Fuel Cell Planes

Kerry-Ann Adamson, Fuel Cell Today – 2005

This short primer looks at the basics of fuel cell planes, both passenger aircraft and smaller light weight planes.

Plane Contrails Crisscrossing a Clear Sky

Passenger Aircraft

Current Environmental Impact of Passenger Aircraft

As with other forms of transport, the impact of planes occurs at local as well as global levels. The main concerns at local level include noise and emissions (NOx, SOx, HC), and at a global level CO_2 emissions, contrails and the formation of cirrus clouds, both of which are now being seen as potential contributors to climate change [1].

A study undertaken by the Civic Exchange in Hong Kong [2] into the contribution to air pollution from the aircraft industry published extensive data tables of local emissions, from which the following table has been extracted.

Phase	**Time Taken** (mins)	**THC** (kg's/min)	**CO** (kg's/min)	**NOx** (kg's/min)	**SO2** (kg's/min)
Take-off	7	0.01	0.17	14.50	0.23
Taxi	10	0.08	0.93	0.16	0.20
Approach / Landing	5	0.02	0.24	1.25	0.06

Note that this table shows the data from one aircraft type only (Boeing 747-400 Passenger) and is only *indicative* of the level of pollution caused per aircraft. What this table graphically highlights though, is that the levels of localised pollution per aircraft are significant.

As to the level of carbon dioxide emissions, these are directly linked to fuel consumption. According to the *MyTravel* environmental handbook [3] a rule of thumb states that the combustion of 1 kg of aviation fuel forms 3.16 kg of carbon dioxide[1] (equivalent to: 1.4 litres of aviation fuel produces 3.16kg of carbon dioxide). The same report indicates that for its fleet of Airbus planes the fuel economy ranged between 0.0245 – 0.0286 litre per passenger kilometre (pkm)[2]. Using 0.026 l/pkm this works out therefore that for every 1000 pkm, 82 kg of CO_2 is produced.

These figures again show is that there is a need, and a scope, to reduce the emissions, both global and local, from the use of passenger aircraft.

Practically there appear to be two technical options to reduce emissions:
1. reduce the quantity of fuel used, either by increasing the efficiency of the engines or decreasing the demand on the engines, or
2. replacing the fuel with a cleaner option.

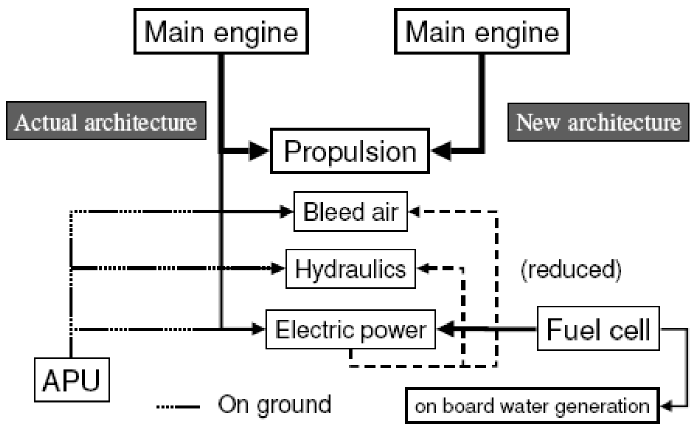
Current research is working on both strands, the first using fuel cells as an APU, reducing the load on the engine, and the second using hydrogen as an alternative fuel.

Fuel Cells as an APU

The term Auxiliary Power Unit (APU) comes from the aerospace industry, with aircraft carrying APUs to provide back-up internal power to the cabin during flight, and, whilst on the ground to provide primary power for the cabin[3]. During the flight the engine, alongside providing propulsion, drives AC generators, to produce all the electricity and heating, etc. to the cabin. It is for both of these functions, the

[1] 1 litre aviation fuel is approximately 0.71kg
[2] This seems to indicate that higher the occupancy of the plane the more "fuel efficient" it becomes!
[3] APUs are not used to provide propulsion power, which comes solely form the engines

traditional APU and the electricity provision, that fuel cells are being considered as a potential replacement. This is indicated in the schematic below [4].



Current and Potential Future Aircraft Architecture

Current research is focusing on SOFC, due its capability of handling comparatively “dirty” hydrogen, which is produced by the reforming of kerosene. This selection of SOFC comes with two caveats. The first is that the reforming of kerosene, and kerosene type fuels, is still at a comparatively early stage of R&D, [5] with substantial advances in the purity of the hydrogen product being possible. The second is that if there were already a source of on-board hydrogen, such as in the Cyroplane, discussed below, then PEM based fuel cells might be more advantageous.

Dave Daggett, an engineer with Boeing, one of the very small number of serious players in this area, suggested that 40% of fuel used during flying could be saved by using a tail-mounted SOFC [6] and a 75% fuel saving over a typical turbine powered APU when used to provide power on the ground [7]. This though is not projected before 2015 as a number of advances in SOFC technology need to made, critically in terms of weight and power density[4].

