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European Research Area



Centro para el Desarrollo
Tecnológico Industrial



Sixth European Aeronautics Days

Aerodays 2011

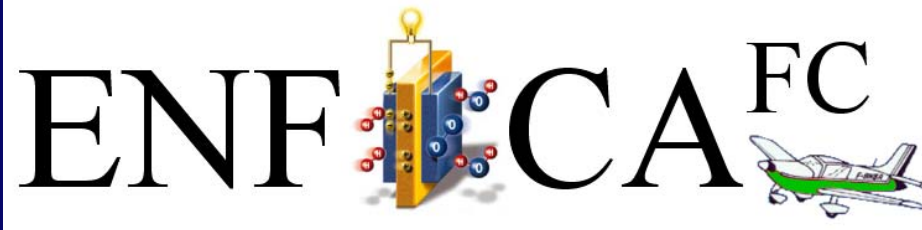
Innovation for a Sustainable Aviation in a Global Environment

30th March - 1st April 2011

Madrid (Spain), Palacio Municipal de Congresos

<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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www.enfica-fc.polito.it

ENFICA-FC Consortium

1. POLITECNICO TORINO (Coordinator)	POLITO	Italy
2. METEC (Adm. Management)	METEC	Italy
3. ISRAEL AIRCRAFT INDUSTRY	IAI	Israel
4. INTELLIGENT ENERGY	IE	UK
5. EVEKTOR	EVE	Czech Rep.
6. JIHLAVAN Airplanes	JA	Czech Rep.
7. UNIVERSITY OF PISA (months 10-43)	UNIPI	Italy
8. AIR PRODUCTS	APL	UK
9. UNIV. LIBRE de BRUXELLES	ULB	Belgium
10. BRNO UNIV. of TECH. (months 1-15)	BUT	Czech Rep.
11. INFOCOSMOS (months 1-4)	INFO	Greece

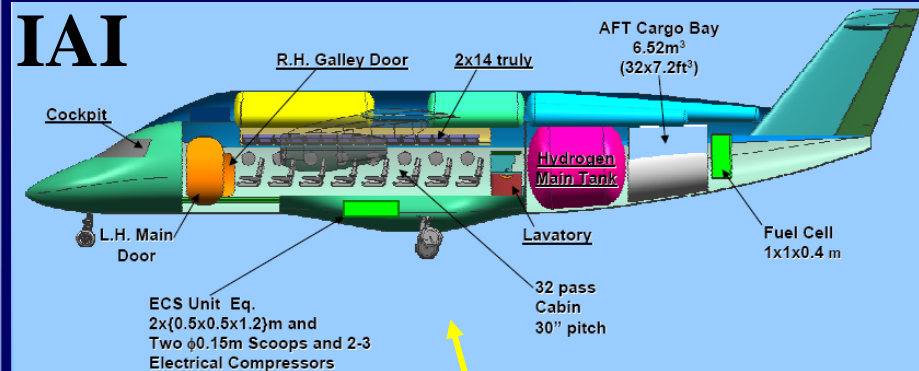
Total Cost: 4.362.765 €

EC Funding: 2.786.600 €

1st October 2006 – 30 June 2010: 36 → 45months

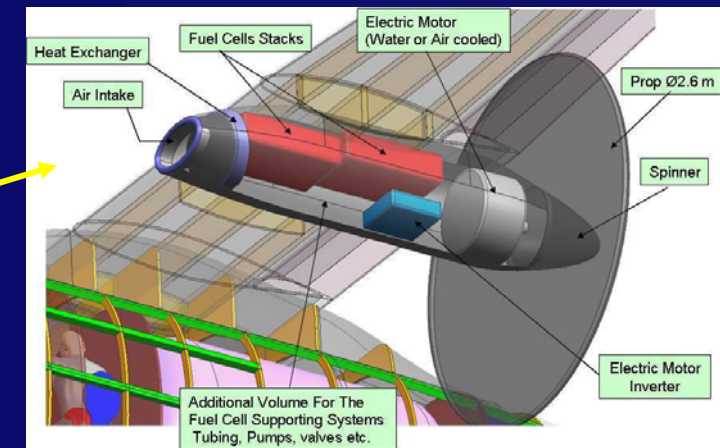
Part 1) Feasibility study carried out to preliminarily design transport aircraft with propulsion systems provided by fuel cell technologies taking into account future generation of fuel-cells with much higher performances as expected within next 10-15 years.

Environmentally Friendly Inter City Aircraft powered by Fuel Cells.



Regional Airplane with Engine fuelled by Liquid Hydrogen

FUEL CELL ALL-ELECTRIC Inter-City Airplane

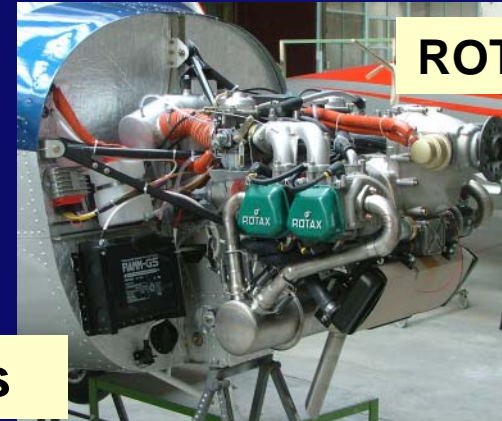


Part 2) electric-motor-driven airplane powered by fuel cells developed & validated by flight-test.



