Fuel Cells for Aircraft Applications: Activities of DLR

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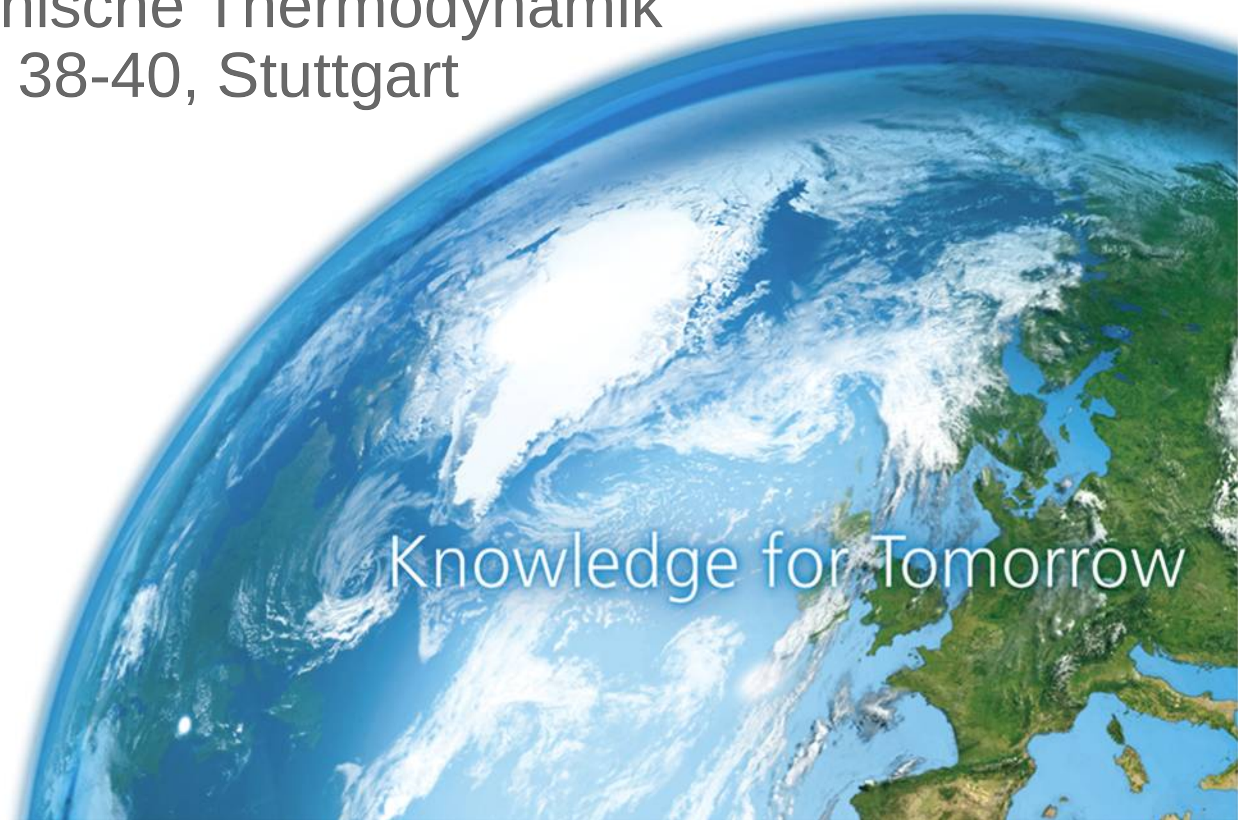


DLR

Motivation: ACARE* 2020 Goals

- Very ambitious targets. Specified in Vision 2020 and ACARE 2050:

Goal	Vision 2020	ACARE 2050
CO_2 Emission Reduction (Reduction per passenger kilometer)	50%	75%
NOx Emission Reduction (Reduction per passenger kilometer)	80%	90%
External Noise Reduction (Reduction per flying aircraft)	50%	65%
Fuel Consumption Reduction (Reduction per flying aircraft)	50%	NA

