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Fuel Cell System Development and Testing for Aircraft Applications

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1 Introduction

For several years the Institute of Technical Thermodynamics of the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR) in Stuttgart and Hamburg work actively for the development of fuel cell systems for aircraft applications. In cooperation with Airbus several fuel cell applications within the aircraft for both ground and cruise operation could be identified. In consequence, fuel cell systems capable to support or even replace existing systems have been derived. In this context, the provision of inert gas for the jet fuel (kerosene) tank and electrical cabin power supply including water regeneration represent the most promising application fields.

This contribution will present the state of development and the evolution discussing the following points:

- Experimental evaluation of fuel cell systems under relevant conditions (low-pressure, vibrations, reformate operation, etc.).
- Fuel cell test in DLR’s research aircraft ATRA (A320) including the test of an emergency system based on hydrogen and oxygen with 20 kW of electrical power. The fuel cell system was integrated into an A320 aircraft and tested up to a flight altitude of 25 000 feet under several acceleration and inclination conditions.
- Fuel cell tests in Antares-H2 – new DLR’s flying test bed

2 The Multifunctional Concept for Fuel Cell Systems in Aviation: A Step by Step Approach

2.1 Power generation

Fuel Cell systems can reach 50 % of electrical efficiency and advantageous replace power supply systems [1-2]. Indeed, one of the main deficits of the current power supply systems in aircraft if that they are often operating in an inefficient way (sometimes high energy consuming). As example, the auxiliary power unit (APU) has a low efficiency of only 20 % and even lower [3] at part load conditions.

Another system not fully efficient in nowadays civil aircraft is an emergency power system the Ram Air Turbine (RAT), which generates electricity from the air stream (essentially the RAT is a propeller). In case all main engines fail (which is a very rare event) the hydraulic system and the electric system of the aircraft are lost.

During cruise the electrical energy is provided by the generators of the main engines. The efficiency of this energy supply is quite high around 30 – 40 %.

The primary goal of fuel cell systems in aircraft is to avoid inefficient operation phases of aircrafts. In this respect, it is envisioned to eliminate the APU and the RAT. An important milestone in the development efforts has been the first tests of a fuel cell in a civil aircraft environment through a collaboration of Airbus, DLR and Michelin to power the aircraft's electric motor pump and the back-up hydraulic circuit and also operated the aircraft's ailerons. During the test, the hydrogen and oxygen based fuel cell system generated up to 20 kW of electricity in flight within the DLR's D-ATRA ("Advanced Testing and Research Aircraft") [4]. This system was integrated into the cargo area of the A320 at the Airbus location in Hamburg/Germany and tested in several flights with standardized missions. In 2007 and 2008. The data acquisition of the fuel cell system performance was measured under realistic vibration loads, heat rejection and safety aspects. The flight specific data measured includes temperature, pressure, vibrations, orientation angles, etc. The fuel cell system demonstrated a robust behavior in all tests so far (see figure 1).

(a) (b)

Figure 1: (a): DLR research aircraft A320 (D-ATRA) at Berlin International Air Show (ILA) 2008. (b): Michelin fuel cell system in the cargo area of the research aircraft.

On top of that power supply, fuel cell systems can also deliver further functions and products like water and low-oxygen containing exhaust air for inerting the jet fuel tank. Another function may be the use the heat of the fuel cells for de-icing. Figure 2 displays schematically the functions that a multifunctional fuel cell system may be able to satisfy.