ICE: W = 450kg – 2 pilot

JIHLAVAN Airplanes

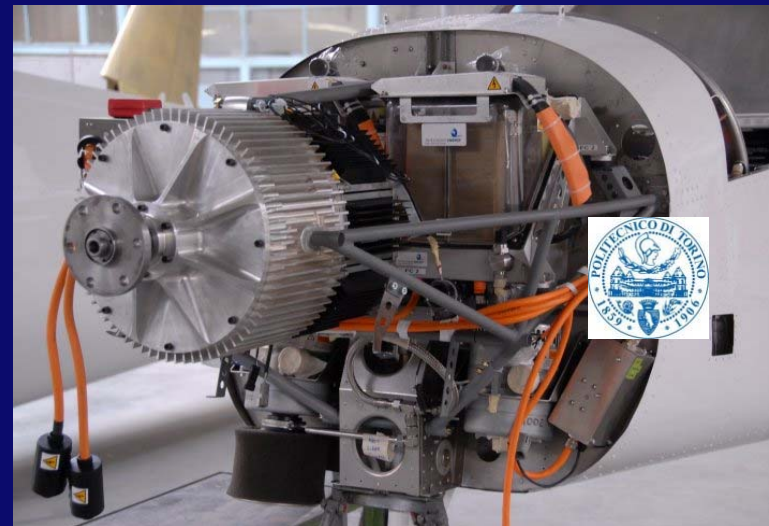


ROTAX 912



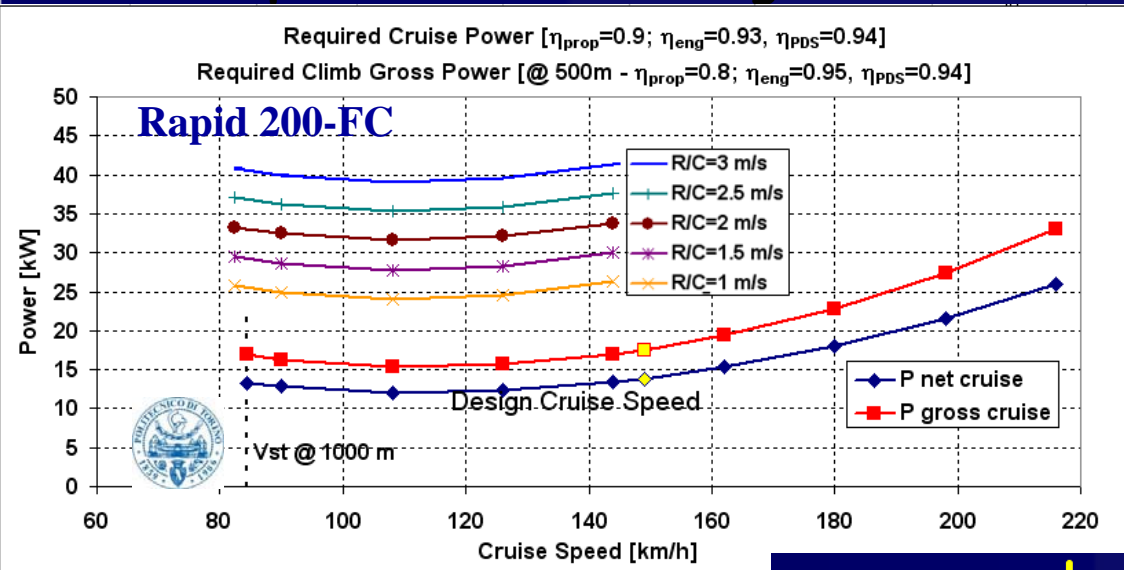
Rapid 200-Fuel Cell

W = 550kg – 1 pilot



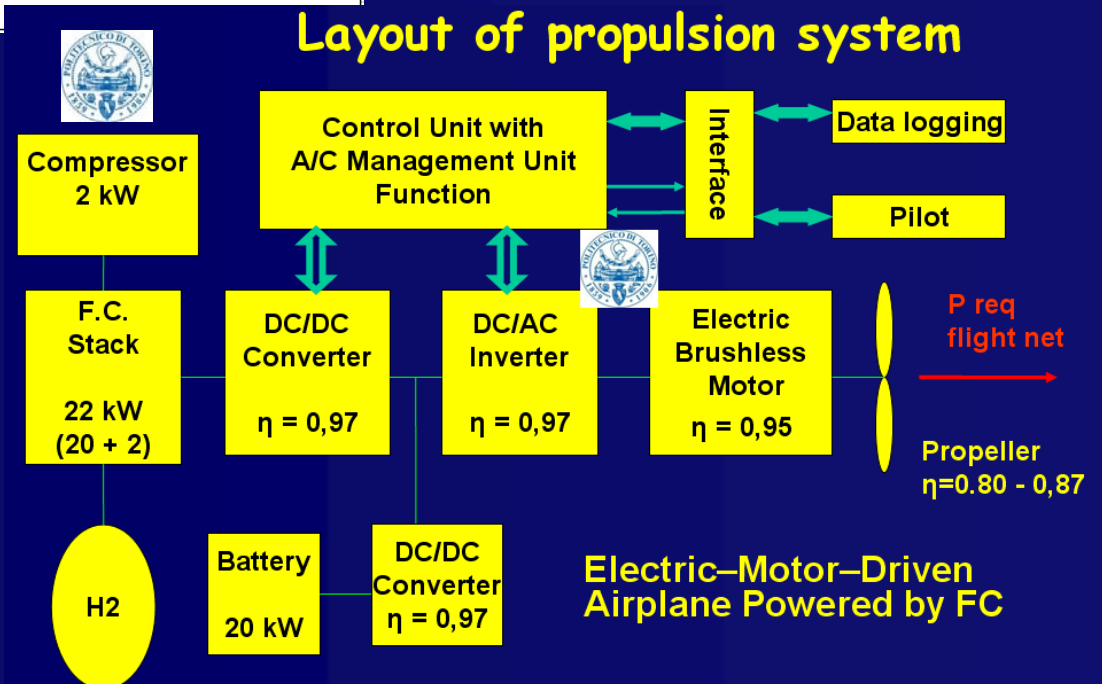
Environmentally Friendly Inter City Aircraft powered by Fuel Cells.

Power Required for Level Flight @ 1000 m



Power at Cruise Speed of 149 km/h
Net: 13,8 kW - Gross: 17.6 kW

Layout of propulsion system



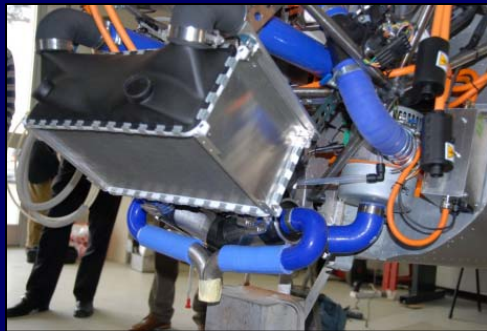
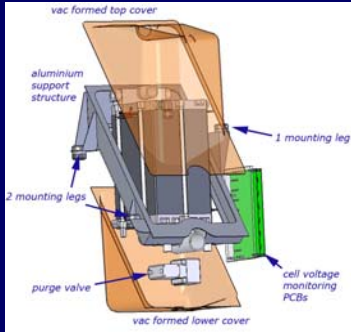
Electric-Motor-Driven
 Airplane Powered by FC

Fuel Cells: Intelligent Energy

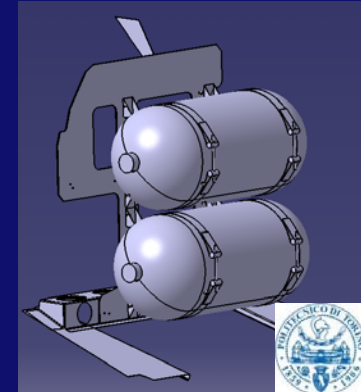
March 2009

H2 Storage System

APL - Feb. 2009



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



2 X Dynetec 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 !!!!

Electric engine: PHASE MOTION

March 2008

Brushless electric motor

Engine case: designed
by Univ. Pisa:

