FUEL CELLS TECHNOLOGY ONBOARD AN HYBRID ELECTRIC AIRCRAFT

Maria del Pilar Argumosa
Energy Area, INTA
Crtra Ajalvir km 4, 28850 Torrejon de Ardoz (Madrid)

SPAIN

argumosa@inta.es

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ABSTRACT

PEM fuel cell systems as power generators offer great advantages: high efficiency, emissions reductions and thermal efficiency gains. The introduction of electric power supplies using non-fossil fuel instead of the conventional systems seems to be a solution to reduce the Green House Gas emissions from the aircraft. The multifunctional Hydrogen-based fuel cell system is a promising technology that can replace several existing systems, different functions are ensured (generation of electricity, heat and water, inerting of fuel tanks,…) exploiting its by-products.

The use of fuel cell system as a propulsive technology is also in the portfolio of future engine concepts for small and regional aircrafts, together with distributed electric motors, Pure electric propulsion has been demonstrated in small aircrafts, using batteries and hydrogen fuel cells as electric generators, but some developments are still required on specific components to obtain a fully FC systems ready to certify for use in a severe flying environment for essential functions.

In non-essential functions several demonstrators have been developed in the last 10 years (emergency power supply, electric taxiing concept, APU, auxiliary power units for a Galley), most of them proof of concepts, that has shown the feasibility of this technology in the aeronautical sector, but there is still some challenge to prove about the airworthiness of these systems.

1.0 INTRODUCTION

PEM fuel cell systems as power generators offer great advantages: high efficiency, emissions reductions, and thermal efficiency gains [1]. The introduction of electric power supplies using non-fossil fuel instead of the conventional systems seems to be a solution to reduce the Green House Gas emissions from the aircraft [2]. The multifunctional Hydrogen-based fuel cell system is a promising technology that can replace several existing systems, different functions are ensured (generation of electricity, heat and water, inerting of fuel tanks,…) exploiting its by-products.

The use of fuel cell system as a propulsive technology is also in the portfolio of future engine concepts for small and regional aircrafts [2], together with distributed electric motors, another electric propulsion type proposed for HE aircraft is a hybrid fuel cell gas turbine which utilizes a single spool gas turbine for take-off and climb and change to a fuel cell power for cruise [3]. But the complexity of this design makes this option much farer in the time horizon.

Pure electric propulsion has also been demonstrated in small aircrafts, using batteries and hydrogen fuel cells as electric generators (DLR Hy4 project), but some developments are still required on specific components to obtain a fully FC systems ready to certify for use in a severe flying environment for essential functions.

The use of hydrogen and fuel cells has also been analysed in the military environment for different applications: soldier wearable power equipment, stationary renewable power units, auxiliary power units for tanks and propulsion of UAVs as the NLR Ion Tiger. In 2006 a STO Technical report (TR-AVT-103) reviewed the fuel cells technology status, searching for key technical challenges for application in power systems for land, sea and air vehicles. In 2011 the SET pannel published another TR on UAVs power sources (TR-SET-126); this report provides a focused assessment of the power source technologies available for UASs, including the fuel cell technology. And in 2014, the same SET pannel has published the result of the activities carried on by the 173 task group about the emerging manportable power technologies, with part II is focused on the use of fuel cells on unmanned vehicles (TR-SET-173). But there is not great interest of using fuel cells in military aircrafts yet, although the development of a FC APU for cargo aircraft has the same advantages for commercial and military platforms as emission and noise reduction, more reliable power and lower maintenance cost; hydrogen is not yet a logistic fuel in military missions.

2.0 HYDROGEN AND FUEL CELLS

Fuel cell technology has shown to be applicable in most of the sectors of our Economy, demonstrators on the mobility, residential and industrial sectors have been installed and proved its advantages as clean power generators. The modularity of this technology has allowed to manufacture since micro generators, to supply power to a mobile phone or a micro UAVs, to big power plants up to 56 MW as the Korea´s Gyeonggi Green Energy Park.