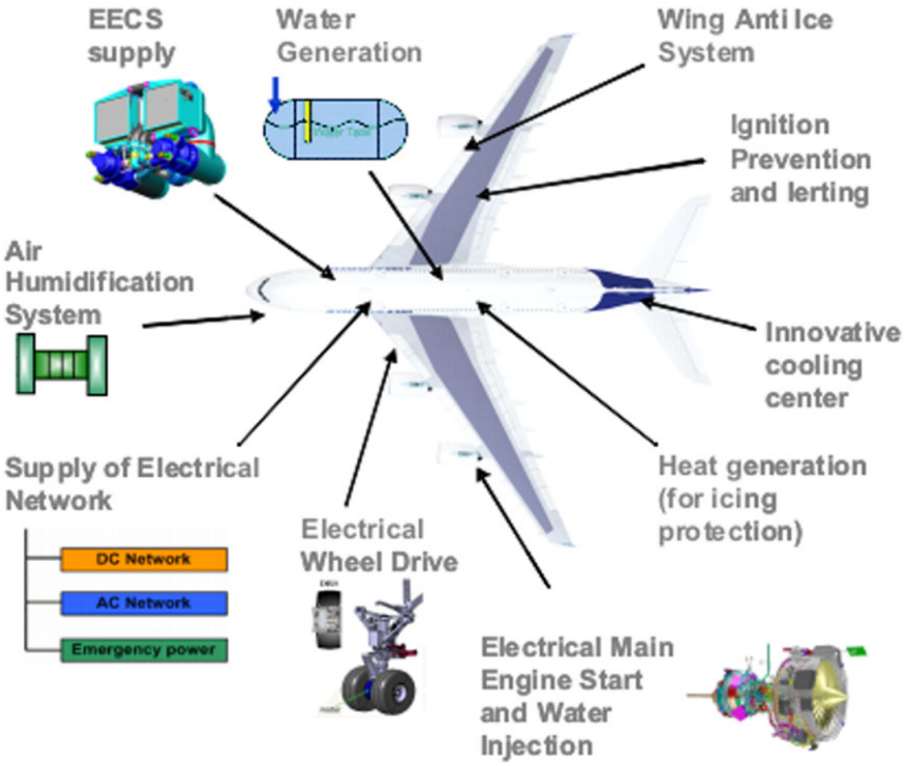
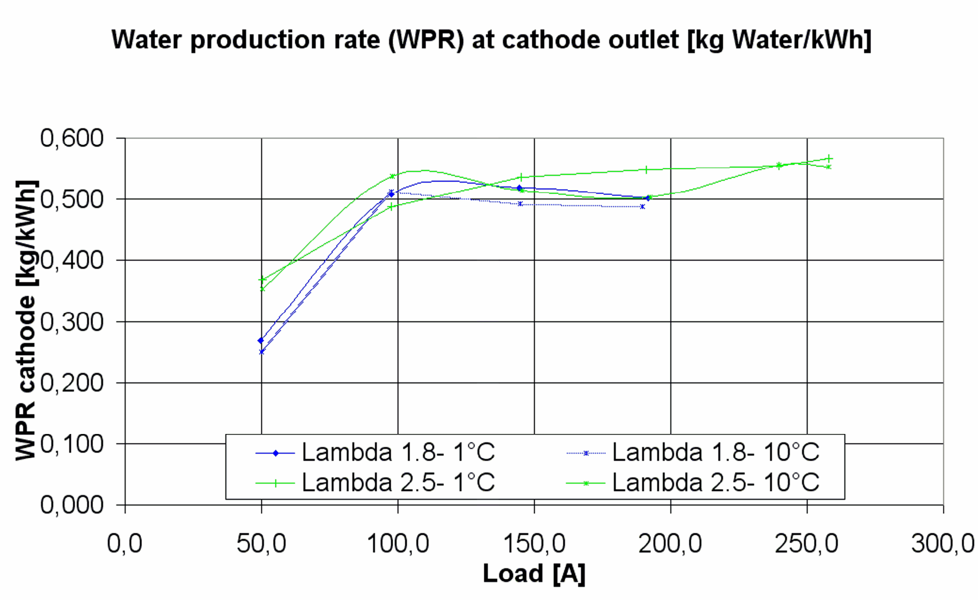


Figure 2: Multifunctional fuel cell system: The possible functions are power supply, emission free ground operation, electrical main engine start, electrical environmental control system (EECS), water generation (potable water and water for toilets), heat generation (icing prevention, hot water generation), explosion and fire prevention and suppression (inerting of tanks, cargo and e-bay compartment), cockpit and / or cabin air humidification.

