Weight and Electrical Response Tradeoffs of PEMFC Hybrid Power Sources for APUs

Introduction
During the last few years, aircraft have become increasingly more electric and this trend is expected to continue well into the future as cost and weight advantages drive the market towards cheaper and more efficient aircraft. More Electric Aircraft will contain ever more electric actuators and cabin features and will need more cost efficient power, both on the ground and during critical in-flight operations [1]. Fuel cells (FC) provide an efficient, clean, and quiet means of generating electric power and are an alternative to other types auxiliary power units (APUs) such as turbogenerators or large batteries. Since aircraft safety is critical and weight is limited, all new systems must be tested not only to comply with strict electrical standards [2], but also they must be optimized with respect to weight and fuel consumption. Incorporating a FC into an aircraft system will require an additional power dense energy source, such as a battery, to permit fuel cells that have inherently slow power response times to comply with aircraft electrical standards. The slow response of a polymer electrolyte fuel cell (PEMFC) [3] is contrasted with the fast response of a lithium ion (LI) battery in Figure 1 [4].

![Figure 1: Response of LI battery and PEMFC to step load changes.](image)

The LI battery responds immediately to the load increase while the PEMFC takes several seconds to ramp up. By creating a hybrid source with both a battery and FC, the system can react more quickly while still taking advantage of the clean and efficient energy provided by the FC. Efficient energy generation by the APU is important for large loads on the ground such as the cabin air conditioning, however the APU’s secondary, and more critical, use is for emergency power in-flight which may require fast and uninterrupted electrical responses.

This paper evaluates the tradeoffs between a more energy dense hybrid system, i.e. a larger fuel cell, and a more power dense hybrid system, i.e. a larger battery, for ground supply on an aircraft. First, the polymer electrolyte fuel cell and lithium ion battery hybrid power source weight is minimized, which results in an increased electrical response time barely complying with aircraft electrical standards. Next, the response time is optimized which results in a heavier overall system. Simulation results from the Virtual Test Bed reveal the electrical and thermal steady state and transient responses of the system. The tradeoffs of both configurations are then discussed.
FC hybrid systems for aircraft are not conceptually new. Fuel cells have been on space vehicles for years, and currently Boeing is working on a Diamond Dimona motor glider completely powered with a PEMFC and Li battery hybrid system. The purpose of the glider project is to learn more about the “balance of plant” of the fuel cell system and evaluate the storage and safety of hydrogen on aircraft. This knowledge will then be transferred to the development of FC powered APU’s for aircraft [5]. Additional examples of previous work in FC and battery-hybrid power system optimizations have been done to optimize the hybrid power source through active control [6] and through energy recovery [7]. Other studies have evaluated the efficiency of several different hybrid systems for vehicular APU’s [8].

Method
The two tradeoffs considered in this paper are weight reduction and electrical response time to a step load change. In order to simplify this study, it was assumed that the PEMFC was fed from a direct-hydrogen source rather than a reformer. The data for the weight of a PEMFC is from [9], which gives the power density of the PEMFC stack at 1,400 W/kg (for an 80 kW PEMFC) with a pure hydrogen source. The weight of the lithium ion battery is 1,800W/kg according to [10]. Both power density values are based on 2005 estimates. The PEMFC stack and battery was then sized to accommodate the load profile and power quality specifications.

The hybrid power source must be capable of both quickly reaching, and sustaining, any power level in between zero and the peak power demand of the load. These two requirements translate to voltage recovery time and the power rating of the system. The specification for a voltage transient on the 28 V DC bus is given by MIL-STD-704E and is shown in Figure 3. From this chart it was extrapolated that the hybrid power source must supply voltage with a rise time of less than approximately 0.1 seconds.
Figure 3: Envelope of normal voltage transient for 28V DC [2]

The minimum power rating of the hybrid power source was calculated from the load profile. The hybrid power source must at least supply the expected peak power demand. Therefore, before any specifications for the system were developed, a reference load profile for ground operation was created based on [11]. Assuming that engine-driven generators provide a majority of the in-flight power, the size of the FC/battery system was thus sized to meet the electrical load profile during ground operations.

Figure 4: Reference load profile for aircraft on ground

The load profile of Fig 4 requires approximately 24.2 kWh of energy. The energy density of a LI battery is approximately 160 Wh/kg; therefore, if the battery is the primary source of power it must be 151 kg to last the duration of this particular ground operation.
load profile. Conversely, if the FC is the primary source of energy, and assuming an unlimited supply of hydrogen the FC stack must be approximately 57 kg to meet the maximum power demand. In a hybrid system, it should be noted that the FC auxiliaries such as a compressor, reformer, etc… will also add weight.

In order to optimize the system weight the battery should be sized to meet the minimum of the transient envelope specified by [2] for the 28 VDC bus, and the FC should be sized to sustain the remainder of the load. Alternatively, to optimize the transient response of the hybrid power source, the battery size should be increased and the FC subsequently reduced to sustain the remainder of the load not supplied by the battery.

**Simulation Results**
For the simulation and performance comparison of the two systems, a PEMFC model based on [12] and a lithium ion battery model based on [13] are used. These models were previously developed in the Virtual Test Bed. The preliminary system is shown below in the Virtual Test Bed simulation environment.

The final paper will include simulation results with a comparison and discussion of the transient responses and weight tradeoffs that will lead to an optimum design.

**Reference**