* Advisory Aeronautics Research in Europe

http://www.acare4europe.org/docs/Vision 2020.pdf

http://www.acare4europe.org/docs/Flightpath2050_Final.pdf

Motivation for Fuel Cell System Application

Ecological and Economical A/C Operation Aspects

Ecological Aspects:

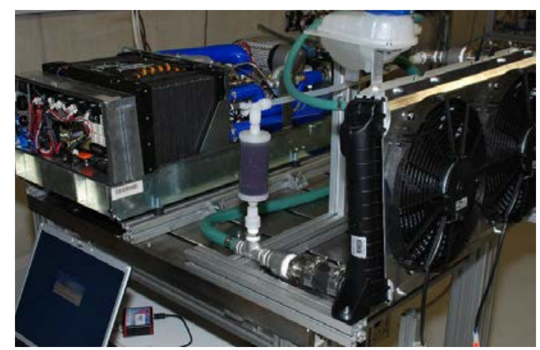
Emission reduction

Higher fuel economy

Noise reduction

$\eta_{APU} \sim 20\ \%$

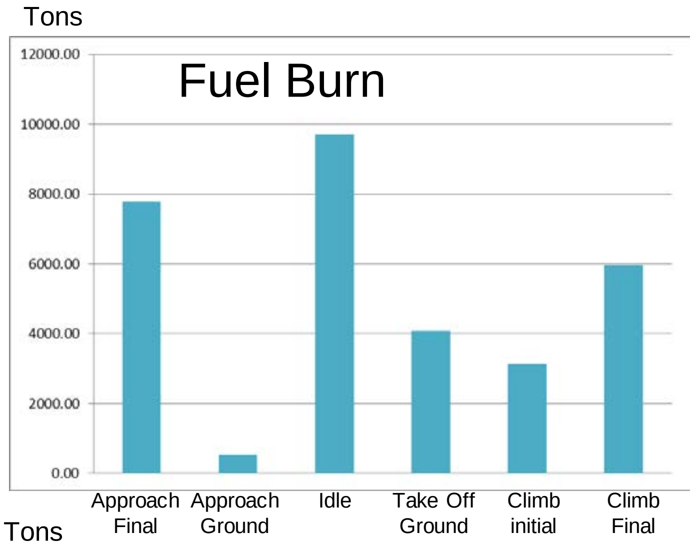
$\eta_{idle} \sim 10\ \%$

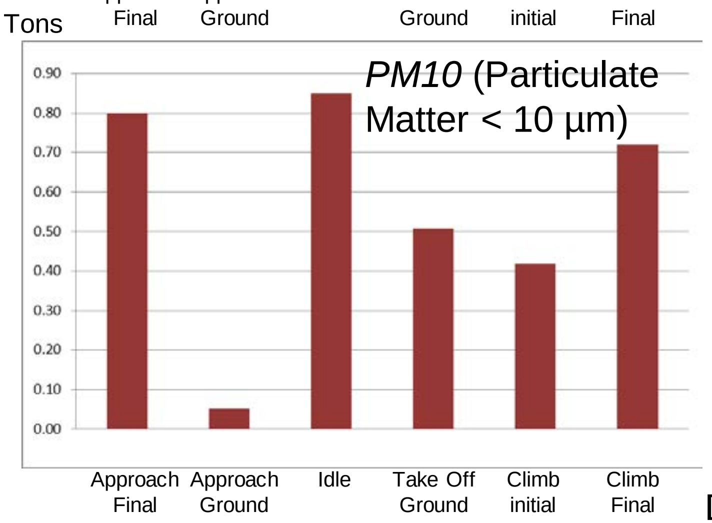


