Evaluations on hydrogen fuel cells as a source of energy for specific operations category civil RPAS systems

F. BONFANTE M. D. L. DALLA VEDOVA P. MAGGIORE
Department of Mechanical and Aerospace Engineering
Politecnico di Torino
Corso Duca degli Abruzzi 24 – 10129, Turin
ITALY
federica.bonfante@polito.it, matteo.dallavedova@polito.it
http://www.polito.it

Abstract: - This paper is on the evaluation of hydrogen fuel cells as a mean to enhance Remotely Piloted Aircraft Systems performances in terms of reachable range and endurance to integrate them into controlled airspaces operatively and safely. RPAS systems are raising deep interest within the civil aeronautical community for their advantages like, among the other issues, preserving human operators from safety risks in a variety of aerial operations. The European Aviation Safety Authority is elaborating a risk based concept of operations for which, RPAS sorties will be classified into open, specific or certified category operations according to the associated level of risk (from low to high level respectively). Among these categories, RPAS systems capable of specific level operations can represent concretely the kind of RPAS really capable of operational integration into controlled airspaces. Starting from these premises, this paper has been developed on the evaluation of hybrid propulsion systems based on hydrogen fuel cells as a possible source of power to enhance range and endurance of RPAS systems to operate into controlled airspaces. Main steps to size a fuel cell system to feed electrical motors of a fixed wing RPAS capable of specific operations category are listed and briefly described in this article. Then, a more extensive parametric model of a fuel cell power line based on operative and safety requirements for medium range/medium endurance RPAS systems is presented and discussed. Finally, main concerns related to the use of hydrogen are listed and discussed laying the basis for future development of this study.

Key-Words: - Controlled Airspaces, Endurance, Hydrogen Fuel Cell, Integration, Parametric Model, Range, Remotely Piloted Aircraft Systems (RPAS), Safety

1 Introduction

Remotely Piloted Aircraft Systems (RPAS) are currently object of in-depth studies and researches on the issues related to their full integration into the civil controlled airspace with manned aircraft. This is the natural consequence of the worldwide recognized utility of these aerial systems for civil applications. In fact, among the other advantages, they can be used to perform repetitive or dangerous aerial operations more quickly and with less effort and risks for the human operator. In Europe, the European Aviation Safety Agency (EASA) is directly committed to define the regulatory framework to achieve the full integration of RPAS with manned aircraft, aware of the economic potential of this new kind of aircraft. Such integration will be gradual, but arranged within a limited time window and divided into two timeframes, performing a sort of gradual accommodation towards the full integration [1]. The first temporal stage will be from present time to 2023. Due to the absence of regulations and industry standards to manage IFR capable RPAS and due to their initial low number, during the first timeframe of integration, RPAS will continue to be accommodated in controlled airspaces using FUA/AFUA techniques. For example, currently, this is a daily practice in Europe for military RPAS. It is expected that the essential SARPS will be issued by 2023. After this milestone, the second temporal stage will be from 2023 onwards. With the definition of proper rules, standards and supporting technologies, RPAS will be integrated into controlled airspace as any other aerial user, except for the fact that the pilot will not be on board. Consequently, "sense, detect and avoid" equipment will be necessary to interact with other manned or remotely piloted traffic. In fact, the mandatory requirement which lays at the basis of this complex regulatory and technical process of integration of RPAS into controlled airspace is and will be the safety. More precisely, the integration of RPAS must not affect the current level of safety reached by aerial transport [2]/[3]/[4]. From this principle, EASA is implementing a concept of operations for the integration of the RPAS with manned aircraft based on a risk-centric approach [3]. Three formal risk categories of operations have been defined by EASA in relation with RPAS sorties according to the level of risk of the considered operation: "open", "specific" and "certified", following an increasing level of operational risk. The "open" category covers RPAS systems of weight below 25 kg and authorized to fly until 500 feet of maximum altitude; the "specific" category includes RPAS systems capable of operations between 500 feet and flight level FL600; "certified" category will include RPAS systems capable of flight operations characterized by a risk level comparable to those of current manned aircraft.

In addition, RPAS systems are entering an aviation scenario that is going under heavy modifications according to the following new elements:

- the recent ICAO recommendations about safety and the mandatory adoption of a systematic way to manage it within aerospace Organizations using methodologies based on Safety Management System model [2];
- the ICAO re-organization of global airspace to make it more efficient in the management of traffic and to accommodate an increasing volume of aircraft maintaining the same level of safety [4];
- the issues raised by the so called 'green aviation' [5] related to the research for more efficient or carbon-neutral propulsion technologies.