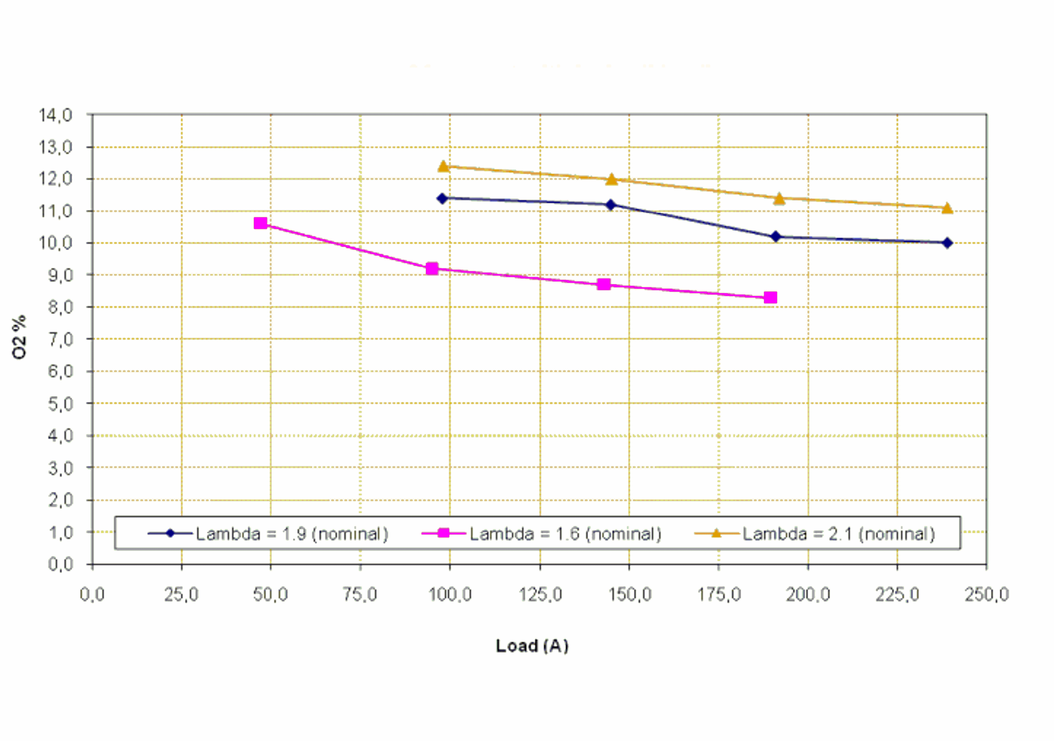
3 Water Generation and Inert Gas Generation

Fuel cell system can deliver ca. 0.5 - 0.6 liter of water per kWhr electrical power (see figure 3 (a)); which means that for 100 kW fuel cell power (appropriate for large aircraft) about 50 liter of water are generated per hour. This can be used for toilets and air conditioning thereby reducing the amount of water to be loaded on-board of the aircraft. Therefore water generation by the fuel cell will help reduce the water tank of the aircraft.

Very innovative is the use of the fuel cell exhaust which is oxygen depleted air. Test of various fuel cell systems have shown only 10 % of oxygen content in the exhaust (see figure 3 (b)).These low oxygen contents in the kerosene tank are effective as fire retardation and suppression or explosion prevention.



(a)