These electrochemical devices produce electricity from the reaction of a fuel as hydrogen and an oxidant as oxygen or air. A fuel cell system that generates electricity and heat, in an useful and safe way, is a complex system that requires, besides the FC stack, some other components and auxiliary sub systems, it is the balance of plant, and it is set up by compressors, pumps, humidifiers pressure regulators, power conditioning, cooling system, fuel storage and conditioning and control units, among others.

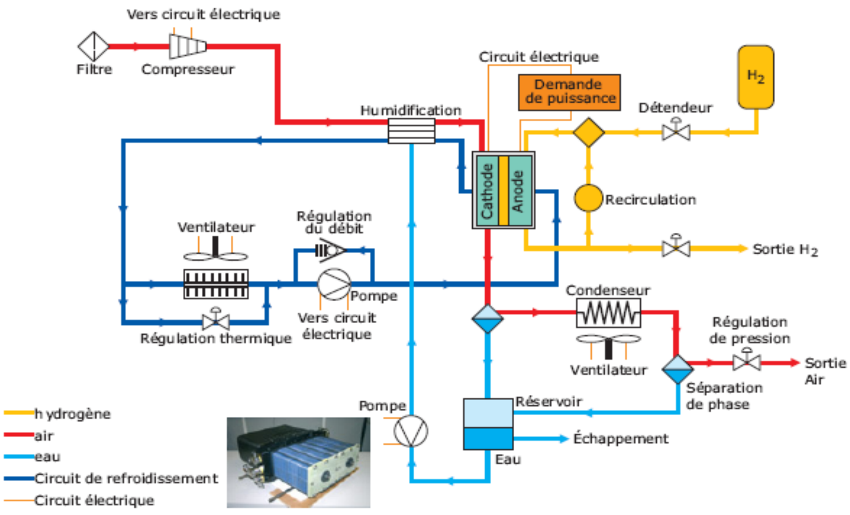

Figure 2-1: Example of a Balance of Plant for a Fuel cell system

There are several types of fuel cell, but the most potential to be used in aviation are the Proton Exchange

Membrane Fuel Cells (PEMFC) and the Solid Oxide Fuel Cells (SOFC). The PEMFCs can be operated at low temperature (80 - 160ºC), it offers a quick start up, but it requires relatively pure hydrogen fuel. The SOFCs operate at higher temperature (700-1000ºC); it may be fed by reformed hydrocarbon fuels because it tolerates higher levels of impurities, indeed it has the potential of making a direct partial reforming in it, and potentially it could achieve higher efficiencies, although it has lower specific power than PEMFC. Both FC types are used in the current developments of automotive applications. The targets propose in new developments are focused mainly on higher power densities, more tolerance on impurities, durability and lower cost.

The fuel used in these fuel cells reactions is Hydrogen. Hydrogen is a versatile, clean, and safe energy carrier that can be used as fuel for power or, in industry, as feedstock. It can be produced from renewable electricity and from carbon-abated fossil fuels. It produces zero emissions at point of use. It can be stored and transported at high energy density in liquid or gaseous form. It can also be extracted by reforming hydrocarbon or alcohol fuels.

3.0 FUEL CELLS ON AIRCRAFTS

Fuel cells (FC) can play an important role in the future aircraft concept. Current research on the aeronautical sector has been addressed to the More Electric Aircraft (MEA) and the Hybrid Electric Aircraft (HEA) as predecessors of the full electric aircraft.

MEA address the use of electric power for secondary systems on aircraft such as control surfaces, wing de-icing or Auxiliary Power Units (APUs). The replacement of the conventional hydraulic, pneumatic or mechanical actuators by electric ones may lead to improvements in reliability, maintainability, supportability and lighter aircraft with the potential of significant fuel saving and more passengers accommodation.

HEA concept requires the combination of more than one propulsive sources such as engines, turboelectric energy generation, fuel cells energy generation, or battery energy storage to propel an aircraft. The target is to optimize the conventional engine operation to the highest efficiency point, using the other power source to supply the peaks or on ground requirements.