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

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

Weight incl. 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

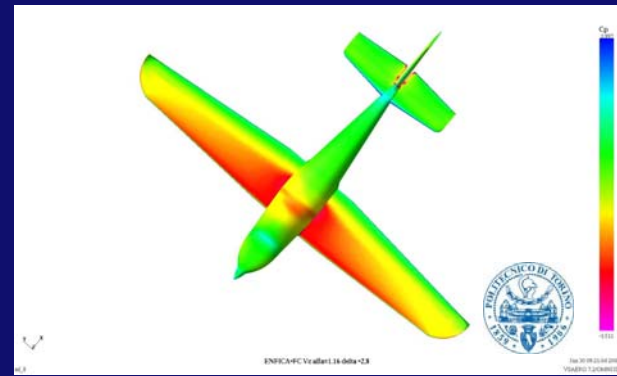
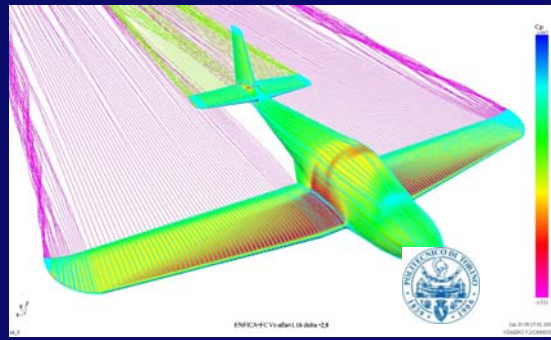
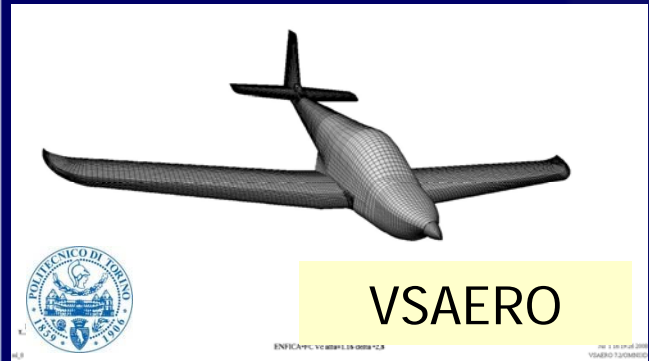
MAVEL srl
March 2009

**Constraint: Easy to
move for safe
recharge & for CG
requirements.
No inside leading
edge!!!!**



Environmentally Friendly Inter City Aircraft powered by Fuel Cells.

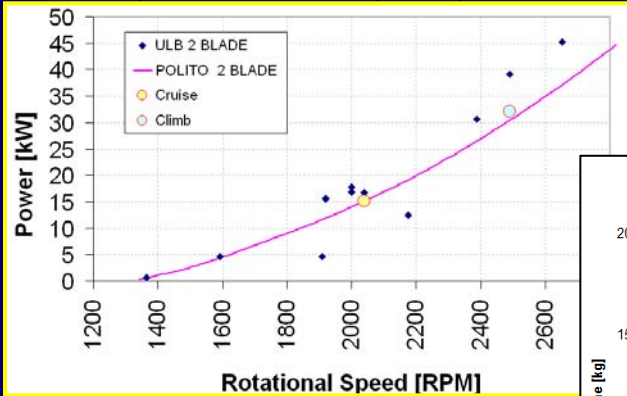
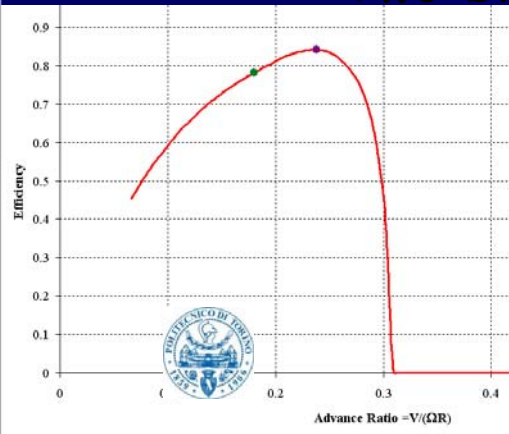
Aerodynamic Analysis Rapid 200 FC



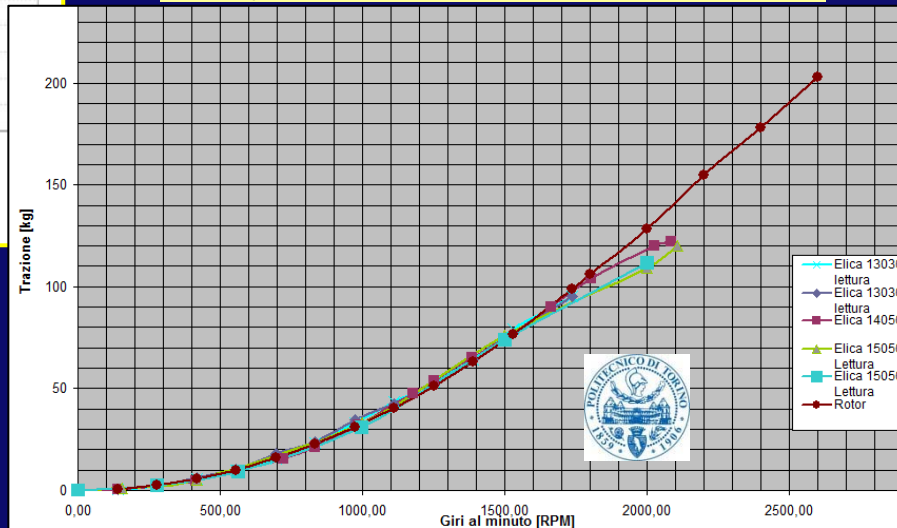
Wakes and On-Body Streamlines at Cruise speed, up view

Upper Surface Pressure Distribution, Cruise Speed

Two blade optimized propeller



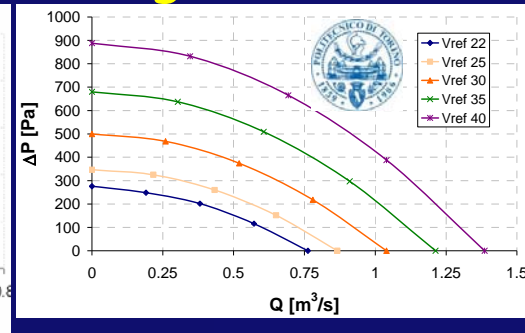
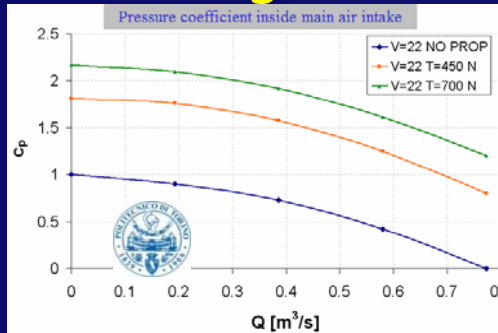
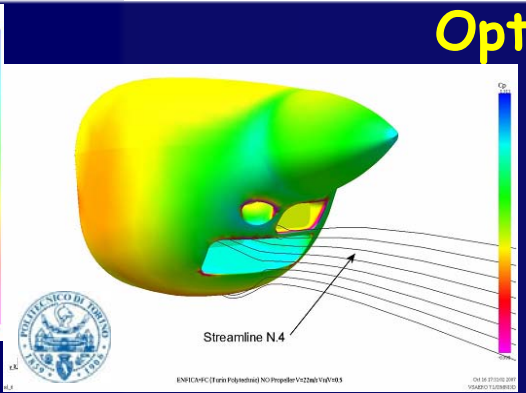
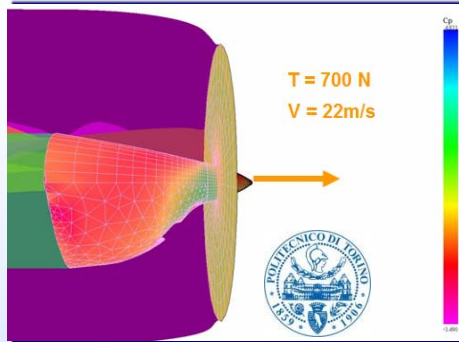
Analytical (Rotor) vs. Experimental