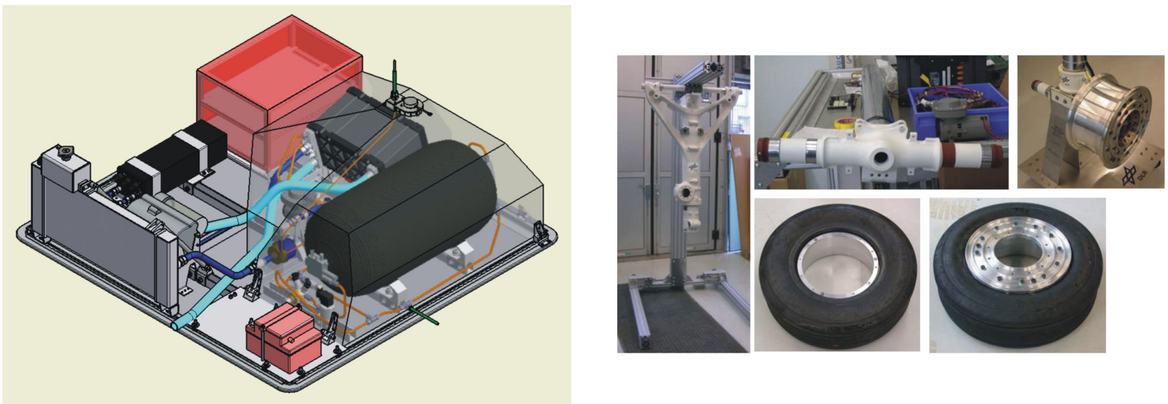


(b)

Figure 3: (a) Water production rate for a PEFC for different operating conditions and different temperatures of condensation (b) Variation of oxygen content in a PEM fuel cell exhaust depending on operating parameters.

4 The Multifunctional Fuel Cell System: A Path towards Aircraft Integration

A H_2/Air fuel cell system being set-up at DLR will demonstrate multiple functions on-board. Besides emergency power, the system should deliver inert gas for the jet fuel tank and water, on ground the system can power an electrical drive on the nose wheel for ground taxiing. The fuel cell system is based on commercial systems which are modified and adapted to fulfill the rules and regulation of aircrafts. A flexible aircraft qualified platform is being developed in which different components can be changed rapidly without the need to start all qualification routines again. With this airworthy test platform the development of aircraft fuel cell can be drastically accelerated. The schematic of this platform is presented in figure 4a. The electrical drive is presented in figure 4b.



(a) (b)

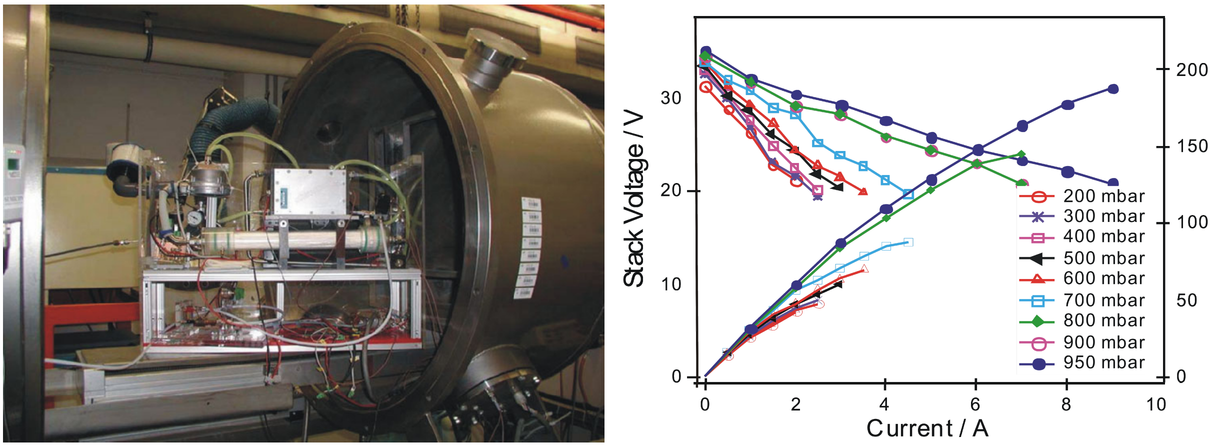
Figure 4: (a): design of the airworthy (aircraft qualified) testing platform for fuel cell systems. (b): components for the electrical nose wheel drive for emission-free ground operation.

5 Aircraft Relevant Investigations

5.1 Tests in laboratory environment

Different test environments have been set up to test cells and systems under aircraft relevant conditions in the laboratory.

A specific test is the low pressure operation test down to 200 mbar which corresponds to a flight height of ca. 12 000 meter (ca. 39 000 feet) (figure 5).