$\eta_{APU} \sim 40\ \%$

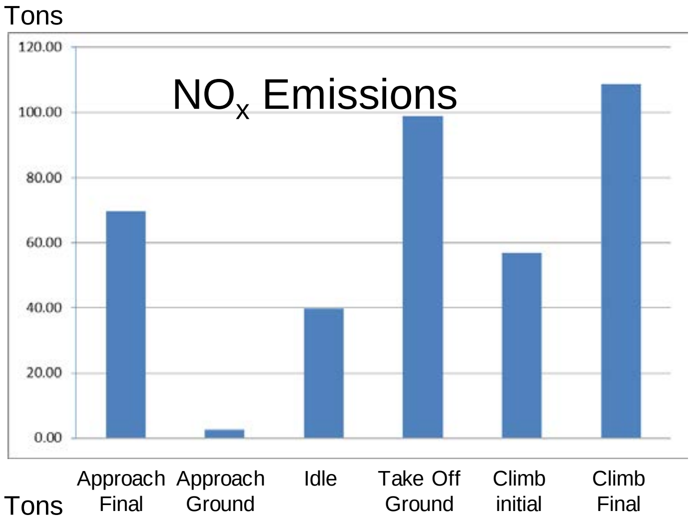
$\eta_{idle} \sim 50\ \%$

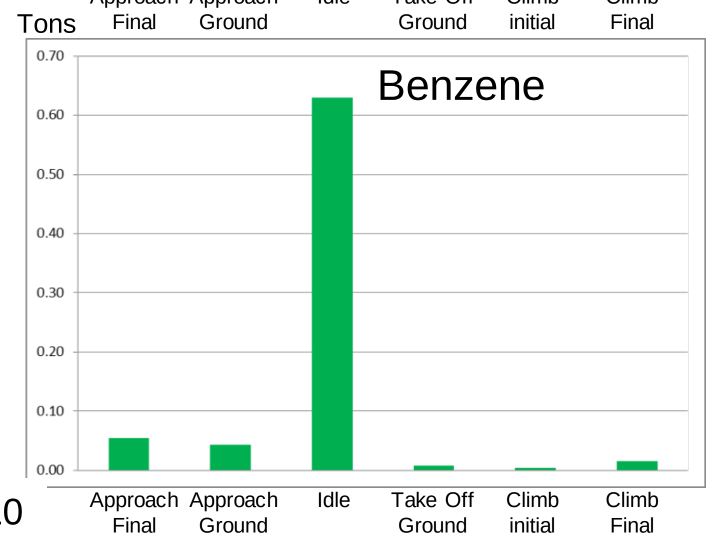
Ecological Aspects at Airports





- **35%** of **fuel consumption** from idling engines or APU (ca. 10 kT/ year or 5680 Flights STR-HAM)
- Ca. **11% of nitrous oxides emissions from idling engines or APU**
- Ca. **45%** of **particulate matter** from APU operation
- Ca. 91**%** of **Benzene** emissions from APU or idling engines



