Test performance of a fuel cell based power plant for a high altitude light unmanned aerial vehicle

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Introduction

Aerial vehicles powered by fuel cells (FC)are being developed in response to the demand for newer, more efficient methods of energy supply which generate fewer pollutant emissions. The use of fuel cells in crewed airplanes is still a future objective [1,2], but manufacturing unmanned aerial vehicles (UAVs) with this power plant can be achieved with current technology.

Depending on the weight, flight ceiling and size, UAVs can be classified as Micro, Tactical, Strategic or Special Task UAVs [3]. The Strategic class of UAVs can be designed to reach high altitudes, flying up to 65 000 ft (20 000 m), andtypically weigh more than 600 kg [4]due to the weight of the power plant (PP). High altitude flights impose some specific challenges related to particular atmospheric conditions. Atmospheric pressure at an altitude of 10 km is only 0.26 bar, with oxygen partial pressure of just 0.05 bar. This causes some restrictions in the operation of the internal combustion engines (ICE) as the low intake reduces volumetric efficiency and therefore delivered power [5,6]. This power loss increases with flight altitude. This is more evident in small cylinder capacity ICEs because in large ICEs this issue can be solved using an intake compressor. This compressor consumes a significant proportion of generated power and increases the total mass of the UAV, which cannot be permitted in small UAVs.

The combined use of electric motors and FC in small UAVs can be an advantageous alternative to small ICEs. Electric motors are more efficient than small ICEs, for any rpm range. In addition, FC can be designed to operate at high altitudes taking into account the special requirements for this application.

Figure 1. Medavia S.L. UAV prototype

The objective of the present work is to develop and test a FC-based power plant designed for an existing UAV prototype, manufactured by Medavia S.L. (figure 1).

The UAV prototype uses a 1.1 HP hybrid-PP, based on an ICE, fueled by ethanol or gasoline. The total mass of the UAV is 10 kg and the wingspan is 4 m.

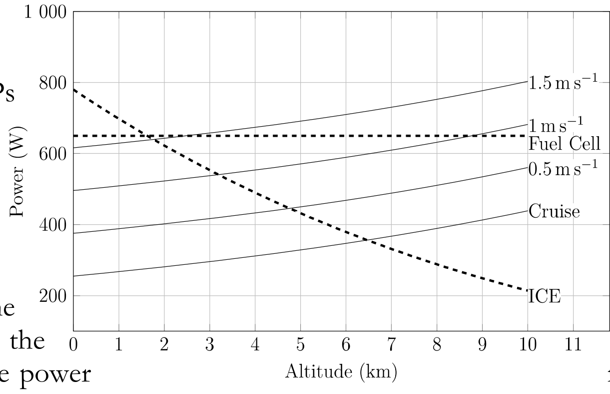

Figure 2. Required power as function of the altitude for different climbing speeds

Figure 2 shows the power requirements for different PPs and flying conditions. The solid lines reflect the required power for the prototype as a function of the altitude for different rates of climb (0.5, 1 and 1.5 m/s) and for cruise flight. Required power for cruise flight is the minimum power needed to keep stable flight at each altitude.

The dashed lines represent the available power at the propeller for both possible power plant sources. Namely, the dashed line which decreases with altitude shows the available power for the ICE based power plant. The dashed line which remains stable with altitude reflects the available power for the power plant based on a FC, carrying not only the hydrogen but also oxygen on-board.

The meeting point between the cruise line and the available power line for each power plant is known as the absolute ceiling, which is the maximum theoretical altitude that can be achieved with this technology. The absolute ceiling for the ICE based power plant is around 6 500 m, but for the FC based power plant the ceiling is over 10 000 m.

Power plant design

The PP has to release enough energy to achieve the service ceiling of 10 000 m. Attending to the aerodynamic parameters of the existent UAV, and considering some possible structural modifications; the power released to the propeller must be over 422.5 W. Considering a linear design for the PP (figure 3), the power efficiency can be calculated as the product of the component efficiencies. Using the most conservative calculations for each component, global efficiency is 65%.

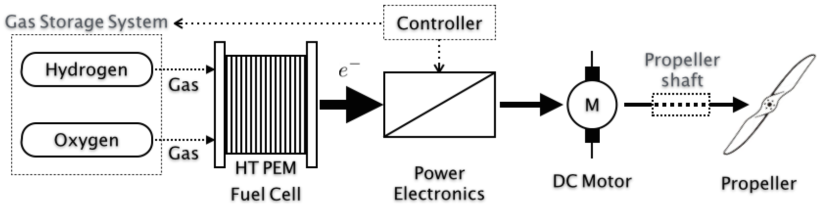

Figure 3. Block diagram of the power plant

For this theoretical efficiency, the FC electrical power must be over 650 W [6].The FC used in the power plant was manufactured in CSIC-LIFTEC laboratories (Zaragoza), using high temperature Celtec® P-1100 membrane technology (figure 4). The final design is a 35-cell stack with a rated power of 780 W [7]. This is considered sufficient to absorb possible perturbations during the flight. High temperature PEM technology is used due to the simplicity in thermal and water management strategy. The high temperature fuel cell works over 150ºC and the membrane does not require water for the electrochemical reactions; all the water can be exhausted as vapor. The exterior temperature is, in all conditions, lower than the temperature of the FC. This permits the use of a simple air cooling system, using a control to force the exterior air to flood the FC chamber [8]. In addition, the high operational temperature can be used to maintain the interior of the UAV warm in order to protect the electronics in colder conditions at high altitudes (-50ºC at 10 000 m).

Power plant assembly

The climbing strategy determines energy consumption. It was demonstrated that the most efficient strategy is climbing using constant power delivered to the propeller. For the estimated power, 650 W, the climbing time is 2.2 h, therefore the energy requirement is 3600 Wh (considering a FC with an electrochemical efficiency of 40%). Using available compressed gas storage technology, the volumes required are 4 L for hydrogen and 2 L for oxygen at 300 bar.

Using commercial components, the FC-based PP is assembled and tested in two different conditions, at sea level and at 10 000 m. The test reflects the changes needed in the temperature control algorithms as a result of different atmospheric conditions. Testing of the gas storage system demonstrates the maximum endurance possible in laboratory conditions.

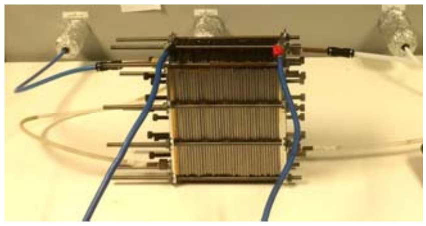

Figure 4. 35-cells high-temp PEMFC manufactured at LIFTEC

Hybridization with ultra capacitors or batteries can enhance the real endurance, and ensure flight safety in adverse wind conditions because of the extra power available. Both storage systems can be recharged during cruise or descending flights, when FC voltage is high.

Acknowledgements

This work has been partially funded by the Secretariat of State for Research of the Spanish Ministry of Economy and Competitiveness under project ENE2012-38642-C02-01/CON.

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