Climb - Cruise:

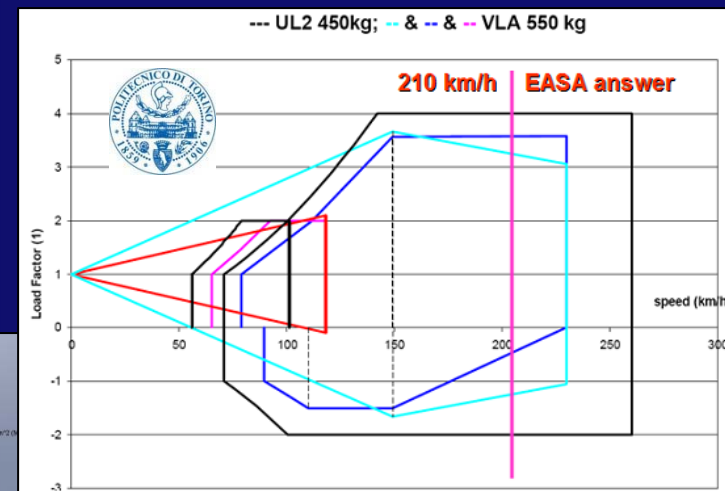
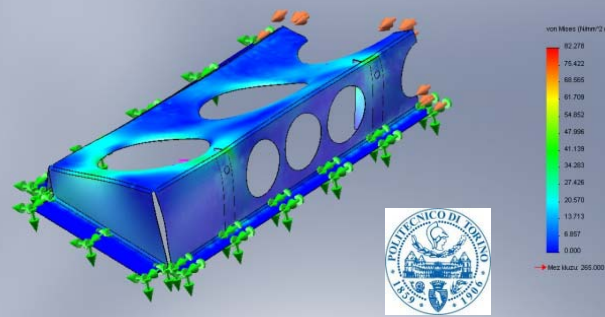
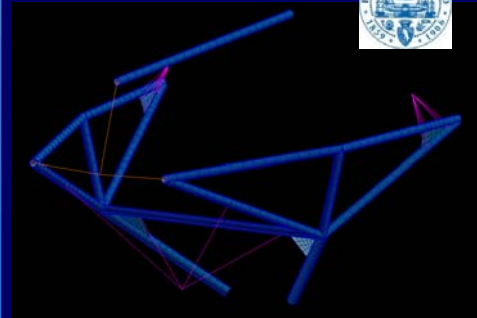
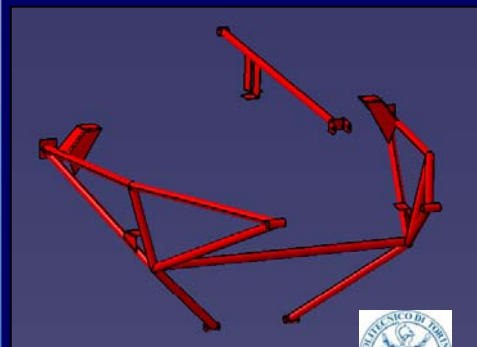
Thrust: 788 - 347N
 Torque: 145 - 78,7Nm
 rpm: 2190 - 2010
 Wind speed: 33 - 40 m/s
 Power Net: 33.25 - 16.56 kW
 Power gross: 36.85 - 18.35 kW





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%)



Fuselage Mock-up for Systems Functional Testing

- System Failure Testing
- Temperature & Software Testing



Integration on Real Prototype (Jihlavan Airplane) - Sept. 2009

Environmentally Friendly Inter City Aircraft powered by Fuel Cells.



Environmentally Friendly Inter City Aircraft powered by Fuel Cells.



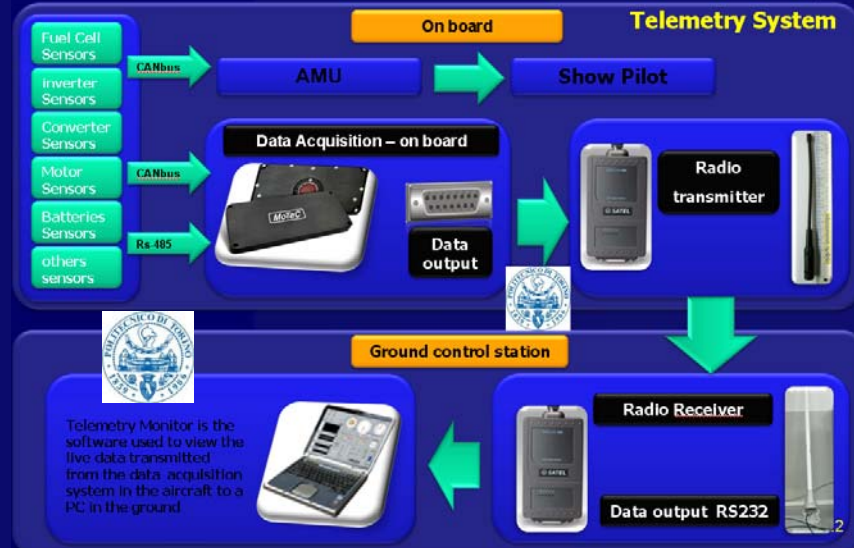
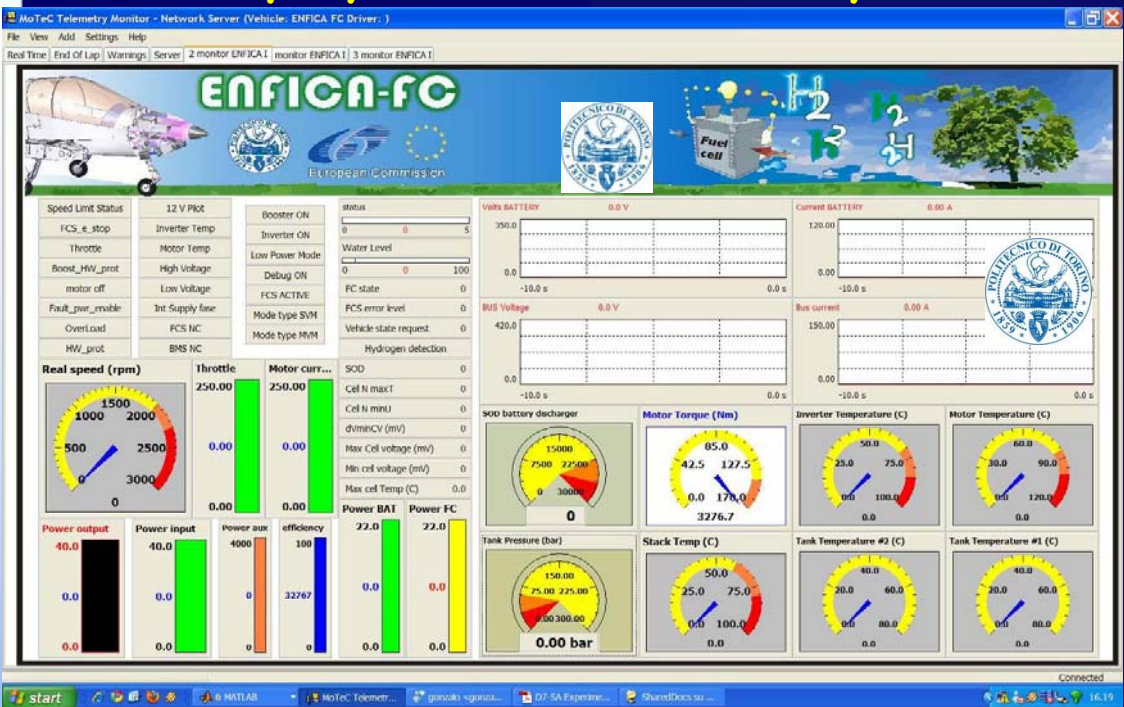
Aircraft Assembly

