Taylor & Francis
Taylor & Francis Group

AVIATION
ISSN 1648-7788 print / ISSN 1822-4180 online
2012 Volume 16(3): 63–68
doi:10.3846/16487788.2012.732304

AIRPLANES WITH AN ELECTRIC MOTOR

Radek Jurecka[1], Karol Bencalik[2]

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), [2]bencalik@fme.vutbr.cz

Received 13 June 2012; accepted 20 July 2012

Radek JURECKA, *Eng.*
Education: 2001–2007 Brno University of Technology, specialisation: aerospace engineering.
Affiliations and functions: post-graduate student at Brno University of Technology, Institute of Aerospace Engineering since 2007.
Research interests: use of fuel cells on airplanes.

Karol BENCALIK, *Eng.*
Education: Brno University of Technology.
Affiliation and functions: post-graduate student at Brno University of Technology since 2009.
Research interests: aircraft design, aircrafts systems.

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		
	Alkaline fuel cells	Proton exchange membrane	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: $H_2+2OH^-\rightarrow 2H_2O+2e^-$ K: $1/2O_2+H_2O+2e^-\rightarrow 2OH^-$ Σ: $H_2+1/2O_2\rightarrow H_2O$	A: $H_2+2OH^-\rightarrow 2H_2O+2e^-$ K: $1/2O_2+H_2O+2e^-\rightarrow 2OH^-$ Σ: $H_2+1/2O_2\rightarrow H_2O$	A: $CH_3OH+H_2O\rightarrow CO_2+6H^++6e^-$ K: $3/2O_2+6H^++6e^-\rightarrow 3H_2O$ Σ: $CH_3OH+3/2O_2\rightarrow CO_2+H_2O$
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	Middle temperature	High temperature	
	Phosphoric acid fuel cells	Molten carbonate fuel cells	Solid oxide fuel cells
Electrolyte	phosphoric acid	molten carbonate of lithium, potassium	zircon oxide
Working temperature [°C]	170–250	600–650	800–1000
Moving ion	H^+	CO_3^{2-}	O^{2-}
Reactions on electrodes	A: $H_2\rightarrow 2H^++2e^-$ K: $1/2O_2+2H^++2e^-\rightarrow H_2O$ Σ: $H_2+1/2O_2\rightarrow H_2O$	A: $H_2+CO_3^{2-}\rightarrow H_2O+CO_2+2e^-$ K: $1/2O_2+CO_2+2e^-\rightarrow CO_3^{2-}$ Σ: $H_2+1/2O_2+CO_2\rightarrow H_2O+CO_2$	A: $H_2+2OH^-\rightarrow 2H_2O+2e^-$ K: $1/2O_2+H_2O+2e^-\rightarrow 2OH^-$ Σ: $H_2+1/2O_2\rightarrow H_2O$
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

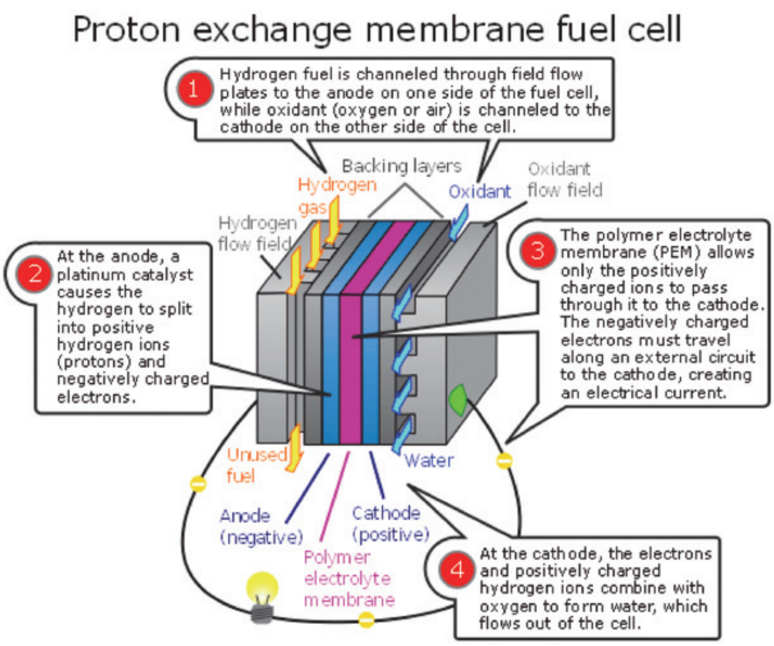

Fig. 1. Principle of PEM fuel cell

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 $LiFePO_4$ 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 H_2 4 kg, 5 kpsi	------	compressed H_2	compressed H_2, 5 kpsi
Pieces:	30 pcs	100 pcs	32 pcs	18 pcs

Fig. 2. NASA Helios

Fig. 3. APAME Electra

Fig. 4. Boeing FC airplane

Fig. 5. Antares DLR H2

Fig. 6. ENFICA-FC

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	-	56 at 130 km/h, 660 kg
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 in 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…).