According to the Authors, on the basis of the above mentioned elements, the most interesting and concrete level of integration of RPAS systems with manned aircraft is the case of RPAS performing specific operations. In order to make this scenario real, the increase of RPAS range and endurance performances is fundamental. This paper focuses on the evaluation of hydrogen fuel cells as a mean to enhance RPAS systems performances in terms of reachable range and endurance to perform specific risk category operations, and integrate them into controlled airspaces operatively and safely.

This article is structured as follows: Section 2 focuses on hydrogen fuel cells. After introducing some generic references to 'green aviation' and hybrid propulsion technologies, fuel cell principle of operation is described. Section 3 describes the main steps to size an hydrogen fuel cell system to feed electrical motors of a fixed wing RPAS capable of specific operations category; then, Section 3 shows a more extensive parametric model of a hydrogen fuel cell power line introducing and discussing strategic operative and safety requirements for medium range/medium endurance RPAS. Section 4 contains a discussion of the possible future development of the present study, and sums up the conclusions related to the topics presented in this work.

2 The hydrogen fuel cells

Green aviation is a trend diffusing in aeronautics according to the new sensitivity on environment concerns. Green aviation studies the impact of aviation on the environment, considering carbon and NOx emissions, and noise [5]. Green aviation can be intended both from the side of air segment of aviation, that is aircraft [6], and from the side of ground segment of aviation, that is airports and their ground facilities: for example auxiliary power units (APUs) to feed airplanes on ground before a flight [6]. Green aviation comprehends investigations on hybrid propulsions systems [7]/[8] as well as on renewable source of energy theoretically capable, among other advantages, to provide good results in terms of aircraft endurance, range, and optimization of fuel consumption.

The fuel cells [8] are electrochemical devices that convert the energy of a fuel (such as hydrogen, natural gas or other hydrocarbon-based fuels) directly into electricity. So, the principle of operation is the same as for traditional cells, but fuel cells use external source of energy to generate electricity with high efficiency. Fuel cells devices are composed of an electrolyte layer in contact with an anode on one side and with a cathode on the either side. The chemical reaction at the base of the operation of a fuel cell is an electrolysis reaction. More in detail, a chemical reaction of oxidation occurs on the anode side of the fuel cell, while a reduction is performed on the cathode side.

There is a variety of fuel cells available on the market. In this paper Polymer Electrolyte Membrane or Proton Exchange Membrane Fuel Cell (PEM FC) technology [8] will be considered, mainly due to their low working temperature (between -25°C and 75°C [9]) and to the very interesting properties of the polymer that composes the cell membrane. This technology was discovered in the 1960s, and over the decades and the applications (from powering a cellular mobile to a train locomotive) it has confirmed its simplicity of use and readiness to use. The above mentioned polymer membrane is characterized by a particular property: it is impermeable to gas, but it allows the passage of protons (hence the name 'Proton Exchange Membrane' also known with its commercial name Nafion®, made by DuPont Company). Such membrane acts as the electrolyte. It is inserted between the two porous conductive electrodes. The electrodes are made out of carbon cloth or carbon fiber paper. At the interface with the polymer membrane, the electrodes are upholstered with catalyst particles, usually containing platinum [8] (Figure 1, from [8]). Electrochemical reactions of interest occur at the surface of the catalyst at the interface between the electrolyte and the membrane. Hydrogen, fed on one side of the membrane, splits into its primary particles, protons and electrons. The protons go through the membrane. The electrons travel through the electrically conductive electrodes; they cross the collectors, and enter the outside circuit where they perform useful work. Then they continue returning to the other side of the membrane. On the catalyst sites of the membrane towards the other electrode they meet with the protons that went through the membrane and oxygen that is fed on the other side of the membrane generating water by mean of an electrochemical reaction. Finally they are pushed out of the cell with an excess flow of oxygen. As final product of the described process a flow of direct electrical current results [8]. This process is graphically shown in Figure 1.

In Figure 1, the side with the hydrogen is electrically negative and corresponds to the anode; the side with the oxygen is positive and is the cathode. The above described basic chemical reactions that occurs within a fuel cell are each one detailed hereinafter [8].

The anodic chemical reaction (hydrogen side) is the following:

$$H_2 \rightarrow 2H^+ + 2e^- \tag{1}$$

The cathodic chemical reaction (oxygen side) is the following:

$$½\, O_2 + 2H^+ + 2e^- \rightarrow H_2O \tag{2}$$

The overall chemical reaction is the following:

$$H_2 + ½\, O_2 \rightarrow H_2O \tag{3}$$

The maximum amount of electrical energy generated by a fuel cell can be calculated, according to the Gibbs free energy formula, as [8]:

$$W_{el} = -\, \Delta G \tag{4}$$

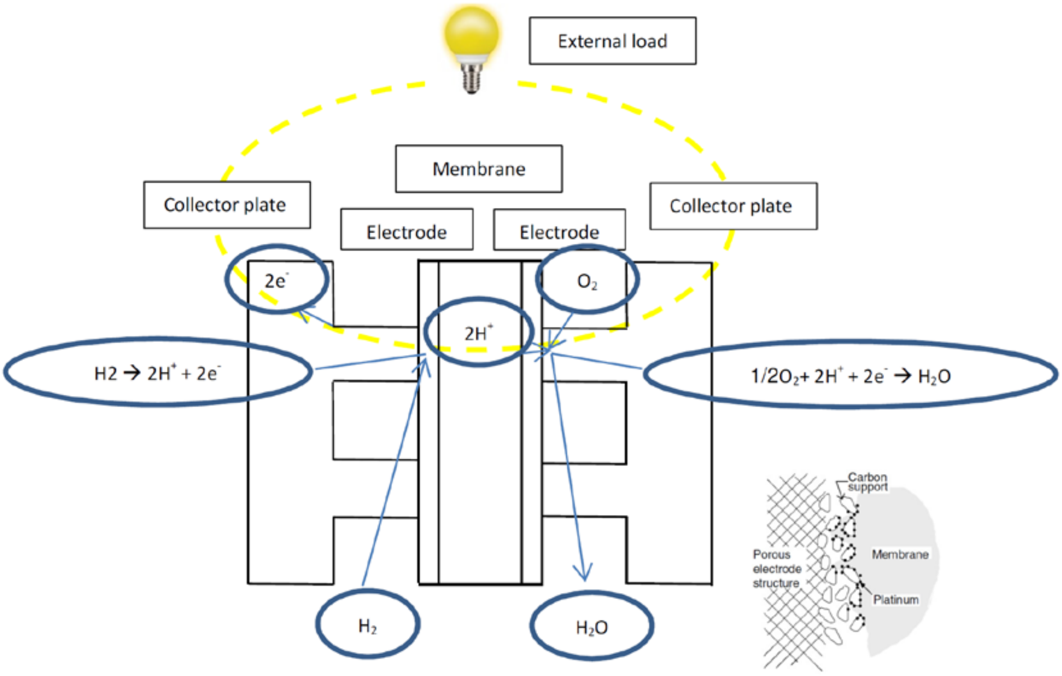

Fig. 1: The basic principle of operation of a PEM fuel cell (from [8])

The theoretical potential E of the fuel cell is [8]:

$$E = - \Delta G/nF \quad (5)$$

Where, ΔG is the free energy of the reaction (equal to 237,340 J mol-1), n is the number of electrons involved (two, in this case) and F is the Faraday's constant (equal to 96,485 Coulombs/electron-mol).

The electrical potential of a fuel cell, at 1 atm of pressure and 25°C of temperature is:

$$E = - (-237{,}340 \text{ J mol-1})/(2 \times 96{,}485 \text{ Coulombs/electron-mol}) = 1{,}23 \text{ V} \quad (6)$$

A value of electrical potential of this order of magnitude is typical of fuel cells; in other words a single cell usually generates very low potential differences and very low currents. For this reason they are usually connected either in series, or in parallel, to form a stack, in such a way that necessary quantities of power can be generated, depending on the requirements [8].

The fuel cell stack requires other components to complete the system: the fuel cell processing section or balance-of-plant (BoP), the power section (that is the components surrounding the stack itself), the power conditioning unit and the control unit [8]. The fuel processing section is required to produce a hydrogen-rich and possibly desulfurized gas. The power-conditioning unit converts variable DC into a regulated AC current, with a specific frequency, active and reactive power; in addition, it acts as feedback to control the fuel flow to the stack [8].

3 Parametric model of a hydrogen fuel cell power line for medium range/medium endurance RPAS systems

The object of this paper is the description of a parametric model of a fuel cell power line based on operative and safety requirements for medium range/medium endurance RPAS systems. According to the Authors, RPAS systems capable of this level of flight performance, can reasonably be able to perform specific risk category aerial sorties according to EASA/JARUS RPAS concept of operations [1]/[3]. Before focusing on this topic, main steps to size a fuel cell system to feed electrical motors of a fixed wing RPAS are listed and briefly described. A high aerodynamic efficiency fixed wing RPAS is supposed to be the most suitable application because rotor wing RPAS usually fed, at the moment, by Lithium Polymer (LiPo) batteries only, in the opinion of the Authors cannot achieve the desired performances (even if some cases have been recently reported [18[and [19]).

A possible realistic mission profile has been defined (Figure 2, from [9]), to calculate the RPAS power necessary to accomplish it. The mission profile is so defined: after take-off and climb the RPAS is required to navigate at its design cruise speed until descending towards the mission area where the payload will be operated. After the survey over the mission area, the flight profile foresees a second climb to come back to cruise altitude and cruise speed, until reaching the waypoint for the final descent, approach, and landing. According to the UVS categorization of RPAS, a medium range /medium endurance RPAS is expected to fly over more than 500 km of range and for a period of time up to 10 ÷ 18 hours [10].