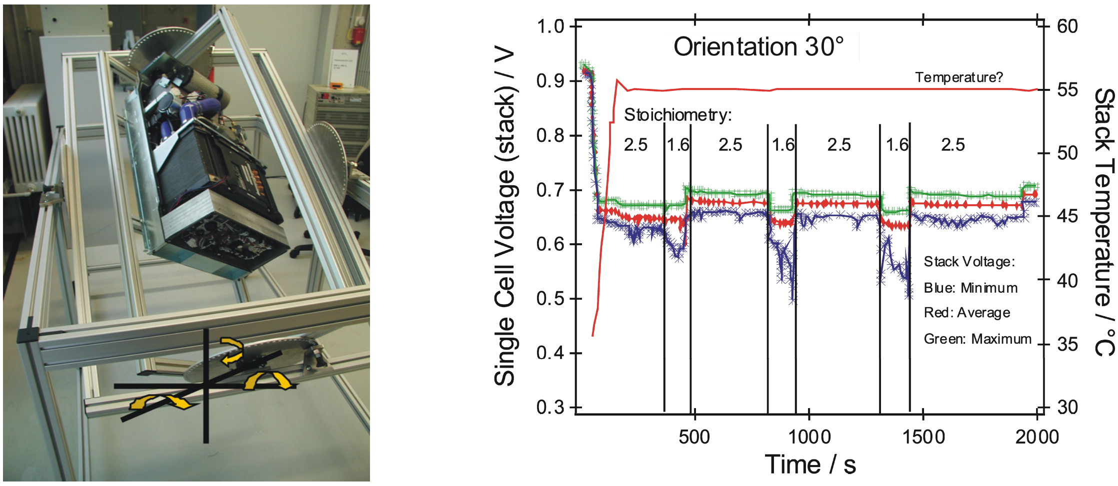


(a) (b)

Figure 5: (a): photo of a test set-up for analyzing low-pressure behavior of PEFC systems. (b): example of the pressure dependence of a 300 W PEFC system in the pressure range from 950 to 200 mbar.

Even if the final fuel cell system probably will be operated with cabin air, such characterizations are of paramount importance for system evaluations. The testing results which also include different orientations, vibrational load behavior, electromagnetic compatibility and water analysis, allow designing a layout of the system regarding its performance during cruise conditions.

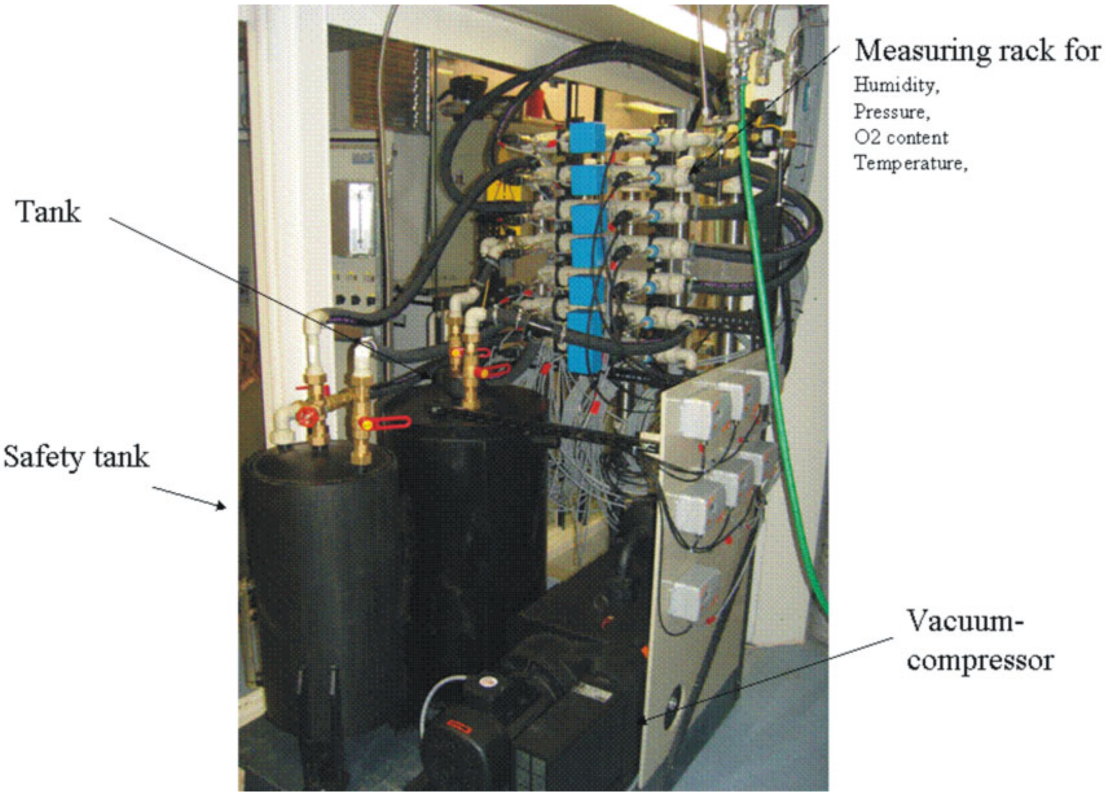
Another specific test is the different orientations tests(inclinations) of the systems to identify adverse angles. An example is given in figure 6 were the system shows a decrease of cell voltage at an angle of 30° (adverse operating condition). This performance instability is due to the water management of the system. With a change in the system configuration this problem can be effectively avoided.