Reggio Emilia Airport - Italy



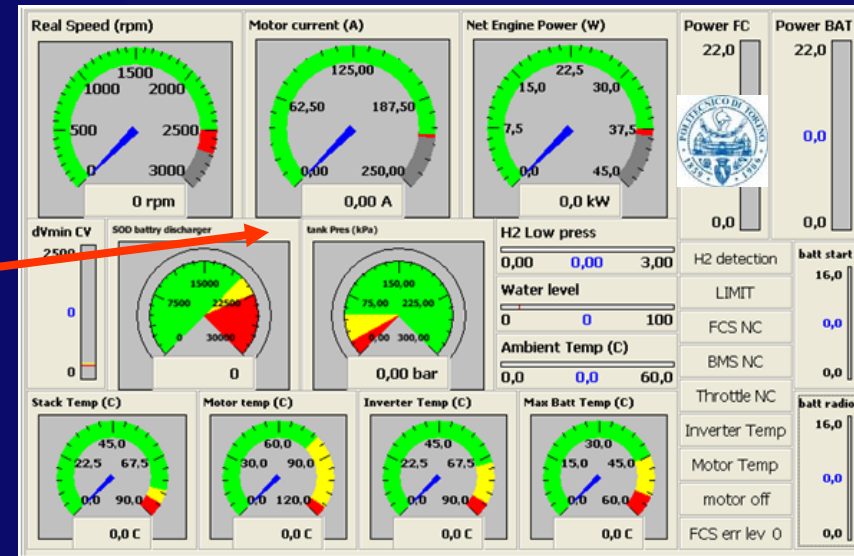
Environmentally Friendly Inter City Aircraft powered by Fuel Cells.

Telemetry System & Data Analysis



Main Digital Display and Back-up Digital Display

The MDD is highly configurable and every piece of information available on CANBUS can be showed as a user-definable instrument

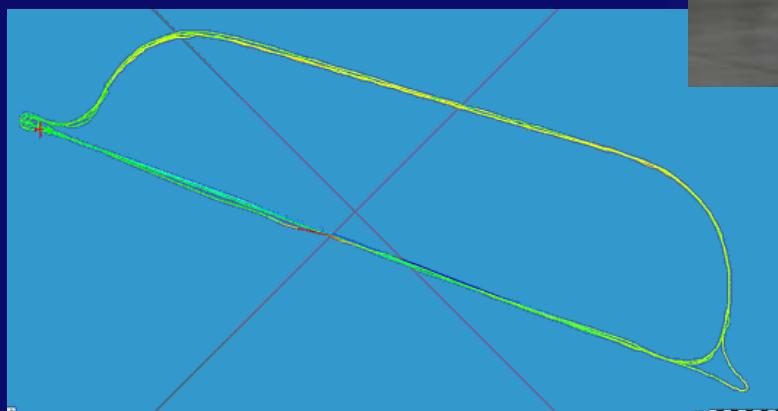


Environmentally Friendly Inter City Aircraft powered by Fuel Cells.