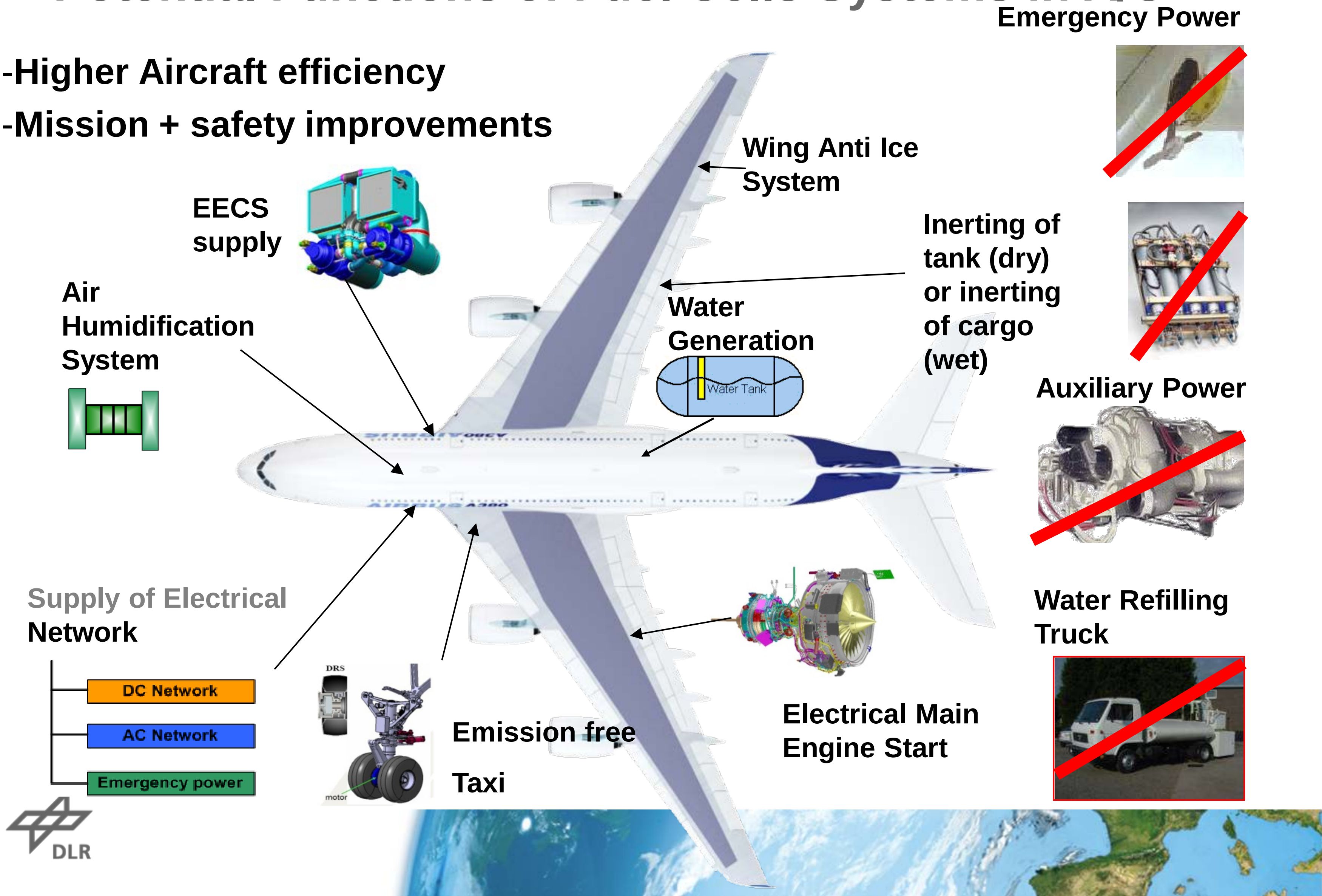


Data: Airport Stuttgart 2010

Potential Functions of Fuel Cells Systems in A/C

-Higher Aircraft efficiency

-Mission + safety improvements



DLR Demonstrators and Research Aircraft

- Multifunctional Auxiliary Power Unit for commercial passenger aircraft (large market and Airbus interest)

A320 ATRA
used in collaboration with Airbus

- Motor glider as test platform with propulsion system for general aviation, military and surveillance

Antares DLR-H2
Test platform and research

Fuel Cell System Development

2008	2010	2011	2012
Emergy Power RAT Replacement	Electric Flying with Fuel Cells	Multifunctional use of Fuel Cells in Aircraft	
First use of DLR 320 ATRA with Fuel cell integration / Airbus Integration	First public flight in Hamburg of Antares DLR H2 with only fuel cell power and HT Fuel cells	Demonstration of e-Taxiing with DLR 320 ATRA	Highly integrated Fuel Cell System in Antares / Endurance flights