(a) (b)

Figure 6: (a): inclination test station. (b): testing results of a 12.5 kW system under different orientations. At low air stoichiometries of 1.6 the voltage decreases at 30° angles.

(a)



(b)

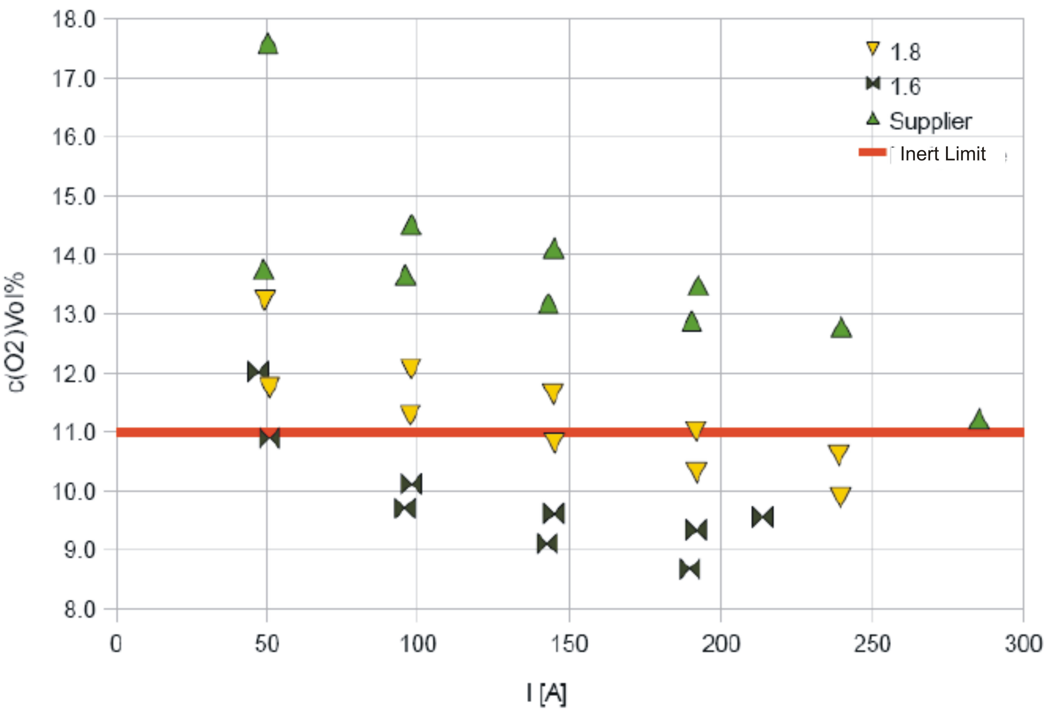


Figure 7: (a) test bed measurement station. (b): typical test results of O_2 concentration measurement n.