In this way to electrification it is required to change the conventional way that the electricity is generated on board, looking for a more environmental friendly way that burning jet fuel. Fuel cells offers great advantages as high efficiency, high reliability, easy maintenance, lower noise and low or ZERO emissions.

In this context the aviation industry has developed prototypes and performed tests to support several application of fuel cells on airplanes as:

- Propulsive generation. Fuel cells can be used as an electricity source for pure or hybrid electric propulsion, Small glider type aircrafts and UAVs powered by Hydrogen Fuel cells systems and batteries have already flown showing the viability of this technology but some developments are still required on specific components and safety and regulatory issues to be able to get the airworthiness certification of an electric manned aircraft powered by fuel cells.

Figure 3-1: Boeing FC Demonstrator (Madrid 2008)

- Electric energy generation on-board. The multifunctional Hydrogen based fuel cell systems concept can replace conventional systems by more eco-efficient fuel cell systems. Fuel cells produces electricity and other by products, that can be used on-board assuring different functions as heat and water supply, cabin air humidification or inerting of fuel tanks.

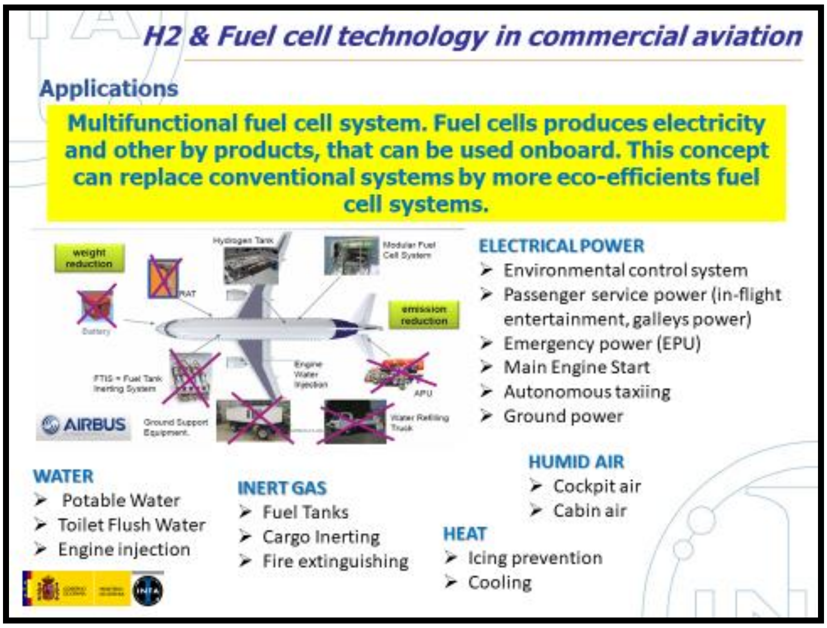

Figure 3-2: Multifunctional concept description.

4.0 MAIN APPLICATIONS AS NON ESSENTIAL SYSTEMS ONBOARD

Aircraft manufacturers and R&D centres have analysed the integration of H2 fuel cell systems to generate part of the electricity required in the MEA concept. A Fuel cell power system can replace some conventional subsystems that supply electricity to aircraft functions as Auxiliary Power Units (APU), Emergency power Units (EPU), autonomous taxiing or passenger service (galleys, in-flight entertainment. But It can also provide other functions (demanded water, inerting gas, heat for cooling or icing prevention,…) thanks to its by-products, replacing heavy conventional systems.

Some demonstrators have also been developed in the last 15 years worldwide. They have been installed in conventional aircraft trying to proof the feasibility of this technology as power generators in the aeronautical sector on flight, but it has also showed the challenges that have to be overcome before success in a safe and real integration on-board.

