THE E-FAN ALL ELECTRICAL AIRCRAFT DEMONSTRATOR AND ITS INDUSTRIALIZATION

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Abstract

Airbus Group and its partners seek to bring the advantages of electric aircraft into daily use opening a future for aviation with fewer emissions, lower noise levels and higher operating efficiency. Lower noise levels of electric propulsion would significantly relieve airport residents – thus potentially allowing extending flight operation times and leveraging the capacity for increasing air traffic. Hybrid propulsion is the enabler to significantly reduce the emissions of CO2, NOx, and particulate. An all-electric aircraft would even cut in flight emissions to zero. The Airbus Group Innovations research and technology network is leading a company-wide electric aircraft roadmap. This strategy outlines a step-by-step approach for Airbus Group's short-, medium- and long-term development of electric planes. The E-Fan project is a key element of this roadmap. Thanks to e-Fan project, industry will gain expertise in everything from developing e-system architecture and validating battery technologies to the actual operation of electrical propulsion systems in real-life aviation conditions.

1 Introduction

Commercial air transportation growth for the next decades shall be sustainable. This global idea have been detailed, like in Flightpath 2050 document, presenting Europe's vision for aviation, including strong objectives for protecting the environment and the energy supply. Current aircrafts architectures improvements have the potential to reduce the emissions but will reach physical limits before achieving these objectives.

Therefore disruptive innovation on aircraft is necessary. One axis is the design of new propulsion architectures. The main key enabler is electricity, used as a new vector of energy. In this context Airbus is driving a roadmap to master and stretch electrical and hybrid propulsion. E-Fan two seat electrical aircraft is a major step of this plan.

In order to assess the long-term potential and opportunities of electricity as an alternative major onboard energy source, Airbus Group and its partners undertook several projects starting by re-engineering an ICE (Internal Combustion Engine) -powered light aircraft into an electrical one using batteries as a main energy storage system and equipped with data acquisition systems to designing from scratch a full electrical aircraft Efan. Impacts study and analysis were performed and a computational simulation platform has been developed and validated against flight measurements for both projects.

2 Achievements: All Cri Cri Electrical Aircraft

As a forerunner the all-electric Cri-Cri paved the way to the E-Fan project. The Cri-Cri is the first-ever four-engine all-electric aerobatic plane. The MC-15 aircraft or CriCri is a very small airplane with low cost and acrobatic flight capabilities. Originally, it is the smallest twin engine aircraft powered by two 2-stroke engines, each one delivering 11 kW at 6000 RPM and consuming 10 l/h at 200 km/h. The 23 liters fuel tank allows a maximum flight endurance of almost 2 hours and a range of 450 km. The all-electric Cri-Cri has jointly been developed by Airbus Group Innovations and a SME (Small / Medium Sized Enterprize) Aero Composites Saintonge. The official maiden flight has been carried out at Le Bourget airport near Paris in September 2010. It has cumulated more than 50 flights making it the first electrical aerobatic aircraft in demonstration at Le Bourget 2011. This low-cost testbed is a French Cri-Cri ultra-light aircraft that has been modified for all-electric propulsion with its original pair of nine horsepower piston engines replaced by four brushless electrical motors, each powered by a high energy-density lithium polymer battery. This unique four engine aircraft has literally turned the future of aviation propulsion upside down.

Figure 1: All electric Cri-Cri

2.1 Electrical motors and power electronics

Electrical motors design was based on the maximum required power for take-off and acrobatic flight. 4 electrical motors of about 5.5 kW were selected off-the-shelf and installed in an innovative configuration. In fact, each 2 permanent magnet brushless synchronous electrical motors were installed in push-pull configuration as shown in Fig. 2. Those electrical motors have external rotors which is not very common compared to classical configurations of electrical machines, however, external rotors enable to install the propeller blades directly on the rotor. The main drawback of this external rotor configuration lies in stator heating issues. To solve the heating problem, a forced passive cooling system for the motors through air circulation in their internal parts was adopted. The power electronics system is located in the nose of the airplane and it has a forced passive cooling system through scoops in the fuselage.