Another test set-up (figure 7) allows experimenting the different possibilities of conditioning the fuel cell cathode exhaust gas in order to optimize the produce water and condition the inert gas before its distribution in the kerosene tank simulating a pressure change in the system representative of the one expected in flight.

6 Flight Testing and Development of New Testing Beds

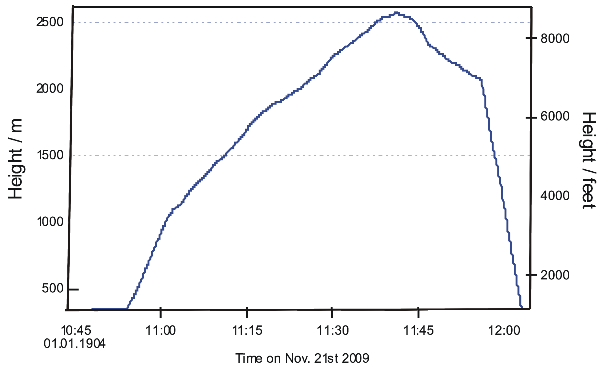
A new testing bed have been developed by DLR in cooperation with Lange Aviation (figure 8): The Antares DLR-H2 is a high-tech motor glider aircraft based on the Antares 20E which has been built commercially and modified by attaching two pods below the wings to carry one the fuel cell system and one the hydrogen tanks [5]. This new test bed allows the combination of different qualifying test routines. Acceleration loads, vibration loads and climatic environments.

(a)

Geometry	
Wing Span	20 m / 65.6 ft
Wing Area	12.6 m^2 / 135 ft^2
Aspect Ratio	31.7
Fuselage Length	7.40 m / 24.3 ft
Fuselage Height	1.64 m / 5.4 ft
Weight	
Empty Weight	460 kg / 1014 lb
Maximum Weight	660 kg / 1455 lb
Waterballast	100 l / 26.4 USgal
Min. Wing Loading *	42 kg/m^2 / 8.6 lb/ft^2
Max. Wing Loading	52.4 kg/m^2 / 10.7 lb/ft^2
Glide Performance	
Best Glide Ratio	56
Min. Sink Rate at weight	0.49 m/s / 96 ft/min | 530 kg / 1168 lb
Stall Speed at weight	73 km/h / 39.4 kt | 530 kg / 1146 lb

(c)

(b)



(d)

Figure 8: (a): testing bed DLR-H2 for fuel cell propulsion with hydrogen. (b): specifications of the Antares motor glider from Lange Aviation. (c): view of the hydrogen tank in the pod. (d) View of the altitude record.

The Antares DLR-H2 first officially took off on July 7th, 2009 at Hamburg airport. It is the world's first piloted aircraft capable of taking off using only power from fuel cells. On November 21st of 2009, Antares successfully completed an altitude record reaching about 8368 feet (ca 2550 m) in height what correspond to an operating pressure for the fuel cell of about 725 millibars [6] equivalent to the minimum air pressure in the cabin of an Airbus A320 flight during a normal flight and is about 290 millibars below the normal atmospheric pressure.

7 Outlook and Summary

A strategic cooperation between Airbus and DLR has resulted in the first results for development of fuel cell systems for future aircraft. The multifunctional approach to fuel cell systems may lead to further modifications in various aircraft systems for efficient energy use on board. The goal of Airbus and DLR is to conceive innovative electrical architectures in which the multifunctional fuel cell system is a key component to ascertain a technology leadership for efficient future aircrafts.

DLR has demonstrated together with Airbus and Michelin the first fuel cell system for emergency power on an A320. An airworthy test platform for flexible investigations of the multiple function and application is being developed. This platform will be used for flight test and rapid change of components. The platform will be tested in-flight in the A320. Furthermore arising from the need to perform tests in the realistic environment the testing bed DLR-H2 will be used intensively within the next few years.

Acknowledgement

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Notes and References

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