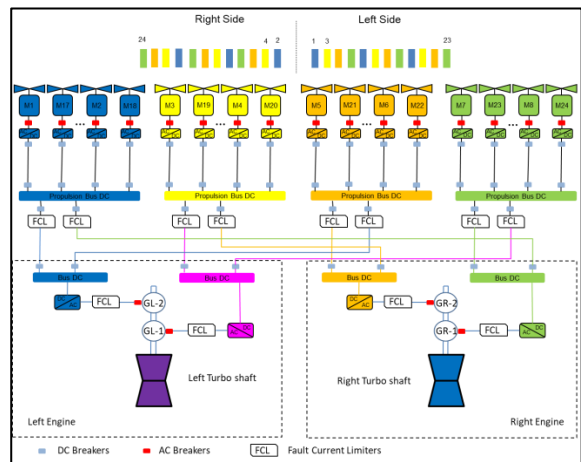


Fig. 3: Cross-redundant Architecture Diagram

| | | |
|---|--------------------------------|------|
| Turboshaft | Power density [kW/kg] (@FL350) | 9 |
| Electric Generator | Power density [kW/kg] | 13,5 |
| | Efficiency | 0,95 |
| Converter (HVAC/HVDC) Including FCL and HV AC/DC Breakers | Power density [kW/kg] | 19 |
| | Efficiency | 0,98 |
| Electric Core Including FCL and HVDC Breakers | Power density [kW/kg] | 20 |
| | Efficiency | 0,99 |
| Inverter (HVDC/PWM) Including FCL and HVDC Breakers | Power density [kW/kg] | 19 |
| | Efficiency | 0,98 |
| Electric motor | Power density [kW/kg] | 13,2 |
| | Efficiency | 0,98 |
| Cables | Maximum voltage [kV] | 3 |

Table 1: Technology assumptions for components

The next step has been to evaluate the technology characteristics of each component. Our choice focused on technologies actually in development (TRL 4-5) [4]. These assumptions are synthetized in

Table 1. Note that for the feeder cables, we have chosen not to exceed a “touch” temperature of 75° C which is a good compromise between admissible current in cables and their integration in the installation environment (max 360 A for 4/0 wire gauge).

As a first approximation, the cooling aspects have been mainly integrated in the assumptions on the power density value of each component.

Evaluation of the DRAGON concept

The Top Level Aircraft Requirements (TLAR) of the DRAGON concept are reported below (Table 2).

| | | |
|----------------------|------|----|
| Range | 2750 | NM |
| Number of passengers | 150 | |
| Mach number | 0,78 | |

Table 2: Top Level Aircraft Requirements for the DRAGON concept

Then, a “typical” mission with its various flight phases is defined as illustrated in Fig. 4. Note that several hypotheses have been considered, as a maximal take-off field length (TOFL) (< 2200 m), a max climb time (< 29 min) to reach the top of climb (33000 ft) and an altitude which is linked to failure cases (400 ft) as previously described.

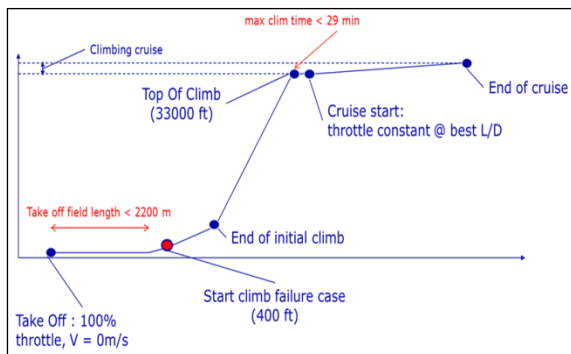


Fig. 4: Illustration of the DRAGON “typical” mission

All the data previously described have been implemented in ONERA MYSTIC overall design sizing tool [5]. In this paper, two scenarios have been analyzed to evaluate the influence of technological assumptions:

- The first scenario considers technological assumptions of Table 1, named “REF”.
- The second scenario considers main technological assumptions of Table 1 but all component efficiencies are estimated at 99% instead of their reference value, named “REF+1”.

The results of this sizing loop are summarized in Table 3. With the “REF+1” scenario, there is an important reduction in the fuel consumption of about 9,64 %. The explanation is that the evolution of the electrical components has two positive impacts. First, the components are more efficient so there are fewer

losses in the transmission of electricity to the fan. Second, the overall propulsion efficiency is directly improved. Besides, the components should be lighter and the overall demand in power would decrease. All these benefits are so important that the lower lift-to-drag ratio with respect to the reference aircraft is no more significant.

| DRAGON | | REF | REF+1 | Diff. % |
|------------------------|------|-------|-------|---------|
| MTOW | [t] | 70,16 | 67,3 | -4 |
| OWE | [t] | 43,51 | 41,88 | -3,7 |
| Mission Fuel | [t] | 12,96 | 11,71 | -9,64 |
| Propulsion weight | [t] | 10,94 | 9,77 | -10,7 |
| Turboshafts | [kg] | 2048 | 1872 | -8,6 |
| Electric | [kg] | 1564 | 1424 | -8,95 |
| Generators | | | | |
| Converters (HVAC/HVDC) | [kg] | 1092 | 992 | -9,16 |
| Cables | [kg] | 1524 | 1524 | 0 |
| Harnesses | | | | |
| Cores | [kg] | 1024 | 928 | -9,37 |
| Inverters (HVDC/PWM) | [kg] | 1032 | 960 | -6,97 |
| Electric motors | [kg] | 1466 | 1358 | -7,37 |

Table 3: Impact of technologies on the DRAGON weight.

As previously explained, three failure conditions (OTI, OGI and OCI) have been considered in our analysis. During the sizing loop, the power level of each power component is evaluated and also cross-checked by mission phases to obtain the optimal power configuration. In Fig. 5, the power setting of the electric propulsion chain for several mission phases has been plotted. We can observe that the EDFs, Cores and generators are used at 100% during the take-off phase, while the turboshaft is at 100% for the Top of climb phase. Note also that, in our case, the nominal mission covers all failure conditions.

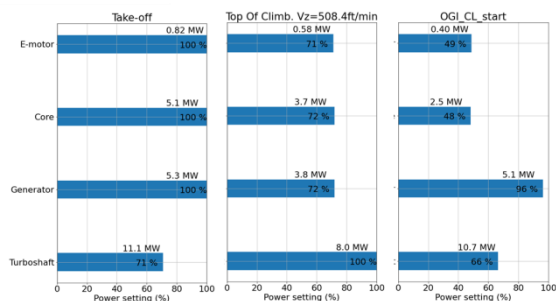


Fig. 5: Illustration of power setting by phase (configuration “REF”, value by unitary element)

Conclusions

In this paper, a safe hybrid electric architecture has been pre-sized to demonstrate the viability of the DRAGON concept for a transport aircraft carrying 150 passengers at a 0.78 Mach-number cruise. In this

paper, we have shown the importance of having a “holistic” integration approach in order to assess the characteristics of the hybrid propulsion chain. Indeed, a one-off modification can lead to a significant gain in the aircraft. We also demonstrated that major innovations are worth being done to obtain technological gain on the electric systems. ONERA will continue the maturation of the DRAGON concept through refined high fidelity disciplinary studies combined with multidisciplinary design analyses and optimizations at aircraft level.

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