Figure 1: Electric motors configuration and air inlets visualization

2.2 Battery Pack High energy density and high power density Lithium-Polymer 5Ah cells were selected for this demonstrator. These battery cells achieve an energy density of 146 Wh/kg that falls to 127.7 Wh/kg after including all necessary sensors and packaging. Each of the 4 motors has one battery pack connected to it, leading to 4 completely independent electrical chains. Each pack is formed by 2 parallel sets of 24 battery cells in series. This results in 192 battery cells for the complete battery system. The final power density achieved by this system was 2.5 kW/kg leading to a lighter propulsive system than the original internal combustion engine system.High integration constraints in terms of mass and volume needed to be taken into account as well as impacts on aircraft centering. Also, since CriCri is designed to perform acrobatic maneuvers, facing high accelerations, the batteries needed to be tightly fixed to the fuselage. Metallic rods were installed connecting the packs to the metallic structure of the aircraft and an isolation foam was installed under the battery packs to improve mechanical loads distribution on the fuselage. Battery packs final configuration and their volume allocation within the aircraft is shown in Figure 3 and 4.

Figure 3: Battery Pack configuration

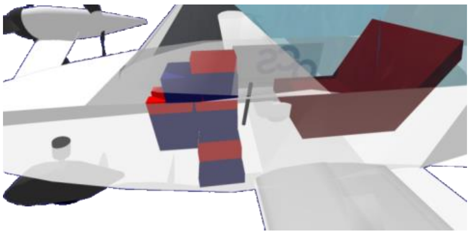

Figure 4: Battery Pack integration

Battery cooling was not necessary since the internal resistance in the batteries is relatively low. Also, in case of an unexpected overheating, there are many sensors scattered all over the packs, so that batteries temperature is always monitored. If the temperature reaches critical levels, alarms on the pilot's panel are activated in order to prevent the pilot to take appropriate measures.

Based on the first success on Cri Cri, Airbus Group has decided to follow the learning curve with EFAN 1.0

3 Achievements: E-Fan 1.0

Following the green cri-cri experience, the E-Fan 1.0 brought electric propulsion to the general aviation sector. The two-seater E-Fan is particularly suited for short missions such as pilot training, glider towing and aerobatics, with a flight endurance of 30 minutes for aerobatics to one hour for pilot training. E-Fan can bring significant benefits in terms of cost per flight hour in the General Aviation domain.
Small electric aircraft are seen as a key step towards introducing electric propulsion on larger aircraft. The E-Fan is a highly innovative technology demonstrator and a flying test bed stimulating research in electric propulsion and also help with the certification of electrical flight. The E-Fan project is supported by the French Directorate General for Civil Aviation (DGAC) as well as regional government institutions in southwest France and involves an association between Airbus Group, SMEs and academia.

The E-Fan is an entirely new concept for an electric aircraft, whose design started with a clean sheet in a very short and agile way: 9 months was necessary for the role out and 9 additional months for the maiden flight.
It is the first purpose-built electric powered training aircraft. All other models to date are based on existing conventionally powered airframes. The E-Fan's aerodynamics, such as the integration of the landing gear into the fuselage for low drag, and the energy management and safety features were designed from the outset specifically for electrical propulsion.
However, the performance of the aircraft is revolutionary in terms of noise reduction, there are no CO2 emissions in-flight and vibrations are significantly reduced compared to aircraft powered by combustion engines. The E-Fan was designed to be compatible with flight training and aeroclub requirements, such as hangar parking space and flight endurance. With electrical propulsion, there is no reduction of performance at altitude and in hot weather, no propeller torque effects and no vibrations, providing a very smooth flight.
As a first for an electrically powered aircraft, the E-Fan features a pyrotechnically deployed airframe parachute rescue system. An optimized electrical energy management system (e-FADEC) is integrated into the aircraft, which automatically handles all electrical features, thereby simplifying the monitoring and controlling of the systems. The e-FADEC reduces the pilots' workloads, allowing the instructor and the student to fly the aircraft and focus on the basic training mission.

3.1 Electrical Propulsion

E-Fan 1.0 propulsion is provided by two electric motors, each with a combined power of a maximum of 60 kW, driving a ducted fan. The duct reduces the perceived noise and improves safety on the ground. With the engines located close to the centre-line of the aircraft, the E-Fan has very good controllability in single-engine flight.