Clean Tech Media Award for DLR 2012

Green Tech Award for Airbus 2013

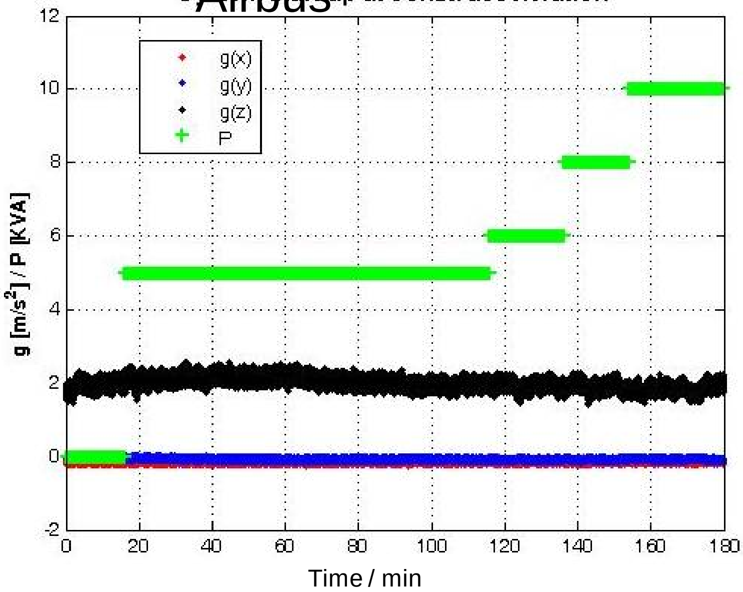
Initial Results – Fuel Cell Emergency Power System Test Flights 2008

- Immediate power after failure of power generation
- Integration into the aircraft body -> independent of flight velocity

Benefits compared to Ram Air Turbine:

- Weight reduction without influence on flow resistance
- Possibility of switch-off and reactivation of system
- **Maximum power independent of flight phase (flight velocity and flight height)**
- **Less maintenance (no moving parts)**

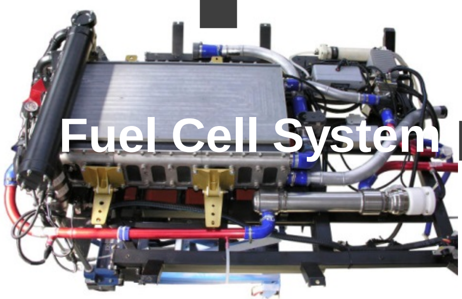
Test flights performed in cooperation with Airbus 2008; integration by Airbus



→ Constant power during acceleration in flight (30.000ft)!

Multifunctional Fuel Cell System (Airbus Concept)

Gaseous Hydrogen or <u>Liquid Hydrogen (cryogenic)</u> or Compressed Cryogenic Hydrogen



Heat
1. Icing prevention
2. Cooling

Elec. Power
1. ECS
2. Main Engine Start
3. Autonomous taxiing
4. Emergency Power
5. Ground Power