The architecture of the considered RPAS power line is shown in Figure 3 (from [11]). The fuel cell is the primary source of energy for the RPAS and it is fed by the hydrogen contained in the tank and by the oxygen contained in the air to generate electric current. The principle of working of the hydrogen PEM FC fuel cell has already been described in Section 2. The fuel cell and the LiPo battery are connected in parallel between them to the DC/DC transformer. This equipment provides the correct potential difference to work to the RPAS loads through the DC power bus. The DC power bus is the component of the line able to select the source of power to use: the fuel cell will be mainly used during the whole flight mission. The LiPo battery will be requested to work by the power bus in case of high demand of energy. The DC power bus also has the function to protect the LiPo battery functionality avoiding extreme discharge cycles.

The main steps to size the power line in object are the following ones [11]:

1 - Determination of the total energy associated to each phase of flight: for each stage of the mission the total energy (ΔE_{TOT}) is calculated as function of the kinetic energy (ΔE_c), of the variation of potential energy (ΔU) and of the quantity of energy wasted for the aerodynamic drags (L_{DRAG}) as follows:

$$\Delta E_{TOT} = \Delta E_c + \Delta U - L_{DRAG} \quad (7)$$

The air density is supposed varying with altitude according to the following relation: ρ =1,2257 x ((288 - 0,0065 x h)/288)^{4,2561} [11].

2 - Determination of the electrical power requested to the power line during each phase of flight: the electrical power requested for stage of the mission is determined as follows [11]:

$$P = (W * V)/(E * \eta_P) \quad (8)$$

where W is the aircraft weight, E is the aircraft aerodynamic efficiency (equal to the ratio Lift/Drag = C_L/C_D); V is the aircraft flight airspeed and η_P is the propulsion system efficiency. The peak of

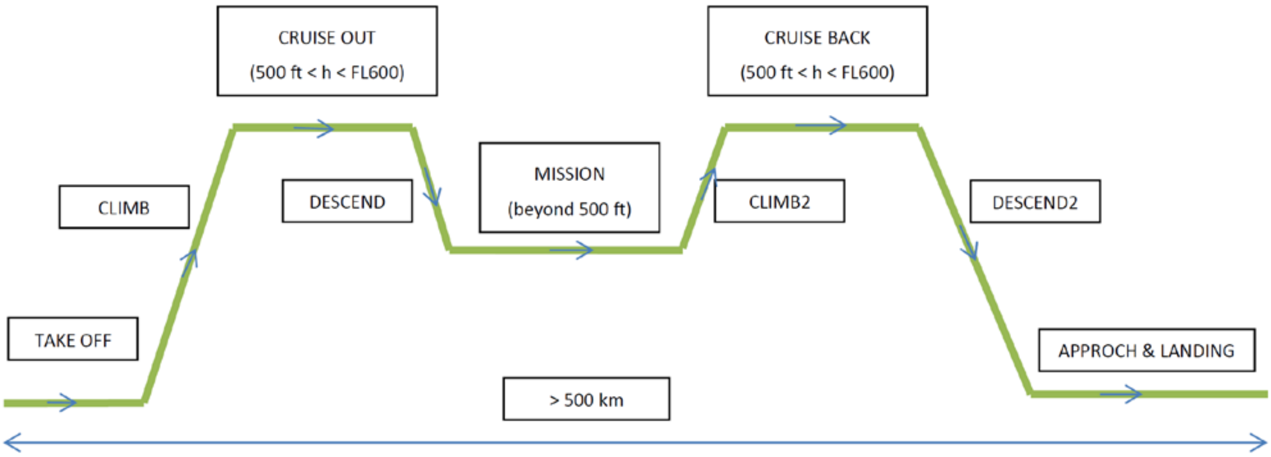

Fig. 2: Example of Remotely Piloted Aircraft Systems (RPAS) mission profile (from [9])

the requested electrical power occurs during the take-off and climb phases of flight. The total value of requested electrical power is equal to the sum of all electrical power values requested for the flight [11].