Installing a fuel cell system on an aircraft always involve some level on integration with other aircraft subsystems. Although the FC system were totally autonomous, generating a small quantity of electricity to a dedicated payload totally independent of the aircraft power sources, minor modifications are required; and demonstrate its safe operation in the aircraft environmental conditions is mandatory before getting any permit to fly. In the opposite side, the integration of a FC system used as primary electrical power source operating in tight connection with other subsystems imposes major modifications to the aircraft whit higher safety implications.

So the classification of this FC applications on board are faced according to the level of integration within the platform and the safety and reliability level of the function that the FC system provides. This classification will provide an idea of the level of complexity of the installation, integration, operation and maintenance of the FC system in a given application [5].

Most of the current prototypes are non-essential power sources (this means functions not critical for the airplane´s operation) that are not connected to the aircraft main electrical grid as galley power, medevac system power and electrical runway taxing. Applications for essential power sources has been also addressed like emergency power supply or APUs. All of them are proof of concepts, that has shown the feasibility of this technology as power generators in the aeronautical sector, but there is still some challenge before getting a fully ready-to certify FC system to use in aircraft flying environment for essential, and critical, functions.

Some examples of these applications are:

- Galley. A fuel cell system generates power and energy (and water) to galley loads as ovens, beverage makers, air chillers, lights…. This technology is ready for early market although some integration topics have to be addressed.

- Stand alone power. The system is self-contained and provide stand alone power, it can be installed and removed from the aircraft. This system can be used to power the payload of special aircraft with specific missions. The current demonstrators supplies power to a medical evacuation aircraft (medevac) but in this group electronic warfare o maritime surveillance mission equipment can be included powering weapons guidance systems or observation devices. It should be a “plug and play” system certified for several aircrafts. Major developments are required to optimize weights, volumes and safety operation.

- APUs. “Fuel cells cannot compete with gas turbine APU in foreseeable future as a form fit function replacement” [5]. But FC technology can be used for a new system to provide auxiliary power in a new More electric aircraft architecture including some traditional functions of the conventional APUs.

- Emergency power. A FC EPU provides power for essential loads when the normal sources for electrical power of the aircraft fails. It may substitute the Ram Air Turbine (RAT). FC technology could be used to support this application, but large transport airworthiness certification is still far away.

- Regenerative fuel cell energy storage. A regenerative fuel cell system is used to store energy from renewable source (solar or wind) and it supplies electricity when it is required. It has been used in solar power aircrafts, but the technology is still very far for large transport aircraft.

HYCARUS project has been one of this attempts to demonstrate the advantages and to analyze the handicaps of a generic H2 fuel cell auxiliary power units running on-board an aircraft. In this project, partially financed by the EU under the FP7 program (FP7/2012 GA Nº325342), a Generic Fuel Cell System (GFCS) was developed in order to power non-essential aircraft applications such as a galley in a commercial aircraft or to be used as a secondary power sources (medievac) on-board business jets.

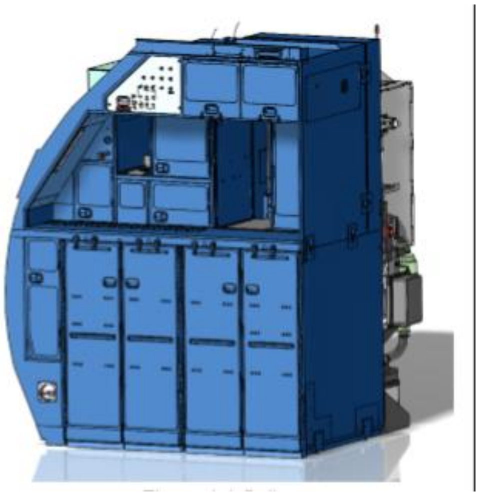

Figure 4-1: HYCARUS Project: Galley ZGEU.

5.0 AIRWORTHINESS QUALIFICATION OF A FC POWER SYSTEM

One of the targets of the project was to demonstrate the GFCS performances in relevant and representative cabin environment (TRL 6). To achieve this goal a flight test readiness process was delivered. Several tasks are inside this process: the definition of the test flight sequences; the definition of the system installation on-board the aircraft; the identification of the major types of modifications for the test aircraft to accommodate a proper operation (for example, there are adaptations required to proper manage the heat rejected by the Fuel Cell system or the hydrogen vented) and the physical implementation of them on the test aircraft, prior to the test campaign.