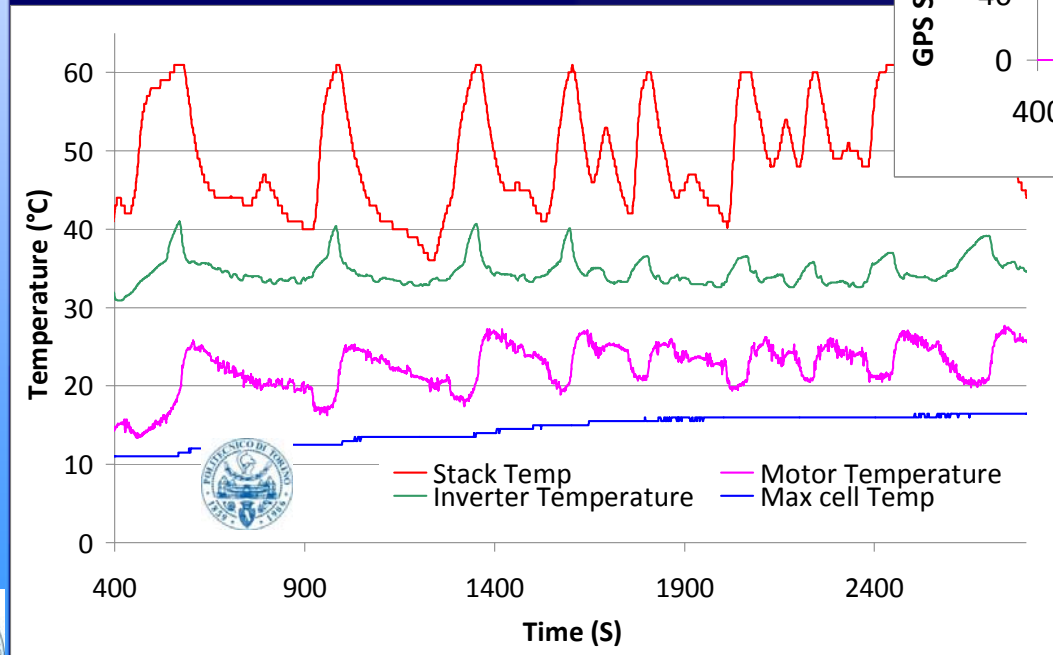
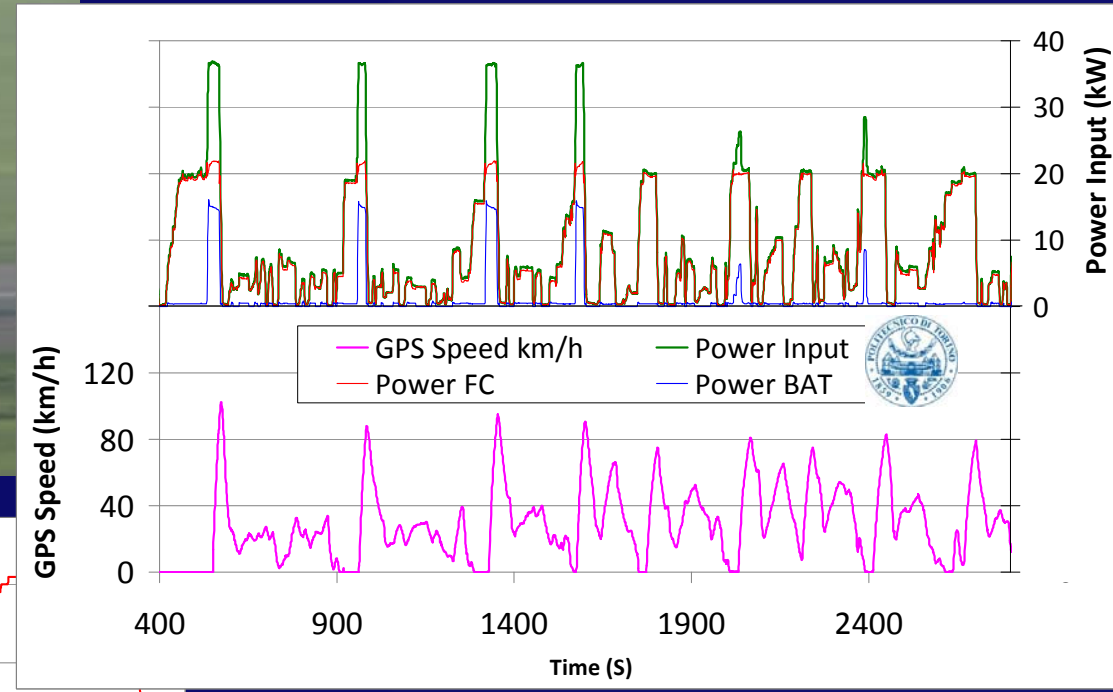
Ground and Roll Tests



© G. Romeo, POLITO, DIASP



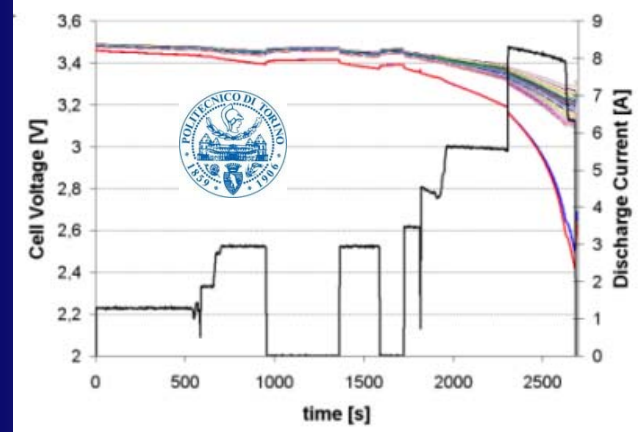
Taxi Tests - Dec. 2009 - Test N° 53



Environmentally Friendly Inter City Aircraft powered by Fuel Cells.