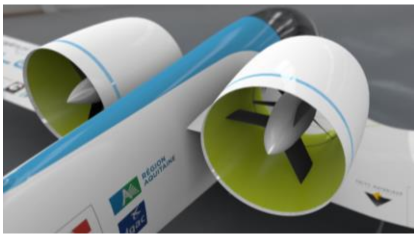

Figure 5: Electrical Ducted Fan

3.2 Battery System

The E-Fan’s motors are powered by a series of 250 V Lithium polymer batteries made by KOKAM in the Republic of Korea. They are housed within the inboard part of the wings outside the cockpit and provided with venting and passive cooling. Because of timing and availability constraints, off-the-shelf Lithium ion polymer batteries are used in the technology demonstrator, giving an endurance of 40 minutes. New batteries with a higher energy density will be installed later on, which will increase the endurance to up to 60 minutes to 90 minutes.

The batteries can be recharged in 3 hour or they can be rapidly replaced by means of a quick-change system (a feature which is not yet available on the demonstrator aircraft). An on-board 24 V electrical network supplies the avionics and the radios via a converter. A backup battery is provided for emergency landing purposes.

Extensive research and stress testing has proven that the E-Fan battery system provides ample safety margins. Close monitoring of all battery cell parameters is performed during test flights.

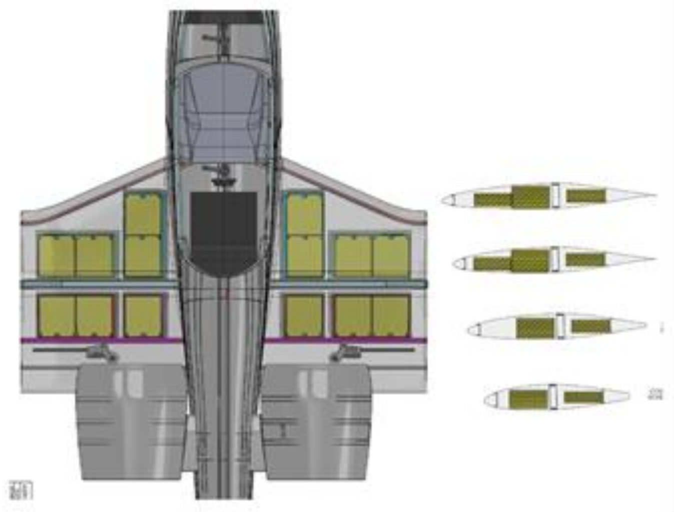

Figure 6: Battery Installation

3.3 Electrical Landing Gear

Another innovation of the E-FAN is its landing gear, which consists of two electrically actuated retractable wheels positioned fore and aft under the fuselage, plus two small wheels under the wings. The aft main wheel is driven by a 5 kW electric motor providing power for taxiing and acceleration up to 60 km/h during take-off, reducing overall electrical power consumption in day-to-day operation.

3.4 The Challenge of the E-Fan 1.0 Channel Flight

Since its first flight in April 2014, the E-Fan team has constantly been working to improve the technology on-board to reach more than 100 flights. At the 2015 Paris Air Show in June, Airbus Group highlighted the continuous enhancements made to E-Fan in just over a year and a half, which have resulted in increased battery capacity, reduced weight and a new retractable landing gear. These are highly valuable stepping stones on Airbus Group’s path towards electrical aviation, which would drastically reduce noise pollution and emissions.

On 10th July 2015 Airbus Group’s E-Fan technology demonstrator became the world’s first twin-engine electric plane taking off with its own power to successfully cross the English Channel, some 106 years after Louis Blériot's epic flight traveling in the opposite direction to the pioneering Frenchman and powered by lithium-ion batteries, the E-Fan took off from Lydd on the English south coast, completing the 74 kilometer flight east to Calais, France, in around 37 minutes.