But, at the same time, a long task has been done to get the "permit to fly" of the experimental aircraft with the GFCS and the Hydrogen storage system on-board. In this case, as it was an aircraft for flight tests, the authorization to fly is given by the flight engineer. A long process to demonstrate the safe operation of the GFCS in the flight environment was performed. One of the main requirements, besides the Functional Hazard Assessment (FHA) and the System Safety Assessment (SSA), is to demonstrate that the GFCS comply with the performance standards of RTCA DO-160G addressing the mechanical, radio frequency and climatic flight environmental conditions. A qualification plan was defined and the environmental test campaign was carried out. This qualification process was based in civil standards, but the process and test procedures to follow in a military qualification are similar, varying the parameter limits according to the aircraft category.

The tests were divided into three main groups according to their nature:

- EMC and RF tests (DO-160 Sections 18, 19, 20, 21 & 25)

- Climatic tests (DO-160 Sections 4, 5 & 6)
- Mechanical tests (DO-160 Sections 7 & 8)

Figure 5-1: HYCARUS Project: RF radiated tests at INTA

As result we can say that the GFCS was designed so that it could properly and safely operate in representative mechanical, climatic and electromagnetic and radio frequency environments, at the levels required for the aircraft type where it was intended to be installed.

But yet, some deviations from the standard DO-160G had to be devised, due to the special features of the system:

- The high temperature limit had to be lowered, as the tests were conducted within a closed chamber that does not have the capability to take out the heat produced; the system was led to enter shutdown mode when it reached the high temperature alarm level.
- The altitude test could not be performed entirely, because of the inherent limitations on the capability to provide enough fresh air to feed the fuel cell while maintaining a low pressure environment in the chamber which requires it to be sealed closed.
- In addition, a protection had to be defined and implemented on the system to limit radio frequency susceptibility and to avoid some radiated emissions, so that it could sustain the levels dictated by the DO-160 standards

Some other technical challenges have also emerged from this project as the necessity of developing lighter components with the aeronautic certification, the advances on the technology are great, shown by the automotive market, but the use of fuel cells in aeronautic applications adds a certain number of constraints in terms of weight, reliability, robustness and compliance with the severe environmental conditions.

6.0 CERTIFICATION PROCESS

To have a fuel cell power system certified to fly in a large commercial aircraft means that it complies with the 14 CFR part 25 FAA regulation. Nowadays there are several technology and safety issues to overcome before to get the advantages of the fuel cell technology on-board these large aircrafts. Industrial developers have also identified a need to develop new and revised regulatory standards to ensure their safe design, installation and operation. Fuel cells have the potential to introduce multiple hazards once installed on board, some of them are the same than other systems in use today, but some are unique due to the new technology.

These hazards have to be analysed and mitigated.

But this work has already started, the FAA in conjunction with EASA has published a report containing the findings and recommendations to develop appropriate airworthiness standards and guidance material for energy supply device installations based on fuel cells on transport aircraft [5]. This document discusses the different airborne applications presented in section 4, and gives recommendations for regulatory standards and advisory material. The authors belongs to Governmental entities and Industries.

The development of smaller electric aircraft and UAVs and their regulation will also promote the improvements on these technology to advance on its airworthiness.

7.0 CONCLUSIONS

Use of fuel cells technology on-board has a promising future, a multifunction device that can replace conventional subsystems, generating not only electricity to supply the future hybrid electric aircraft, also heat or water. Its feasibility have been shown but challenges on the hydrogen management and on the compliance with the current and future airworthiness regulation have to be addressed. The use of fuel cells on military application is ongoing mainly in UAVs, but it seems that the integration of FC power system on board military aircraft will follow the civil industry developments and regulations, where ZERO emission requirement are stricter.

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