Although fuel cells as an APU face a number of design challenges if they are to be integrated into aircraft, one other potentially substantial issue is ensuring that they function at different pressures and temperatures.

[4] The goal here is for a power density of around 1 kW / kg

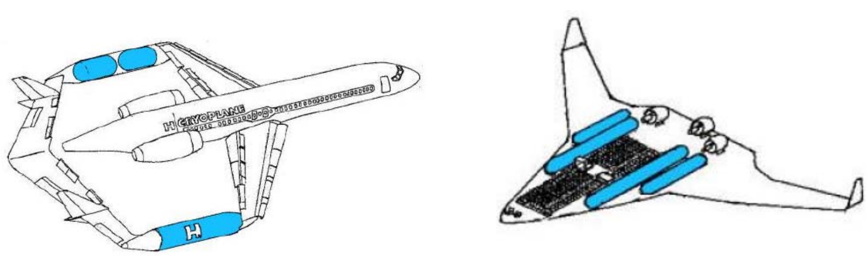
Hydrogen as a Replacement for Jet Fuel

Between 2000 and 2003 the European Union funded a multinational project looking into the systems analysis of a hypothetical liquid hydrogen fuelled plane – the Cryoplane [8].

An artists impression of the EU funded project Cryoplane

Coordinated by Airbus Germany, and with over 30 partners, the project looked at various aspects of a hydrogen fuelled passenger aircraft. These areas included aircraft configuration, propulsion, safety and transition scenarios. The results from the project included:

- A hydrogen fuelled engine could be as efficient as a kerosene engine in terms of energy consumed; also conversion of conventional turbo engines could be done, but the fuel supply and injection systems need to be redesigned,
- With regards to safety the overall conclusion was that a hydrogen fuelled aircraft would be no less safe than a conventionally fuelled aircraft,
- The level of emissions benefits varies, depending on the hydrogen production route, when considered from a well-to-wheel perspective,
- There are a number of "missing" parts and materials that need to be developed through focused R&D before the design is to be taken forward.



Two of the more unorthodox design shapes, with hydrogen storage tanks shown in blue.

Light Weight Aircraft and Prototypes

There have been a small number of substantial projects to develop light weight fuel cell aircrafts, and by far the best known of these was Nasa and AeroVironment's flying wing Helios.

The Pathfinder – Helios Project [9]

The Helios was a prototype high altitude, remotely piloted craft, powered by solar cells feeding an experimental fuel cell system.

During its test flight in 1999 Helios was powered solely by the solar array and an onboard battery pack. After this, its 4 year development included working on, and integrating, a regenerative (and a non regenerative) fuel cell. Unfortunately when Helios crashed into the ocean in 2003 the fuel cell was lost.

Fuel Cell Powered Motor-Glider

Boeing, one of the two forerunning companies developing the technology for commercial airlines, has joined forces with a number of companies, including the UK's Intelligent Energy, to develop a small lightweight aircraft which uses compressed hydrogen to fuel a PEM unit for propulsion and power. Test flights were slated for early 2004, though we have heard no news regarding their taking place or the results from these.

Schematic of the Boeing Fuel Cell Plane

The E-Plane [10][5]

The E-Plane is a light-weight 2 seater aircraft, being developed by an American consortium, lead by Advanced Technology Products. Other project participants include NASA, the Foundation for Advancing Science, and Technology Education, Dyn'Aero & Diamond Aircraft, for the aircraft, Gore for the fuel cell membrane electrode assembly and Lynntech for the PEM fuel cell stacks.

As well as being designed to collect data on the use of fuel cells in an all electric plane, the E-Plane is being used as an educational resource, providing a tool for schools.

The E-Plane is not only being used to test and develop the technology but also as an educational resource.

[5] Many thanks to James Dunn for providing the information on the E-Plane and the two pictures used here.

The research and development programme is due to last three phases with the completion of phase three, the fuel cell only aircraft, being slated for the end of 2005. We look forward to hearing the test results from this.

Although the development of lightweight aircraft has been slower than other niche applications substantial inroads have been made, as highlighted by the projects mentioned above, and are starting to show that an all electric lightweight plane may be viable, sooner than some think.

Discussion and Conclusions

As there is no expected downturn in the aircraft industry, in fact the opposite is projected, then we can fully expect to see an associated increase in absolute terms from aeroplane pollution. Unless we see an about face by governments imposing some form of pollution levy on passengers to reduce numbers, then the most attractive option is to address the technical issues. There is no question that each generation of aircraft has been getting cleaner and more fuel efficient, but there is still a large scope for improvement. The aerospace industry is one area therefore where the potential benefits of employing fuel cells could be significant.

The fuel cell and hydrogen conference circuit is growing, with more long haul locations being added to the programme each year. If we as a community want to continue flying around the globe, relatively cheaply, to meet colleagues and discuss research and news, then maybe we should be focusing, and targeting, more efforts now into applying this technology where it is needed. Boeing and Airbus may be blazing a trail but isn't it about time that more companies were following?

References and Further Reading

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Information available at: www.AviationTomorrow.com

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