AIRPLANES WITH AN ELECTRIC MOTOR

Radek Jurecka¹, Karol Bencalik²

Brno University of Technology, Institute of Aerospace Engineering,
Technicka 2896/2 616 69 Brno, Czech Republic
E-mail: ¹ yjurec01@stud.fme.vutbr.cz (corresponding author), ²bencalik@fme.vutbr.cz

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Abstract. With the decreasing supply of fossil fuel, we can see more and more attempts to substitute combustion engines with other sources of propulsion. This article deals with the possibility of using alternative sources of energy in aviation. Namely, it describes the possibilities of the advantages and disadvantages of using hydrogen fuel cells in aviation.

Keywords: airplane, electric motor, fuel cells, hydrogen, PEM.

1. Introduction

Today many vehicles have alternative power instead of common combustion engines. Scientists and engineers are looking for a new type of energy. The reason is that we have limited supplies of petrol. Due to this fact, research of batteries and fuel cells has high priority.

This article shows the recent utilization of alternative power in different types of vehicles. More detailed description is given to airplanes and the use of fuel cells on airplanes.

2. Types of fuel cells

Fuel cells are divided into three main groups, low temperature, middle temperature and high temperature (Český et al. 2003) (Tab. 1). Low temperature fuel cells are widely used in aviation. These cells work at normal temperatures, around 20°C and maximum 100°C. The most used are Proton Exchange Membrane (PEM) fuel cells.

The principle of the PEM fuel cell is as follows: hydrogen is divided into proton and electron on the anode by a catalyst (platinum) (Fig. 1). The proton goes
through a non-electric membrane, which separates the anode and the cathode. The electron goes through an electric circuit. On the cathode, there is a reaction with the electron, the proton, and the air, which creates water. The working temperature of the cell is approximately 70–80°C.

Table 1. Types of fuel cells

| Type                      | Low temperature | Direct methanol fuel cells |
|---------------------------|-----------------|---------------------------|
| Electrolyte               | Potassium hydroxide membrane | membrane |
| Working temperature [°C]  | 60–100          | 20–80                     | 20–130     |
| Moving ion                | OH⁻             | H⁺                        | H⁺         |
| Reactions on electrodes   | A: \( H_2+2OH⁻→2H_2O+2e⁻ \) K: \( 1/2O_2+H_2O+2e⁻→2OH⁻ \) Σ: \( H_2+1/2O_2→H_2O \) | A: \( H_2+2OH⁻→2H_2O+2e⁻ \) K: \( 1/2O_2+H_2O+2e⁻→2OH⁻ \) Σ: \( H_2+1/2O_2→H_2O \) | A: \( CH_3OH+H_2O→CO_2+6H⁺+6e⁻ \) K: \( 3/2O_2+6H⁺+6e⁻→3H_2O \) Σ: \( CH_3OH+3/2O_2→CO_2+H_2O \) |
| Electric efficiency [%]   | 45–60           | 40–60                      | 40          |
| Power [kW]                | up to 20        | up to 250                  | up to 10    |
| Fuel                      | Hydrogen        | Hydrogen, reformed fuels   | Methanol (ethanol) |
| Applications              | Spaceships, ships, submarines | Universal                  | Portable cells |

Type

| Type                      | Middle temperature | High temperature |
|---------------------------|--------------------|-------------------|
| Electrolyte               | Phosphoric acid    | Molten carbonate  | Solid oxide   |
| Working temperature [°C]  | 170–250           | 600–650           | 800–1000      |
| Moving ion                | H⁺                 | CO₃²⁻              | O²⁻           |
| Reactions on electrodes   | A: \( H_2→2H⁺+2e⁻ \) K: \( 1/2O_2+2H⁺+2e⁻→H_2O \) Σ: \( H_2+1/2O_2→H_2O \) | A: \( H_2+CO₃²⁻→H_2O+CO₂+2e⁻ \) K: \( 1/2O_2+CO₂+2e⁻→CO₃²⁻ \) Σ: \( H_2+1/2O_2+CO₂→H_2O+CO₂ \) | A: \( H_2+2OH⁻→2H_2O+2e⁻ \) K: \( 1/2O_2+H_2O+2e⁻→2OH⁻ \) Σ: \( H_2+1/2O_2→H_2O \) |
| Electric efficiency [%]   | 38–45             | 45–60              | 50–65         |
| Power [kW]                | 50–hundreds of kW | up to several MW   | up to several MW |
| Fuel                      | Hydrogen, reformed fuels | Hydrogen, non-direct fuels | All types without reforming |
| Applications              | Energy production | Energy production  | Energy production |

Fig. 1. Principle of PEM fuel cell
3. Batteries

Commonly used batteries are Lithium-ion (Li-Ion), Lithium-polymer (Li-Pol), or Lithium-ferrite (Li-Fe) (which are now being developed). These batteries have a lower weight and more power and energy density than lead or silver-zinc batteries, which is definitely their advantage.