3 - Energy allocation: the energy necessary to perform the flight operation is allocated between the hydrogen fuel cell system and the LiPo battery [11]: the total amount of energy requested during the most demanding phases of flight (take-off and climb) is equal to the sum of the energies requested for each single phase; the sum is considered twice for safety, as follows:

$$E' = [2 * (E_{TAKE\text{-}OFF} + E_{CLIMB})]/\eta_P \quad (9)$$

This quantity of energy is split between the fuel cell and the LiPo battery according to the following expressions:

$$E'_{FUEL\_CELL} = E' * P_{FUEL\_CELL\_MAX}/P_{MAX} \quad (10)$$

$$E'_{LiPo} = E' * (1- P_{FUEL\_CELL\_MAX}/P_{MAX}) \quad (11)$$

where E'_{FUEL_CELL} is the total energy requested to the fuel cell and E'_{LiPo} is the total energy requested to the LiPo battery

4 - Determination of the volume and mass of hydrogen to feed the fuel cell: for a given size of electrical power requested to the fuel cell [11]: the quantity of necessary hydrogen in terms of volume and mass is determined as follows:

$$V_{H2} = q_{H2} * E'_{H2} \quad (12)$$

$$m_{H2} = (\rho_{SL} * V_{H2} * M_{H2})/(RT_{SL}) \quad (13)$$

where q_{H2} is the hydrogen volume specific consumption (measured in L/min/kW or m^3/J); the mass of hydrogen is calculated with reference to the sea level, at ISA conditions.

5 - Determination of the mass of the LiPo battery [11]: for a given size of electrical power requested to the LiPo battery, the mass of the battery can be determined as follows:

$$m_{LiPo} = E'_{LiPo}/\ e_{LiPo} \quad (14)$$

where e is the LiPo battery specific energy (measured in kJ/kg).

This methodology leads to more general considerations and to a more comprehensive parametric model that helps identifying parameters and conditions necessary to make fuel cell a real option to integrate RPAS systems into controlled airspaces (Figure 4).

Two kinds of parameters are identified: operational parameters and safety parameters.

Operational parameters are: RPAS weight, RPAS airspeed, RPAS airframe shape including scaling factors and aerodynamic efficiency; factor of utilization of the fuel cells with respect to the redundancy; the power line efficiency, function of the fuel cell efficiency and of the conditions of flight (altitude, pressure, temperature); logistics for hydrogen supply.

Safety parameters are related to the integration of the LiPo battery in the power line as a redundant source of energy with respect to the fuel cell used as the primary one.

Considering RPAS weight parameter, as a first estimation, the power requested to the fuel cell can be assumed to be directly proportional to the weight of the aircraft for a given set of design performances. An RPAS of greater weight requests more power to the propulsion system to satisfy the same performances. Even if considering the high efficiency of PEM fuel cell (equal to 52% [11]) to convert chemical energy in electrical energy and the high energy content of hydrogen, due to the lowest density of hydrogen, large volumes of it can be requested. For aeronautical applications as well as for automotive ones, the common and consolidated practice is to store hydrogen at the gaseous state inside appropriate tanks at very low temperatures and high pressure to increase density [11].

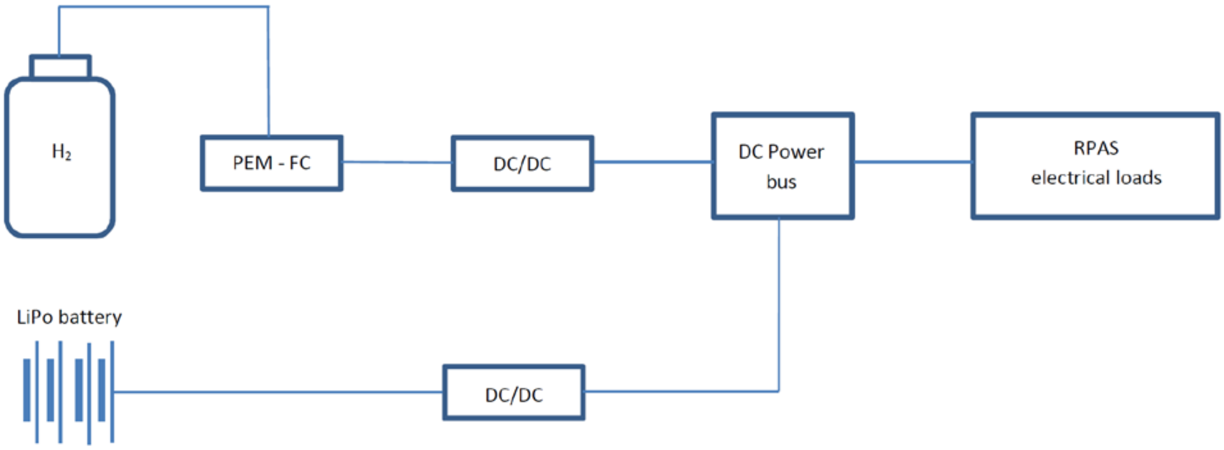

Fig. 3: Fuel cell system architecture (from [11])

In the worst case, the weight of the fuel power system can affect RPAS flight attitude and performances. The best compromise shall be found among these parameters [11]: the quantity of hydrogen to be stored into the tank to perform mission profiles; the resulting dimensions of the tank; the volume size of the tank with respect to the space of the RPAS where it will be located; the total weight of the tank due to the greater thickness of its walls to contain the internal (high) gas pressure. It is to be noted, that for the above mentioned considerations the sizing of the hydrogen tank can be recognized as the most delicate phase when designing a fuel cell power line. As a general requirement, the best combination of pressure and volume of the hydrogen tank shall be calculated with regards to an accurate evaluation of the RPAS global flight performance [11].