Battery Maintenance



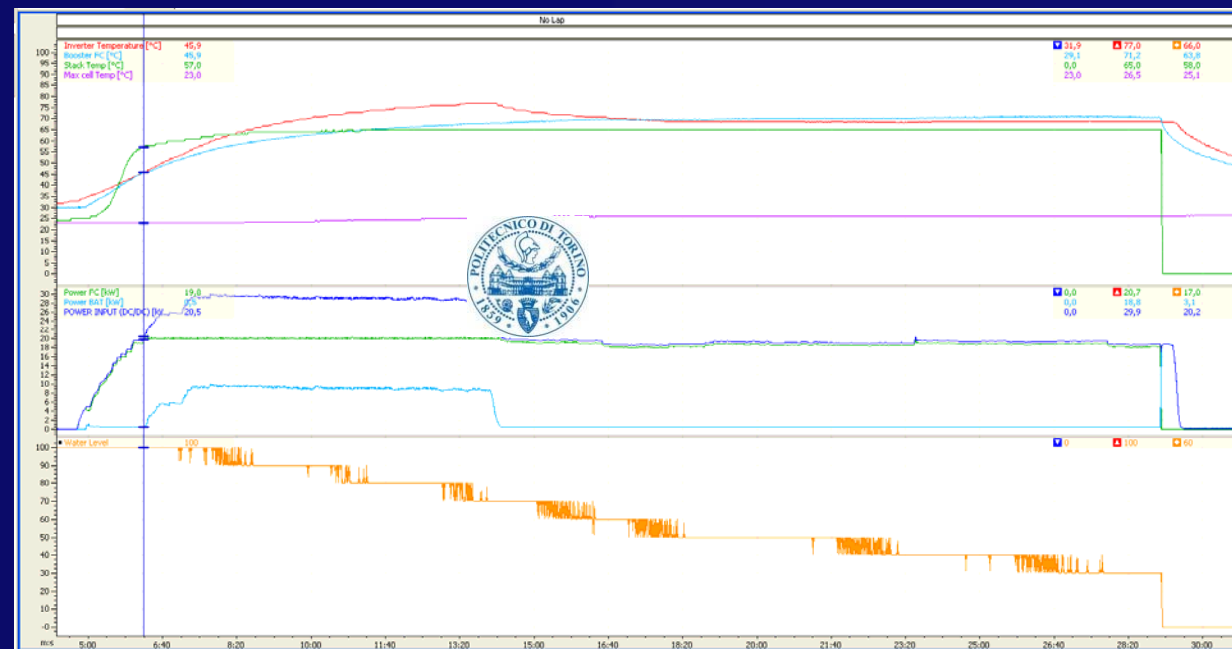
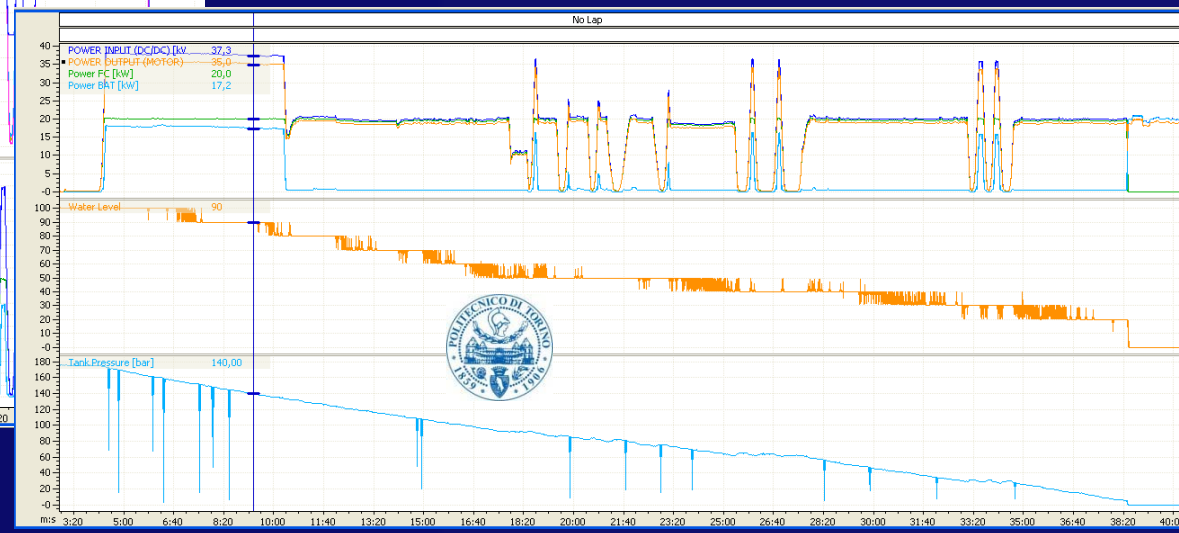
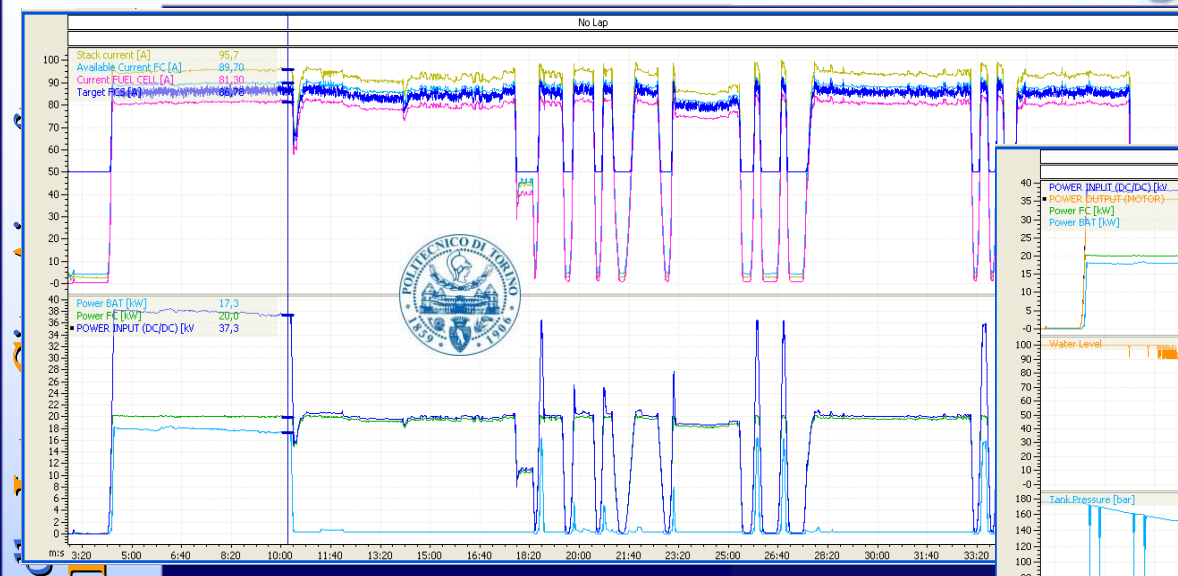
Inverter Maintenance



Test 93: Blending Power Test

Environmentally Friendly powered by

Test 95: Flight Duty cycle



ENvironmentally **F**riendly **I**nter **C**ity **A**ircraft
 powered by **F**uel **C**ells.



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
 - (1 day set-up time)



Hydrogen Fueller:
 APL & SAPIO



© Giulio Romeo, POLITO



Maiden Flight: 2 min



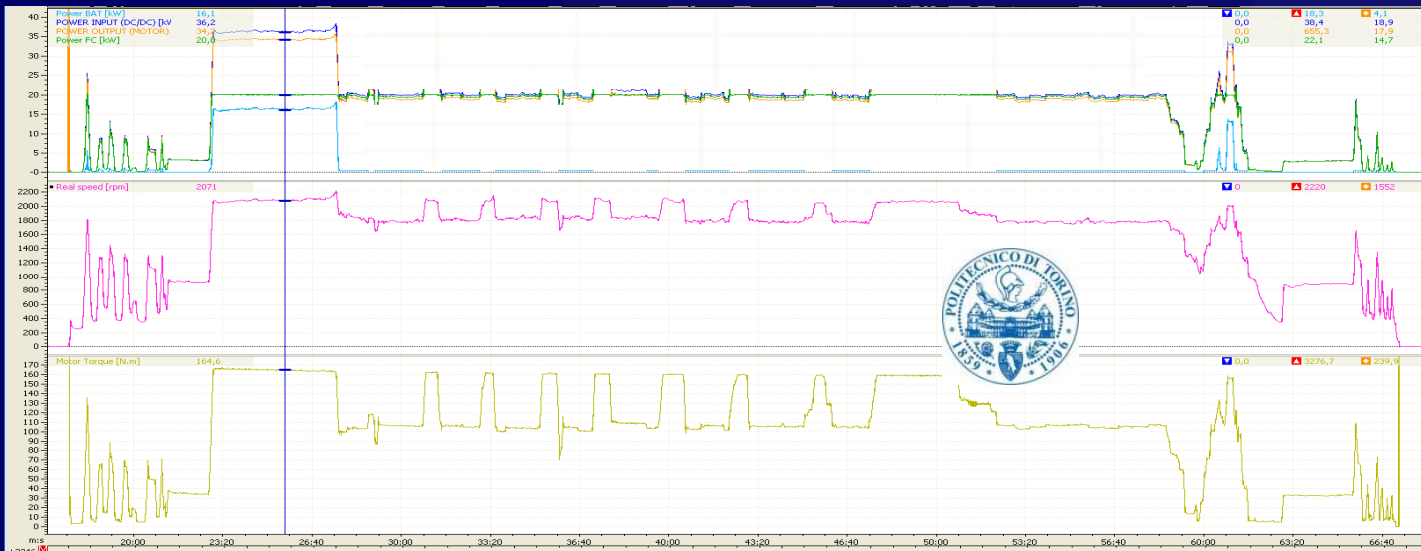
2° Flight: 11min

© Giulio Romeo, POLITO



Environmentally Friendly Inter City Aircraft
 powered by Fuel Cells.

