Fuel Cell system integration for aeronautic applications

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Abstract

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Abstract Fuel cells arouse growing interest for various applications, in both stationary and mobile domains. Meanwhile, aircrafts meet drastically increasing needs in terms of electrical consumption as their electrification progresses with new systems such as electric breaks, electric actuators, IFE, Green Taxiing... SNECMA (SAFRAN group) conceives, develops, assembles and tests Fuel Cell Systems (FCS) for airborne aeronautical applications. This paper presents in a first section a functional description of FCS and its equipments and underlines the key points of the system integration. Fuels integration and stack cooling are two main challenges for integration of FCS in aircraft environment. In a second part, the different competencies and tools implemented at SAFRAN are presented through an overview of “Fuel cell department” activities on FCS developments for airborne aeronautical applications. Introduction Fuel cell systems are arousing growing interest in the aeronautical research and industry [1-3]. Indeed, as a clean and efficient energy converter (water and heat as only by-products), fuel cells bring a smart and elegant answer to both the increasing need of electrical power onboard aircrafts and environmental concerns of today and tomorrow. A fuel cell converts chemical energy from a fuel (as hydrogen) and an oxidant (as oxygen) into electricity, heat and water. Unlike a battery, the reactants are not contained in the cells, but apart. Hydrogen is usually contained in a storage, oxygen can be provided from ambient air, or from a storage as well. In order to operate, a fuel cell requires auxiliaries, as reactants supply systems, cooling systems or control unit. Fuel cell development gathers many different competencies, such as electrochemistry, fluid mechanics, thermal science, mechanics, electricity and processes. Since 2004, SAFRAN conceives, develops, assembles and tests fuel cell systems for airborne aeronautical applications. Thanks to several projects, knowhow is gained, technology maturity increases and breakthrough allow to make the technology more and more competitive to others. In a first section, a brief description of fuel cell systems is given and their potential applications in aircrafts are listed and associated to various technologies of FCS. In a second time, the different competencies and tools implemented at SNECMA are presented. Integration of Fuel cell system into aircrafts Various applications of fuel cells for aircrafts are conceivable, from light aircraft propulsion [4] to airliners systems supply [1-3,5], such as electric breaks, electric actuators, IFE (In Flight Entertainment), Green Taxiing, APU (Auxiliary Power Unit), Emergency Power Supply... SAFRAN, as a major aircraft systems supplier and integrator, focuses on fuel cell applications for power generation in airliners. As shown in Table 1, applications can be classified within two categories: essential and non-essential, depending on their vital aspect for the aircraft’s security. Applications that failure would not compromise aircraft’s security are non-essential (IFE as an example). Those that failure would compromise aircraft’s security are essential. Class Application Power (kW) H2 mass (kg) FC type Non essential IFE ~30 ~3 PEMFC HT/LT Galleys ~20 ~2 PEMFC HT/LT Special aircraft ~15 1-3 PEMFC HT/LT Essential Actuators ~10 1-3 PEMFC HT/LT APU 50-200 10-50 PEMFC HT/LT – SOFC RAT ~15 1-2 PEMFC HT/LT Green Taxi ~50 1-2 PEMFC
HT/LT Table 1: Fuel cell potential applications for airliners and associated power and hydrogen mass required. Based on electrochemical reaction, a fuel cell system needs several functions to generate electricity (figure 1). One of the main components is the fuel cell stack, as electrical and thermal generator. Then, hydrogen and oxygen generators feed the anode and cathode compartments of the fuel cell stack with needed reactive regulation (pressure, flowrate). By-products (non-consumed reactive, water and heat) of electrochemical reactions have to be collected or evacuated. Even though the fuel cell stack reaches high electrical efficiency, it has to be cooled by an external source. The electric connection between FCS and aircraft electric grid is usually performed through an electric convertor. Anode Cooling Cathode H2 storage Air Electrical conditioning Control Unit Application Air supply system H2 supply system Cooling system Exhaust management system

Fig. 1: Example of a Fuel Cell System with auxiliaries. A Fuel cell stack consists in an assembly of several unit cells together, electrically connected in series and fluidly connected in parallel. Stack voltage depends on the number of unit cells and stack current depends on the cell active surface area, allowing to adjust stack power. Moreover, fuel cell stack performances depend on operating conditions. Indeed, internal conditions such as reactants properties (gas purity, reactive concentration, gas pressure ...), internal temperature or regulation point impact the electrical characteristic of the fuel cell stack (figure 2). As an example, a given stack would reach various electrical characteristics depending on the purity of reactants, as follow:

| PH2/O2 > PH2/air > Preformate/air. Voltage (V) Current density (A/cm²) H2/O2 H2/Air 1 2 Réformate/air 0, 3 1 0, 7 0, 6 iUSnP actcellel ... |

