Sixth European Aeronautics Days

Aerodays 2011

Innovation for a Sustainable Aviation in a Global Environment

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http://www.aerodays2011.org/
Realization and Flight Test of All Electric 2-Seater Aircraft Powered By Fuel Cells fuelled by Hydrogen

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# ENFICA-FC Consortium

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**Total Cost:** 4,362,765 €  
**EC Funding:** 2,786,600 €  
**1st October 2006 – 30 June 2010: 36 → 45 months**
Part 1) Feasibility study carried out to preliminarily design transport aircraft with propulsion systems provided by fuel cell technologies taking into account future generation of fuel-cells with much higher performances as expected within next 10-15 years.

Regional Airplane with Engine fuelled by Liquid Hydrogen

FUEL CELL ALL-ELECTRIC Inter-City Airplane
Part 2) electric-motor-driven airplane powered by fuel cells developed & validated by flight-test.

ICE: $W = 450\text{kg} – 2$ pilot

ROTA9 912

JIHLAVAN Airplanes

Rapid 200-Fuel Cell

$W = 550\text{kg} – 1$ pilot

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**Power Required for Level Flight @ 1000 m**

Required Cruise Power \[ \eta_{\text{prop}}=0.9; \, \eta_{\text{eng}}=0.93, \, \eta_{\text{lbs}}=0.94 \]

Required Climb Gross Power \[ @ 500 \text{m} - \eta_{\text{prop}}=0.8; \, \eta_{\text{eng}}=0.95, \, \eta_{\text{lbs}}=0.94 \]

**Power at Cruise Speed of 149 km/h**

Net: 13.8 kW - Gross: 17.6 kW

**Rapid 200-FC**

**Layout of propulsion system**

- **Compressor** 2 kW
- **F.C. Stack** 22 kW \((20 + 2)\)
- **Control Unit with A/C Management Unit Function**
- **DC/DC Converter** \(\eta = 0.97\)
- **DC/AC Inverter** \(\eta = 0.97\)
- **Electric Brushless Motor** \(\eta = 0.95\)
- **Battery** 20 kW
- **H2**
- **Data logging**
- **Pilot**
- **Electric–Motor–Driven Airplane Powered by FC**

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Fuel Cells: Intelligent Energy
March 2009

Fuel cell system output: >20 kW
System weight: ~105 kg

2 X Dyneteck L026 tanks:
Working pressure: 350 bar
Volume: 52 litres
H₂ mass: 1.2 kg
Weight: 31 kg

Safety Constraint:
Sealed and Vented Area
No in pilot cabin !!!!

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Electric engine: PHASE MOTION
March 2008
Brushless electric motor
Characteristics:
• Ang. Velocity: 1500-2500 rpm
• Rotor weight: 10 kg
• Stator weight: 13 kg
• Air cooled
• Efficiency: 95%-96%
• Max torque: 250 Nm
• Nominal power: 44 kW
• Power at max speed: 73 kW
• Diameter: 300 mm
• Length: 100 mm

Engine case: designed by Univ. Pisa:

Battery pack (POLITO & Air Energy)
Lithium Polymer (Kokam) (Oct. 2008)
Nom. Voltage: 207,2V
Nom. Capacity: 30Ah
Nom. Energy: 6,2 kWh
Energy at 20kW, 20°C: 5,8 kWh
Cell Weight: 48kg
Weightincl. Case and BMS: 52 kg
Charge Time @3kW: <3h

DC/DC converter
2 DC/DC converter (20 + 20 kW)
Average efficiency 96-97%

DC/AC inverter
DC/AC inverter (40kW)
Average efficiency 96-97%

+ Vehicle Controller
Total Weight: 15kg

MAVEL srl
March 2009

Constraint: Easy to move for safe recharge & for CG requirements.
No inside leading edge!!!
Aerodynamic Analysis Rapid 200 FC

Wakes and On-Body Streamlines at Cruise speed, up view

Two blade optimized propeller

Upper Surface Pressure Distribution, Cruise Speed

Analytical (Rotor) vs. Experimental

ENvironmentally Friendly Inter City Aircraft powered by Fuel Cells.