Flight n. 3 ENDURANCE



Flight time: 39 min
Battery cons: -16 Ah

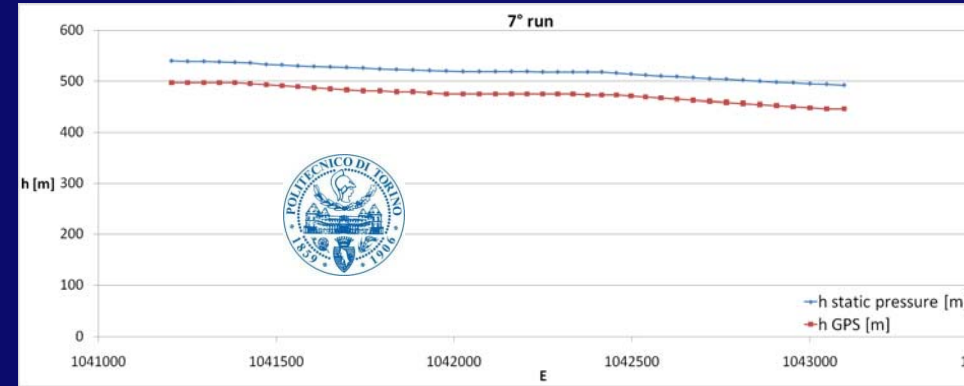
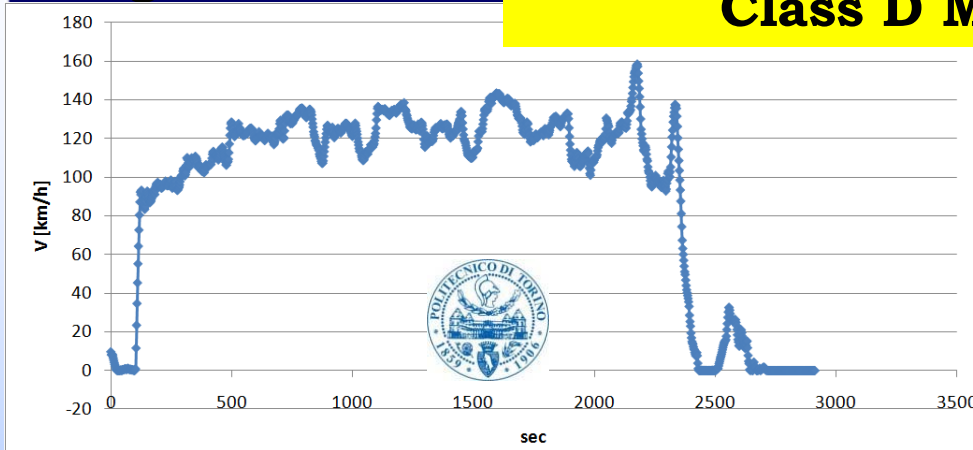
H2 consumption: -230 bar
Max GPS speed: 152 km/h



Flight n. 3

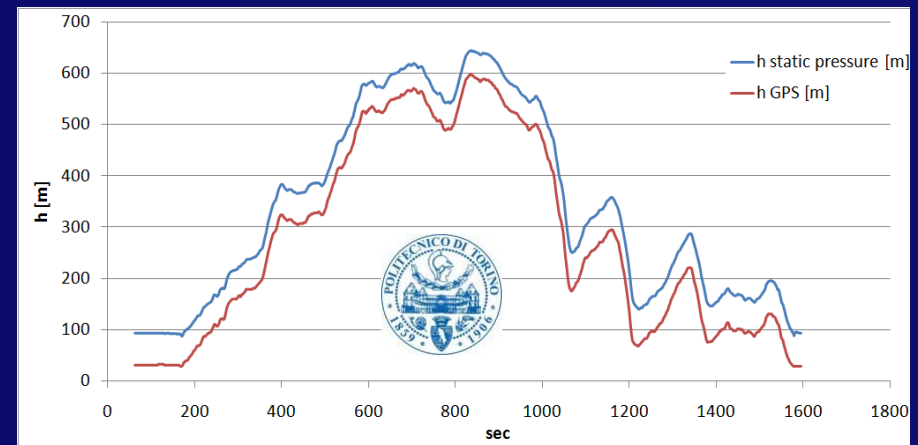
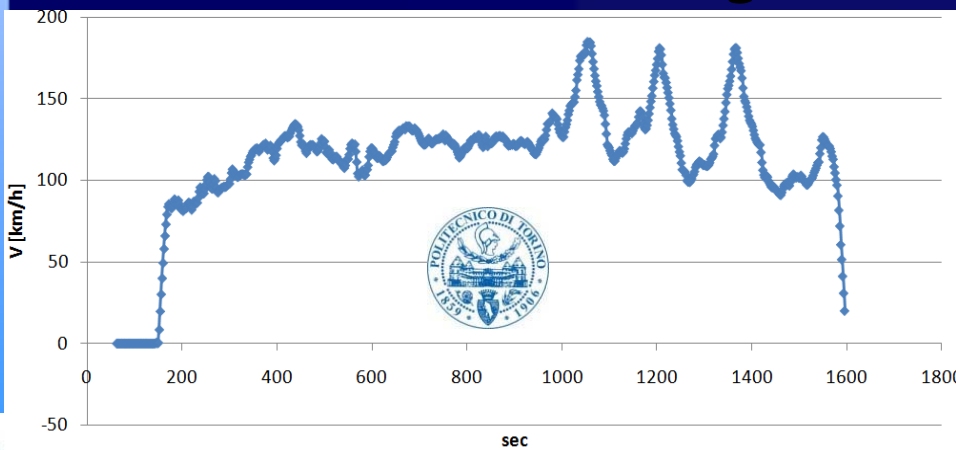
**FAI: Class C Aeroplane
Class D Motor-Glider**

**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**

Total tests carried out: 110**Total summary TEST - ENFICA-FC -RAPID 200**

	total time (min)	Fuel cell		Battery		Time inverter
		time FC	time max power	Time Batt	time max power	
Total MINUTE	1679,3	982	739,1	914	248,3	1667,3
TOTAL HOUR	27,98833	16,36667	12,31833	15,23333	4,138333	27,78833

**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.

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).

Environmentally Friendly Inter City Aircraft powered by Fuel Cells.



Prof. G. Romeo, Politecnico di Torino

THANKS FOR YOUR ATTENTION

The flight movies are loaded on:
www.enfica-fc.polito.it