RPAS airspeed and aerodynamic efficiency have impact on the request of energy to the power line during the cruise phases, that is during most of time of flight. Aerodynamic design solutions able to assure high values of efficiency and scale factors [12]/[13] that positively influence the efficiency of the RPAS through different airframe dimensions shall be preferred. In fact, for given desired values of flight range and endurance, efficiency influences consumption and sizing of the power line.

The power line efficiency depends on the efficiency of the fuel cell and of the other components of the fuel cell system [8]. The fuel cell efficiency is the ratio between the electricity produced and the hydrogen consumed and is directly proportional to its potential.

With reference to the factor of utilization of the hydrogen fuel cells with respect to the redundant LiPo battery, the fuel cell is sized to work and to serve the RPAS for the whole mission while the battery is mainly foreseen to provide necessary power supplement for most demanding stages of flights [11].

Flight altitude, pressure and temperature conditions are factors with a huge impact on the fuel cells performances. For example, Figure 5 (from [13]) referring to flight tests performed by Politecnico of Turin for the research project 'Green Glider' (an innovative all electric ultralight motor glider with electrical motor fed by hydrogen fuel cells) shows that voltage of hydrogen fuel cell decreases with altitude. On the basis of this statement, and considering that the fuel cell efficiency is a function of the cell voltage according to the following expression [8]

$$\eta_{FUEL\_CELL} = V/1{,}482 \tag{15}$$

it is reasonable expecting that fuel efficiency as well decreases with altitude. So stable conditions of altitude and pressure would be better for the work of the fuel cell. Pressure conditions that lead to loss of hydrogen (diffusion through the membrane of the fuel cell, combination with oxygen that diffuse through the membrane, internal currents) or hydrogen in non-stoichiometric quantity, imply decrease of the fuel cell efficiency according to the following relations respectively:

$$\eta_{FUEL\_CELL} = (V/1{,}482) * (i/(i + i_{loss})) \tag{16}$$

in case of loss of hydrogen [8], and:

$$\eta_{FUEL\_CELL} = (V/1{,}482) * \eta_{fu} \tag{17}$$

in case of hydrogen in non-stoichiometric quantity; in (17) η_{fu} is the fuel utilization, equal to the inverse of the stoichiometric ratio [8]. Temperature of the