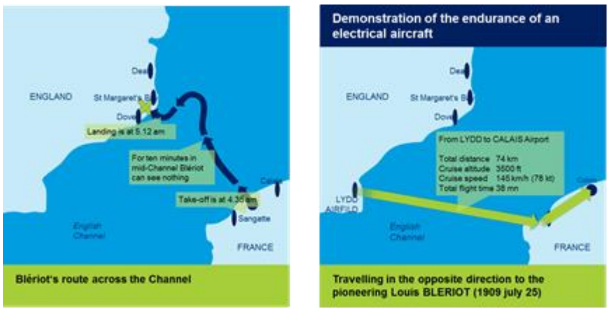

Figure 7: Blériot's & E-FAN's route across the Channel

Flown by Didier Esteyne, the all-electric plane weighs around 600 kilogram and travelled at an altitude of about 1,000 meters [3,500 feet].

While the E-Fan has made more than 100 flights preparations for this very special trip were extensive and included a dedicated test and verification program put together by French flight authorities, Airbus Group and its partners (Safran and Zodiac as key partners for Electrical Power Unit). During this flight test campaign, the E-FAN retrofitted demonstrated an endurance up to 1 hour and a capability to perform the mission in a total safe way both in nominal and degraded mode. At the time of the Channel crossing, all the Electrical Power Unit data was in real time monitored thanks to an air-air telemetry system.
The E-Fan's successful journey demonstrated the future possibilities of electric flight; it has been also homage to Louis Blériot, one of the all-time greats of aviation.

Figure 8: E-Fan 1.0 crossing the Channel

4 E-Fan 2.0

Airbus Group's E-Fan demonstrator settled the stage for subsequent production versions: first, the two-seat E-Fan 2.0 version for basic pilot training, then the E-Fan 4.0, a four-seat airplane for full pilot licensing and the general aviation market. To achieve these production versions, the company has already signed agreements with its partners for the E-Fan program's industrialization phase. Voltair SAS, a new 100% Airbus Group-owned company, will develop, build and offer services for E-Fan 2.0 versions. These production versions are focused on users' needs. E-Fan 2.0 operating costs are pegged at one-third of traditional piston-engine light aircraft. A ground-based charging unit will be able to bring the aircraft batteries to their full flight endurance in 60 minutes.
Voltair SAS is committed to working closely with airworthiness authorities on E-Fan's certification as a Light Sport Aircraft (LSA), as this will be the first time an electric plane is approved for general aviation operations.

Engineering schools and their apprenticeship program will also have a strong involvement in the E-Fan's development and production. They will bring the fresh perspective and ideas of young talent that represents the aerospace industry's next generation.

The E-Fan 2.0 version is a fully electric training aircraft powered only by batteries recharged by a ground station. It requires a light structure, high efficiency powertrain and batteries with both high power density and high energy density. The plane will also use the experience of the latest Airbus Group Innovations concept about connected cockpit for electric aircraft. The E-Fan 2.0 is a purpose built aircraft requiring massive innovations. This aircraft is currently in its design phase.

4.1 Main E-Fan 2.0 Characteristics

The main characteristics of EFAN 2.0 are:

- Endurance : 60 minutes + 30 reserve including several TO during the mission
- Recharge : 1 hour
- 2 seat
- MTOW = 600 kg
- Certification : CS-LSA

5 Other Projects

E-Fan 2.0 is setting the stage for the Airbus Goup E-Aircraft roadmap, which ranges from serial E-Fan production to long-term goals such as a potential hybrid-electric regional airliner or helicopter.

The product strategy is closely supported by the roadmap's other component – the concurrent technology development of ground and flying demonstrators to evaluate the feasibility and benefits of e-aircraft technology.

This activity is led by Airbus Group's E-Aircraft System House and covers research on a wide range of disruptive technologies and programs, along with collaborative projects. The knowledge and expertise gained will enable improvements across the Group's product range, including more on-board electrical power to increase aircraft efficiency, reduce noise and lower emissions.

6 Conclusion

All electric flight demonstrators from Cri-Cri to E-Fan did successfully demonstrate that electrical propulsion is applicable to Light Sport Aircraft. The industrialized E-Fan 2.0 as an all electrical aircraft mainly dedicated to the initial training of private pilots will introduce an essential number of electrical aircraft into real day to day flight application thus paving the way for electrical-/hybrid propulsion step by step to larger aircraft.