Fig. 2: Example of fuel cell electric response for various fuels and oxidants. Oxygen supply can be performed by different sources: air (cabin or exterior) or O2 storage (gas tank or solid storage). The nature of cathode reactant impacts the O2 partial pressure of the chamber and thus, the stack performance. Air cabin can be directly used thanks to an appropriate air blower. This equipment is mainly associated to high energetic FCS that should work either on ground or in flight. For high electrical power FCS, the recycling air cabin flowrate could be a limitation. Pure O2 compressed gas tank is an alternative solution to be independent of cabin internal pressure that usually varies with altitude. Various H2 sources are possible for onboard applications. As commonly chosen for automotive, High Pressure (HP) H2 storage seems to be an evidence for first aircraft fuel cell products. Nevertheless, other technological solutions (reforming and solid storage) are more and more studied, considering security aspects. Still, a large amount of work needs to be done in order to increase global mass efficiency of such solutions. Security is very seriously taken into account, especially concerning the management of high pressure hydrogen. The current lack of regulations for hydrogen onboard aircraft makes this task even more complicated. As a consequence, when conceiving and evaluating technological solutions relying on high pressure hydrogen, it is important to consider the whole fuel supply system impact. Electrochemical reactions are not efficient up to 100%. Depending on the running point, the stack (electrical box) needs to be cooled thanks a cold source. The availability of such cold source into aircraft could be a challenge or an opportunity for FCS integration for high power units. FCS by-products (unconsumed hydrogen, depleted air, water and heat) can be valorized in order to increase system’s efficiency. Heat can be recovered to for various needs, as well as water. Depleted air can be employed for kerosene tank inerting. By-products that cannot be valorized could require to be managed. Unconsumed hydrogen shall not be released inside the aircraft, risking to create an explosive atmosphere. Appropriate venting with sufficient flowrate and destination is one solution. Another solution is to dispose of a recirculation loop, increasing the system’s efficiency. When rejected to the exterior, unconsumed gases pressure needs to be controlled. Depending on the selected option, specific components are required, such as gas pumps, pressure controllers, solenoid valves, condensers or heat exchangers. SAFRAN’s Fuel Cell activities SAFRAN have structured its own R&D activity by creating a fuel cell department, which integrates key knowledge of its different companies dedicated to fuel cell system development. Thanks to it, SAFRAN conceives both the fuel cell stack and the overall system with necessary auxiliaries since 2004. Fuel cell stack development SNECMA company designs all SAFRAN’s fuel cell stack components except for MEAs (Table 2). The main objective of stack development is to meet high power densities, which is partially achieved by reducing the mass of components, mainly bipolar plates and end plates. Another key objective is to meet efficiency target by reducing the reactant consumption, which is achieved by optimizing the different fluidic circuits. Finally, optimizing the stack and its fluidic circuits also allows to reduce its impact on the auxiliaries mass and consumption. The fuel cell stack is dimensioned with respect to the power profile and depending on factors such as electric signal, efficiency, mass and life time. Up to today, PEMFC stacks designed by SNECMA reach very low specific density of 0.8 kg/kW at high current density (1A/cm²) and under standard conditions (H2/air) (figure 3). Component Objectives Tools Bipolarplates Reactant homogenization CFD Reactant pressure drop CFD/tests Coolant homogenization CFD Coolant pressure drop CFD/tests Heat extraction CFD/tests Electrochemical performance CFD-electrochem. /tests Mechanical resistance FEM/tests Mass FEM/material choice Gaskets Sealing FEM/tests/material choice End plates Mechanical resistance FEM/tests Mass FEM/material choice MEA electrochem. performance Specifications Life time Flexibility Table 2: Stack components, associated objectives and tools employed to ensure development. Fig. 3: Evolution of specific density of fuel cell stacks developed by SAFRAN. Fuel cell system development SAFRAN is developing energetic power plants based on fuel cell for multiple aircraft applications in a range of 5-50 kWe. Every FCS uses a fuel cell, which type is determined with respect to the targeted application, its conditions of use and integration requirements. SAFRAN has made many efforts on High Temperature Proton Exchange Membrane Fuel Cells development, as they present several advantages easing-up their integration and operation onboard aircrafts. HT-PEMFCs are tolerant to non pure hydrogen mixture as fuel, which allows system versatility. Another advantage of HT- PEMFC is that water is generated as vapor, which is easier to manage compared to liquid water, especially in aircraft environment. Finally, the heat to be evacuated is generated at higher temperature than common Low Temperature Proton Exchange Membrane Fuel Cell (nation-based LT-PEMFC), that is also easier to manage, because of the greater temperature difference with the cold source allowing enhanced thermal exchange. SAFRAN (Herakles company) develops systems fueled either by pure hydrogen from high pressure storage, kerosene reformate or by solid hydrogen gas generator.
For the cathode air supply, developments are carried-out (by Technofan company) to design specific compressors, characterized by high pressure ratios (2-3), oil-free functioning and certified. Electrical architecture and equipments such as wires and high efficiency converters are developed by Labinal Power Systems company to fulfill the particular requirements of fuel cells and aircraft, in terms of voltage levels and variations. LPS is also focusing their work on fast starting of FCS. Conclusions

Conception and regulation of fuel cell systems deeply depend on their application and on the environmental constraints. Onboard an aircraft, the current development objectives are to reduce the weight of fuel cell systems and to valorize as much as possible their byproducts, water and heat, that can be useful for various aircraft consumers. Thanks to its diverse activities in the domain of aircraft equipments, SAFRAN holds and gathers all the competencies required to understand aircrafts requirements and to adapt its fuel cell systems to these very specific applications.

References

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