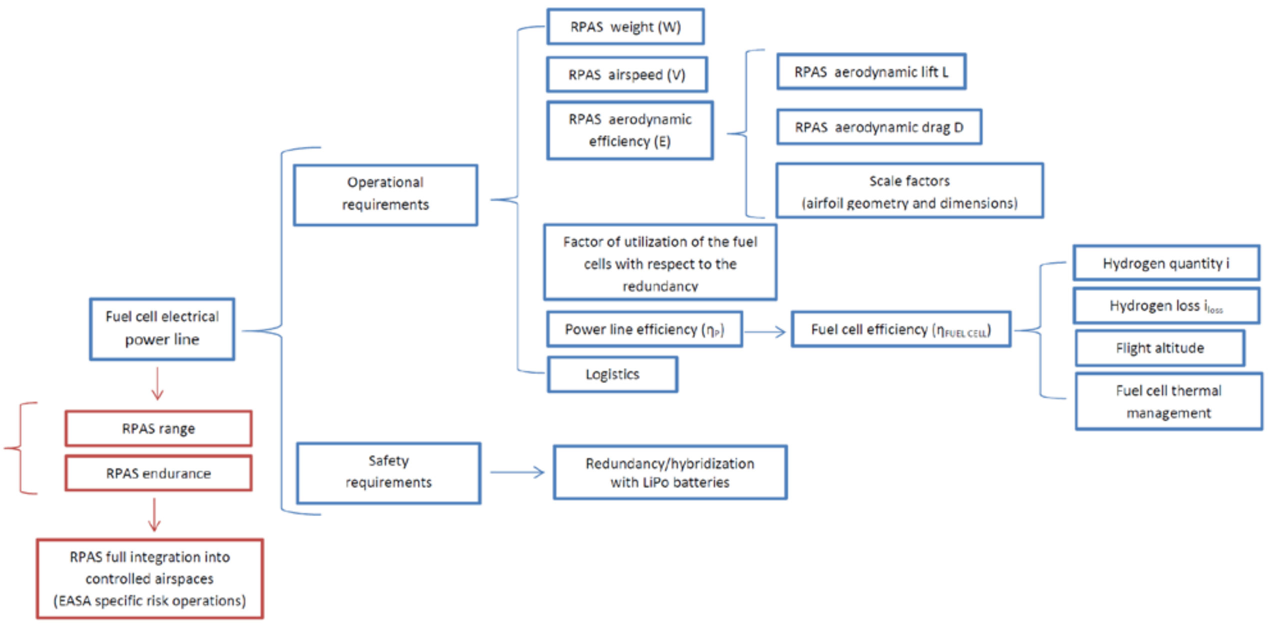

Figure 4 – Fuel cell power line parametric model

Hydrogen fuel cell shall be kept within a suitable range by mean of thermal management of the fuel cell [14]. Too high fuel cell temperatures would cause water evaporation and drying of the membranes. In this case, no hydrogen ion conduction though the membranes would be possible. Too low fuel cell temperatures would avoid water condensation inside the stack. This condition impedes the gas diffusion and the transport of the reactants to the membranes [14].

Hydrogen fuel cells installed on board RPAS will need for refurbishment supported by a strategic logistic to make these hybrid aircraft RPAS capable of regular/daily specific operations in controlled airspaces. In fact, hydrogen fuel cells installed on board RPAS are the most evident component of a future integrated logistic infrastructure able to produce, transport and storage hydrogen to make it available in airports operated by RPAS together with manned aircraft as well as it currently occurs with kerosene. Hydrogen is produced from hydrocarbons by mean of stem reforming or from water by mean of electrolysis [15]. Main concerns related to hydrogen logistics are about its transportation and are closely related to its physical properties. As it happens for natural gas, hydrogen can be transported in liquid or gaseous state. Considering hydrogen at liquid state, it can be stated that the minor losses during transport and the higher volumetric storage density imply less frequent refill of stationery tanks with liquid hydrogen, even if energy is spent to liquefy hydrogen at temperatures of 21 K and at pressures of 1.3 MPa. Major concerns for supply of hydrogen at gaseous state are related to the higher energy expenditures caused by density of hydrogen that is the lowest one among all chemical elements [15]. With reference to new logistic infrastructure for hydrogen refurbishment, common pipelines could be implemented to make hydrogen available both to refuel hybrid RPAS and for example to feed APUs on ground [6] reducing their fuel fossil consumption and noise. In addition, hydrogen could be used to feed hydrogen fuel cells installed on possible hybrid manned aircraft sized to perform at least on-ground movements again reducing noise, and saving more fuel for flight [6].

From a functional viewpoint hydrogen fuel cells result to be more reliable than, for example, small internal combustion engines, with a higher MTBF (up to 5 times according, for example, to [16]). A redundant LiPo battery working in parallel to the fuel cell system enhances the safety of the power line. In addition brings other benefits to the functionality and performance of the whole power line. In fact, due to its high power density, the LiPo battery easily provides the excess of power requested during the most demanding phases of flight ([11] and [17]) remaining in stand by for the rest of the time like during cruise stages when significantly low power is requested ([11] and [17]). Configuring the power line with a LiPo battery working as an active redundancy of the hydrogen fuel cell avoids PEM FC oversizing; hydrogen fuel cell and overall power line weight restraint is saved [17]. The resultant technical solution is more efficient and flexible ([11] and [17]). System safety is further preserved thanks to the LiPo battery prompt capability to immediately response to sudden variations of electrical power demand. This is due to LiPo battery power density that is higher than fuel cells, known to be characterized a slow dynamics. From the viewpoint of the fuel cell this disadvantageous feature is necessary as well in order not to damage the membrane by mean of fuel or oxygen starvation [17].

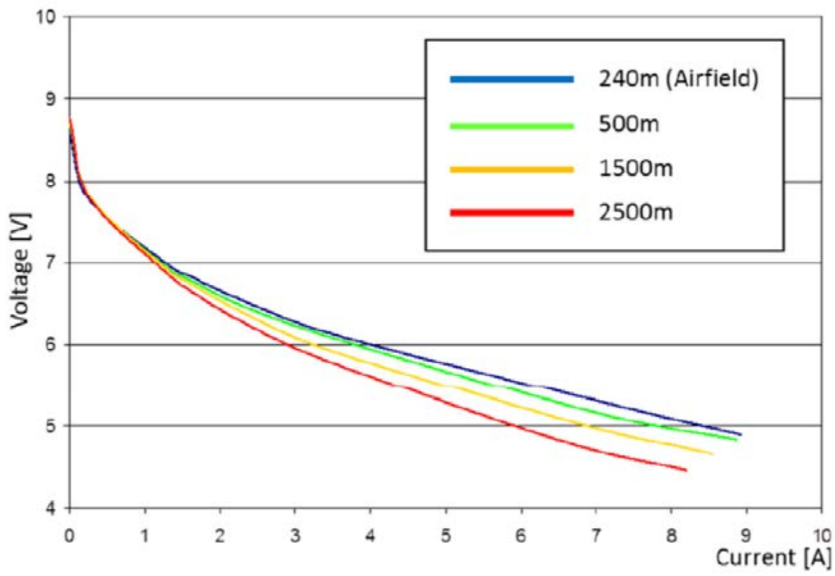

Fig. 5: Flight tests on a 100W hydrogen fuel cell: polarization curves at different altitudes