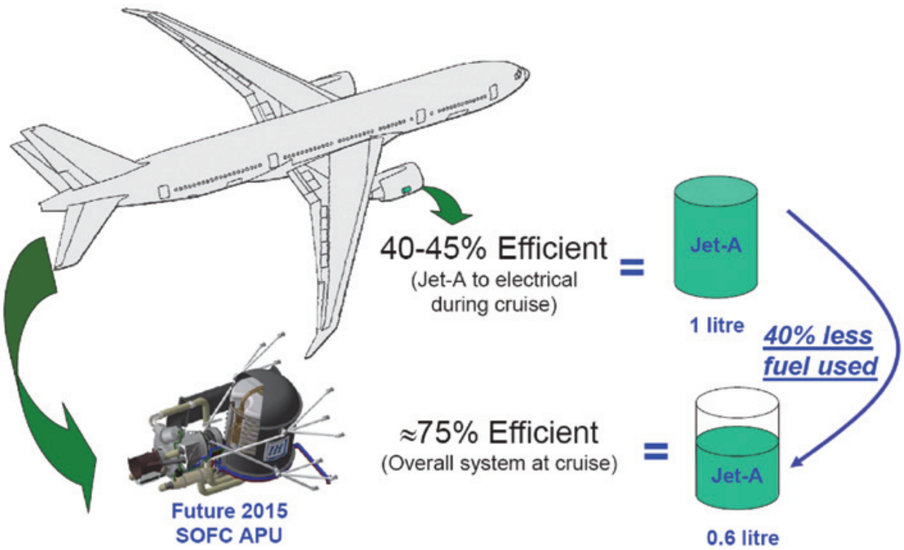

Fig. 7. Boeing – fuel saving during flight

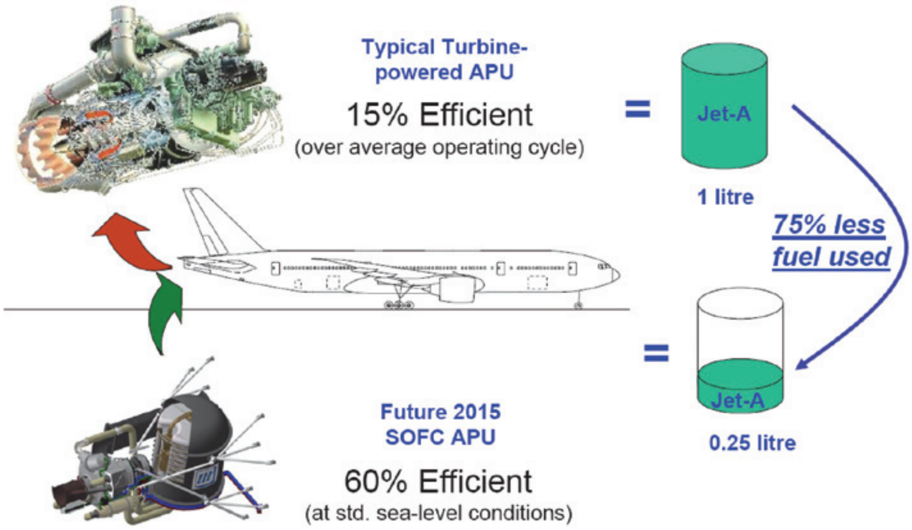

Fig. 8. Boeing – fuel saving on the ground

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.

References

Antares DLR-H2 [online]. Available from Internet: http://www.dlr.de/tt/desktopdefault.aspx/tabid-4935/8219_read-13587/.

Boeing Successfully Flies Fuel Cell-Powered Airplane [online] [cited 3 March 2008]. Available from Internet: http://www.boeing.com/news/releases/2008/q2/080403a_nr.html.

Breit, J. Fuel Cell APU for Commercial Aircraft Systems. Concept Centre, Boeing Commercial Airplanes (in Conjunction with NASA). Available from Internet: http://www.scribd.com/doc/42734644/Boeing-OFCC-Presentation.

Český, A., *et al*. 2003. *Palivové Články – Progresivní Technologie pro Ekologickou Výrobu Energie*. ČEA, (3111.pdf). Available from Internet: http://www.ceacr.cz.

ENFICA-FC Fuel Cell-Powered Aircraft Setting Speed and Endurance Records [online], [cited 9 July 2010]. Available from Internet: http://www.greencarcongress.com/2010/07/enfica-20100709.html.

Fuel cell vehicles. 2012. [online]. Available from Internet: http://www.fuelcells.org/wp-content/uploads/2012/ 02/carchart.pdf.

Helios prototype [online], [cited 1 December 2009]. Available from Internet: http://www.nasa.gov/centers/dryden/news/FactSheets/FS-068-DFRC.html.

Lithium-based batteries [online]. Available from Internet: http://batteryuniversity.com/learn/article/lithium_based_batteries.

Technical data of Antares 20E [online]. Available from Internet: http://www.lange-aviation.com/htm/english/products/ antares_20e/technical_data.html.

Worldwide premiere: first aircraft flight with electrical engine [cited 23 December 2007]. Available from Internet: http://www.apame.eu/AA%20Projects.html.