The lithium-ion battery, also called lithium-cobalt (LCO), has an anode made from carbon, its cathode is made from metal oxide, and the electrolyte is lithium salt in an organic solvent. The characteristics of a Li-Ion battery are thus: energy density 150–190 Wh/kg, minimum self-discharging (5%), nominal voltage 3.6 volts, cycle life 500–1000 charging cycles, the capacity of the battery is reduced (higher temperature and current increase wastage of capacity), probability of explosion, fire, or other damage if voltage is under 2.8 volts (Lithium-based...).

Lithium-ferrite batteries, also called lithium-phosphate (LFP), come from lithium-ion batteries. The cathode is LiFePO4 with a layer of carbon that increases internal conductance.

The characteristics of a Li-Fe battery are thus: energy density 80–120 Wh/kg, nominal voltage 3.3 volts, cycle life 1000–2000 charging cycles, temperature resistance (in a case of short circuit or overheat does not explode or burst into flames due to the stronger Fe-P-O chemical bond compared with Co-O in the Li-Ion battery), lower capacity than a new Li-Ion battery (after several charging cycles capacity is the same), probability of damage if battery capacity is under 33% of nominal capacity (Lithium-based...).

4. Electrically powered vehicles

Vehicles are widely powered by electric engines. These engines take energy from batteries or other sources of electric energy. It is usually some kind of fuel cell or photovoltaic panel. For example, there are electric bikes, scooters, cars, buses, ships and submarines. Fuel cells for cars have power of around 60–90 kW and range mostly over 200 km (Tab. 2). A common type of fuel cell is the proton exchange membrane fuel cell that works in normal conditions (Fuel... 2012). Other types of vehicles are airplanes.

5. Electrically powered airplanes

Hydrogen fuel cells (HFC) are not anything new in aviation. They were used in projects such as Apollo and Gemini. There are several airplanes powered by electric motors. Some ultralight airplanes have batteries and bigger airplanes are equipped with fuel cells or photovoltaic panels or a combination of these two energy sources (batteries and fuel cells or photovoltaic panels and batteries/fuel cells): for example Apame Electra, Antares, Helios, etc. Recently, some aircrafts fuelled by electric engines have emerged. These are ultra-light aircraft fuelled by batteries, but there are also bigger aircraft that have fuel cells or photovoltaic panels or are fuelled by a combination of two sources (batteries and fuel cells or photovoltaic panels and battery/fuel cells). This applies to aircrafts such as the Apame Electra (Fig. 3, Table 3) and Antares 20E (Table 3) and Helios (Fig. 2). The first aircraft powered by HFS was the HK 36 Super Dimona FC (Fig. 4) (Boeing... 2008). The rebuilding was performed by Boeing. The aircraft’s first take off was in 2008 and the fuel cell performance was 20 kW. The aircraft was powered using HFC and batteries. The same concept was used in the project ENFICA–FC (Environmentally Friendly Inter City Aircraft powered by Fuel Cells) (Fig. 6) (ENFICA-FC... 2010). It was a European project focused on developing an aircraft powered by HFC and batteries, and the first take-off was in 2010. The project was carried out by reconstructing the propulsion of Rapid 200 produced by the JIHLAVAN airplane company. The first aircraft powered only by hydrogen fuel cells was the Antares DLR H2 (Fig. 5) with performance of 25 kW (Antares...). The hydrogen fuel storage and fuel cell were located in the nacelles under the wings. The first take-off was in 2009.