[Politecnico of Turin, 'Green Glider' Research Project (2012) (from [13])]

4 Discussion and conclusion

The arising issue of integrating RPAS into civil airspace requests to overcome the technological barriers that limit RPAS performance in terms of range and endurance of flight [16]. Without relevant flight capabilities a real integration of RPAS into manned airspaces cannot be possible. This is a technical problem strongly related to the propulsion systems that equip current civil RPAS systems.

Studies on new solutions to enhance RPAS range and/or endurance are going on concurrently with the studies to develop RPAS systems compliant with EASA requirements and regulations for specific operations within controlled airspaces

One of the most promising technology is related to the use of hydrogen fuels cell as showed by the various RPAS technological demonstrators equipped with this kind of propulsion system built and flight tested [17].

According to the experimental results, power line based on hydrogen fuel cells showed durability, range perspective, more reliability with respect to small internal combustion engines, safety and need for low maintenance. In addition, RPAS systems powered by fuel cells have demonstrated to be able to operate longer than those fed by batteries only too ([16] and [17]).

Many issues related to hydrogen fuel cell as a source of energy to really integrate RPAS into controlled airspaces have been raised and discussed in this paper.

The storage of hydrogen on board the RPAS is a critical factor both in terms of weight (hydrogen tank weight, choice of proper resistant but light weighted materials to build the tanks), resulting aircraft flight performances, available spaces to locate it and in terms of safety, posing delicate questions to face during the design of hybrid RPAS.

With reference to safety, the presence of hydrogen on board the RPAS introduces a potential hazard related to the risk of formation of explosive mixtures that shall to be considered, quantified and managed. In fact, hydrogen, as an energy carrier, is flammable [15]. Pure hydrogen is not explosive or reactive, but it can be in presence of oxidizing gas like oxygen or chlorine [15].

Considering the overall power line, critical elements are the optimization of the power allocation/management between the hydrogen fuel cell and the LiPo battery or other possible redundant sources of energy. In fact, while performing aerial operations into controlled airspaces, RPAS systems will face a variety of flight contingencies. Therefore a proper dynamic response of power management systems to the aircraft power demand shall be deeply investigated [17]. The use of real technological demonstrators and the performance of flight test activity is suggested.

On ground the most critical issue is the implementation of a proper network and logistic infrastructure to transport and store hydrogen to regularly refuel RPAS for flight sorties.

In conclusion, in order to lay realistic technical basis for RPAS integration into controlled airspaces, this paper proposes the use of Proton Electron Membrane Fuel Cells (PEM FC) as primary source of energy for a medium range/medium endurance fixed wing RPAS. Main operational and safety issues related to the design of hydrogen power lines able to provide such performances have been presented and discussed.

Hydrogen propulsion can be a feasible solution to make RPAS perform specific risk operations as defined by EASA into controlled airspaces.

Beside the above statement, the following issues raised in this paper need further investigations:

- the safety risks caused by the flammability of hydrogen and the risk of explosion in presence of oxidizing gases;
- the need of more systematic studies about the power allocation/management between the hydrogen fuel cell and its redundancy for an optimized dynamic response to contingences potentially occurring during future RPAS ordinary commercial flight activity;
- the implementation of a suitable network/logistic infrastructure on ground to refurbish hydrogen for regular flight activity.

List of abbreviations

AC	Alternate Current
AFUA	Advanced Flexible Use of Airspace
AR	Aspect Ratio
BoP	Balance of Power
CD	Coefficient of aerodynamic Drag
CL	Coefficient of aerodynamic Lift
DC	Direct Current
EASA	European Aviation Safety Agency
FL	Flight Level

FUA	Flexible Use of Airspace
ICAO	International Civil Aviation Organization
ISA	International Standard Atmosphere
IFR	Instrumental Flight Rules
JARUS	Joint Authorities for Rulemaking on Unmanned Systems
LiPo	Lithium Polymer
MTBF	Mean Time Between Failures
PEM FC	Polymer Electrolyte Membrane or Proton Exchange Membrane Fuel Cell
RPAS	Remotely Piloted Aircraft Systems
SARPS	Standard and Recommended Practices
SL	Sea Level
SMS	Safety Management System

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