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Climb - Cruise:
Thrust: 788 - 347N
Torque: 145 - 78.7Nm
rpm: 2190 - 2010
Wind speed: 33 - 40 m/s
Power Net: 33.25 - 16.56 kW
Power gross: 36.85 - 18.35 kW

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ENvironmentally Friendly Inter City Aircraft powered by Fuel Cells.

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Optimized Engine cowl Cooling

Structural Design & Analysis

- Design of structural elements: engine mount, H₂ tanks support system,…
- Re-evaluation of flight loads to obtain the Permit-to-fly (W=550 kg – CG = 23%)

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Fuselage Mock-up for Systems Functional Testing

- System Failure Testing
- Temperature & Software Testing

Flight Duty Cycle Simulation
Integration on Real Prototype (Jihlavan Airplane) – Sept. 2009

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ENvironmentally Friendly Inter City Aircraft powered by Fuel Cells.

Aircraft Assembly

Reggio Emilia Airport - Italy

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The MDD is highly configurable and every piece of information available on CANBUS can be showed as a user-definable instrument.
ENvironmentally Friendly Inter City Aircraft powered by Fuel Cells.
ENvironmentally Friendly Intra City Aircraft

powered by Fuel Cells.

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ENvironmentally friendly

Aircraft powered by fuel cells.

Test 93: Blending Power Test

Test 95: Flight Duty cycle
**Aerodays 2011**

**Series 100**
- Introductory fuelling system for small car fleets
- Fill performance
  - Nominal 350 bar
  - 2 kg per fill
  - 1–2 fills per day
  - 3–4 minutes per fill
    - (requires 2–6 hours between fills)
- Product features
  - Fed from cylinder pack or tube trailer supply
  - Integrated compression, HP storage & dispenser system
  - Can be relocated

**Hydrogen Fueller:**
- APL & SAPIO

**Maiden Flight: 2 min**

**2° Flight: 11 min**

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Flight n. 3 ENDURANCE

Flight time: 39 min
Battery cons: -16 Ah

H2 consumption: -230 bar
Max GPS speed: 152 km/h
Flight n. 3
FAI: Class C Aeroplane
Class D Motor-Glider

- V top = 160 km/h
- V max av 1run = 142 km/h
- V max av 2run = 135 km/h

World Speed Record: 135 km/h
World Duration Rec: 39 min

Flight n. 6

- V top = 180 km/h
- V max av 2run = 129 km/h
About 28 hours of experimental tests were carried out.
The fuel cells have been working for more than 16 hours;
The battery have been working for more than 15 hours;
The inverter have been working for about 28 hours.
2 hours of effective flight were performed during 6 tests for a total path of 237 km.
Conclusion

A lot of effort was spent in order to guarantee the safe flight of the aircraft while the Battery power source system is working together with the FC power source System.

The S100 H2 fuelling system used for fuelling the airplane at 350bar worked perfectly.

Six flight tests were successfully carried out in total by POLITO on the ENFICA-FC aircraft RAPID200-FC at Reggio Emilia airport.

The completely electrical power system was successfully tested during the experimental flights. The rotation speed of 84 km/h was obtained within 284 m of taxi at power of 35 kW.

Level flight at 135 km/h was attained by mean of only fuel cell power setting.

Flight n. 4 showed the non complete reliability of the Fuel Cell System. the fuel cell had a fault and FC power revealed an abrupt power decrease before completely switched-off. The battery continued to supply power to the motor with its maximum power (20.8 kW) and the airplane continued to climb to the maximum altitude of 760 ft and speed of 97 km/h. It was showed as the battery system immediately supply the power to the motor in case of malfunctioning of the fuel cells.

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Conclusion

Higher values of flight speed were measured during free flight with altitude variations of 200m. Speeds higher than 155 km/h were measured several times, with a top of 180 km/h measured during several dive and pull-up manoeuvres.

Positive handling qualities and satisfactory engine performances of these six flight tests let the team to consider this successful flights as good starting point for further long endurance high speed flights.

2.8 hours of block time and 2 hours of effective flight were performed during these 6 tests for a total path of 237 km.

The results obtained during flights can be considered as a further step in the European and World Aeronautics Science in introducing a completely clean energy (ZERO EMISSION).
The flight movies are loaded on: www.enfica-fc.polito.it