Table 2. Examples of cars

| Manufacturer: | Ford Focus | GM Equinox | Hyundai Tucson | Toyota Highlander |
|---------------|------------|------------|----------------|------------------|
| Year:         | 2002       | 2006       | 2004           | 2002             |
| Motor:        | fuel cells/batteries | fuel cells/batteries | fuel cells | fuel cells/batteries |
| FC type:      | PEM Ballard 900 | PEM | PEM | PEM Toyota |
| Power:        | 85 kW      | 93 kW      | 80 kW          | 90 kW            |
| Range:        | 290 km     | 320 km     | 300 km         | 290 km           |
| Max. speed:   | -----      | 160 km/h   | 150 km/h       | 155 km/h         |
| Fuel:         | compressed H2, 4 kg, 5 kpsi | ----- | compressed H2 | compressed H2, 5 kpsi |
| Pieces:       | 30 pcs     | 100 pcs    | 32 pcs         | 18 pcs           |
The advantage of combined energy source (photovoltaic panels with batteries or fuel cells) is that during the day the aircraft uses solar panels and during the night batteries and fuel cells. The power gained from the panels mainly serves as propulsion. In addition, it can be used as a source to recharge the batteries and for water electrolysis. As a suitable example, we can mention the Helios UAV (Fig. 2) made by NASA (Helios… 2009).

To use exclusively solar energy we need an aircraft with a large wingspan because of the amount of area needed for photovoltaic panels. Such an aircraft is the Sunseeker II glider. The aircraft flew over the Alps being powered by solar energy only.
### Table 3. Battery-powered airplanes

| Airplane          | Apame Electra (Worldwide…, 2007) | Antares 20E (Technical…) |
|-------------------|-----------------------------------|--------------------------|
| Seats             | 1                                 | 1                        |
| Wing span         | 9 m                               | 20 m                     |
| Length            | 7 m                               | 7.4 m                    |
| Empty weight      | 134 kg                            | 460 kg                   |
| MTOW              | 265 kg                            | 660 kg                   |
| Cruise speed      | 90 km/h                           | -                        |
| Endurance         | 48 min                            | -                        |
| Best glide ratio  | -                                 | -                        |
| Max. ceiling      | -                                 | 3000 m with fully charged batteries |
| Motor type        | LEM, brush electromotor           | EM 42, brushless DC/DC electromotor |
| Motor power       | 18 kW                             | 42 kW                    |
| Motor weight      | ca 8.5 kg                         | approx. 29 kg            |
| Battery type      | KOKAM, Li-Pol                     | SAFT VL41M, Li-Ion       |
| Battery weight    | 47 kg                             | 77 kg + installation     |
| Battery charging  | quick charge 45 min               | approx. 9 hrs            |

#### 6. Airplanes and fuel cells

Even though first aircraft with HFC propulsion have already been developed, this propulsion is not, for the time being, adequate substitution for piston engines since the performance they achieve is not sufficient yet. Various other reasons stand in the way of their wider use. During the fitting of the HFC system in the aircraft, it is necessary to take into account some important parameters. One of them is the weight of the whole system that is dependent on required performance and selected components of propulsion. For propulsion we need quite substantial performance, and for this matter there is only a small difference between maximal performance and middle value of performance. Nowadays, HFC usable for aircraft propulsion achieve a good rate of kW/kg, but subsystems for operation of fuel cell are considerably heavy. This weight can be partly decreased by using optimised parts, but even so the reduction is small. The efficiency of hydrogen fuel cells is nowadays approximately 40–50%, which leads to high demands on the cooling system. From the operational point of view, there is a disadvantage in price and availability of hydrogen. For UL aircraft, an electric motor is more suitable for its lighter weight than classic combustion motors. Other advantages lie in minimal noise and easy maintenance. Disadvantages are the weight and capacity of batteries. Batteries must be located in the aircraft, which results in shorter flying range.

In large passenger airplanes, fuel cells are used as an auxiliary power unit more and more today. Both Boeing and Airbus are working on APU fuel cell development. They are trying to reduce emissions at airports with less fuel usage of the main engines. Boeing is focused on developing a solid oxide fuel cell for APU in the More electric airplane project (Figs. 7, 8; Breit…).
7. Conclusion

Fuel cells are not being used as a power source for small planes yet today because of the low efficiency, high weight, and large volume of the fuel cell systems. This situation leads to the use of batteries or hybrid power sources in small airplanes. After a few years, fuel cells will become more effective and will more often be used in everyday life. The batteries will have better capacity and lower weight, and the lithium batteries will be safer. In the future, more ultra light airplanes will be powered by an electromotor with batteries, and large passenger airplanes will use fuel cell APUs for less pollution at airports.

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Fig. 8. Boeing – fuel saving on the ground