Condenser / Separator

Water
1. Potable Water
2. Toilet Flush Water
3. Engine injection

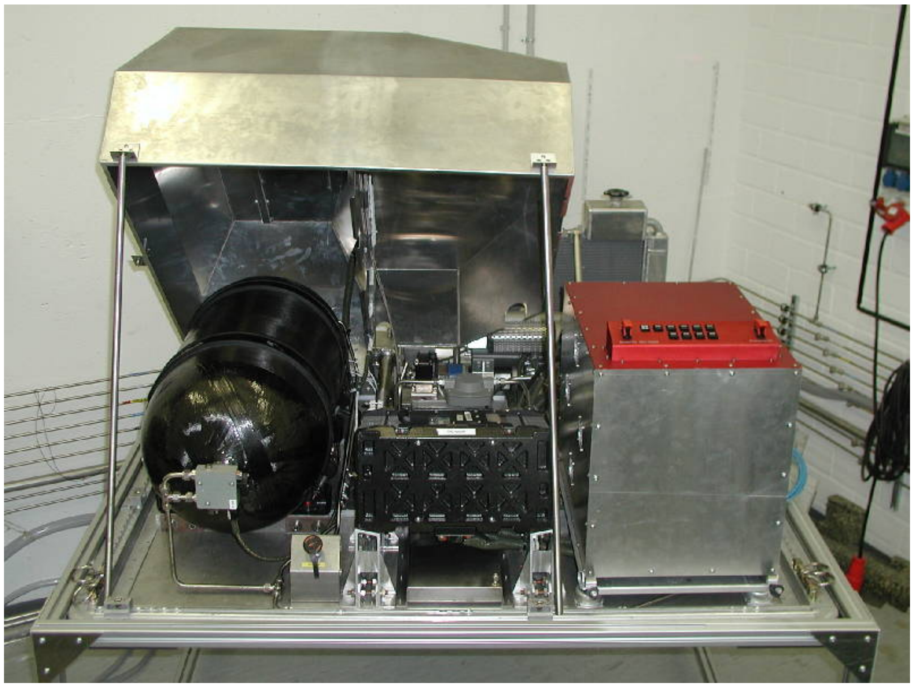
Gas / Gas humidifier

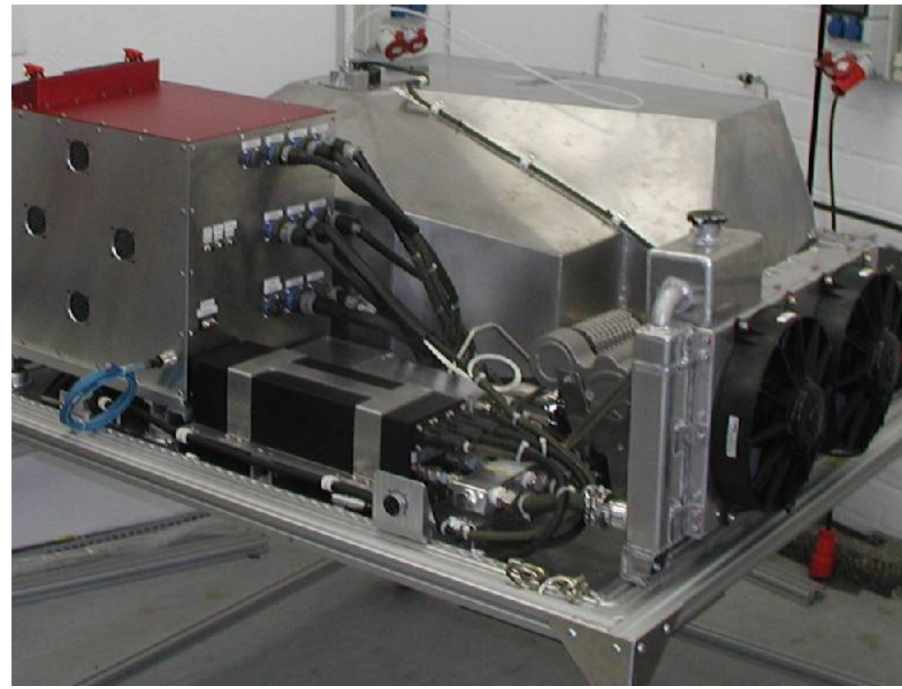
Humid Air
1. Cockpit air
2. Cabin air

Inert Gas
1. Fuel tanks
2. Cargo Inerting
3. Fire extinguishing

DLR

DLR Fuel Cell System for Flight Testing





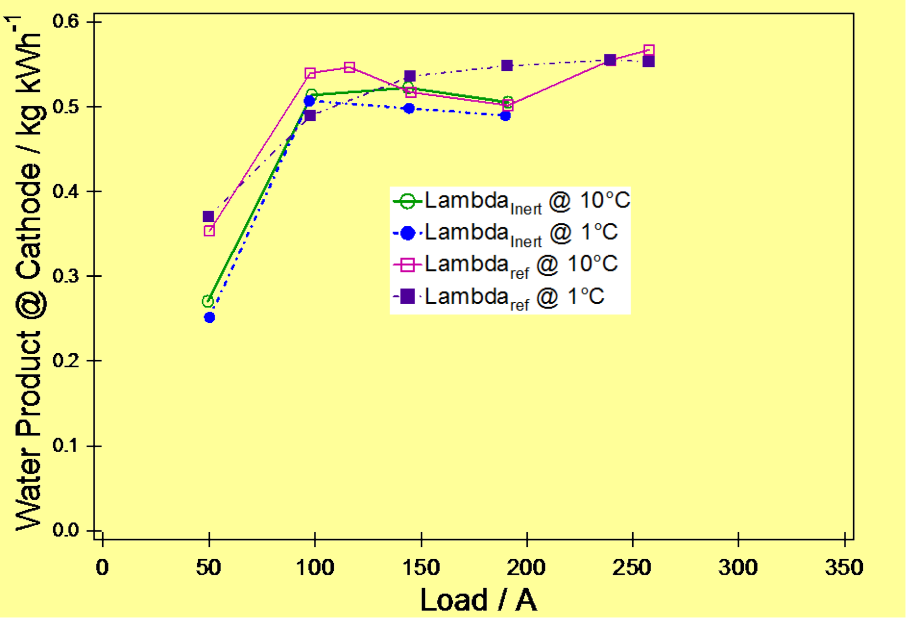
Air Fuel Cell System for multifunctional use: Power > 12.5 kW

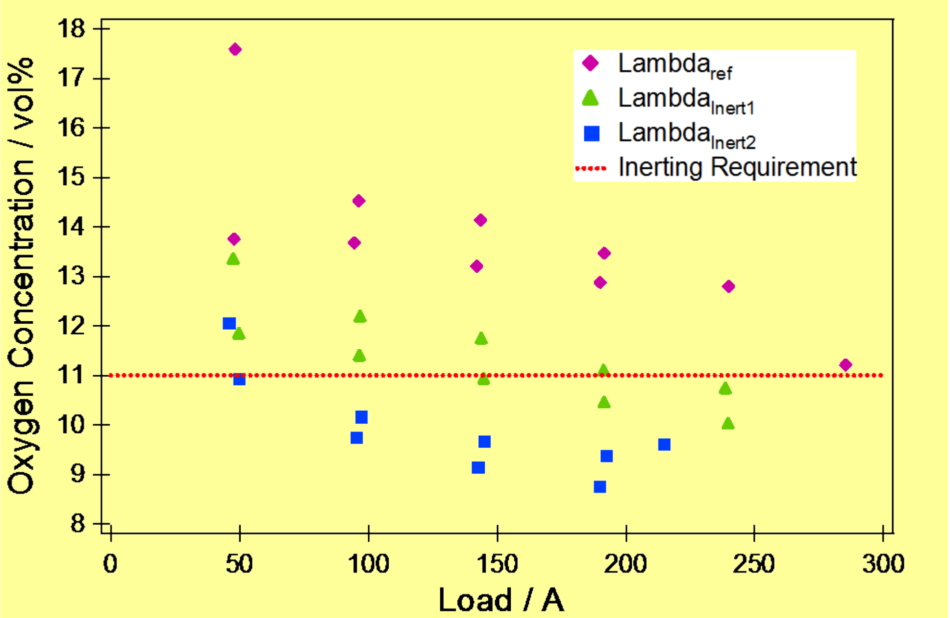
Water generation and inerting function demonstrated

Multifunctional Fuel Cell System

System of 12 kW electrical power with aircraft relevant design shows inert gas generation (oxygen content < 12 Vol.%) and water generation

Major importance is air stoichometry





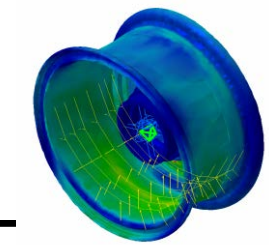
Modelling for flight operation according to Federal Aviation Administration (FAA) publications

DLR Development Emission-free Taxiing with Fuel Cell and Electric Nose Wheel Drive

Multifunctional fuel cell system in cargo bay
- Output Voltage 300 VDC

DC/DC
+
DC/AC

Control Box and Data Aquisition



High Torque 11.000 Nm

DLR Development Emission-free Taxiing

Emmission free taxi on ground (nose wheel or main wheel)
Saves up to 1200h/year engine time with lower emissions (e.q. A320)

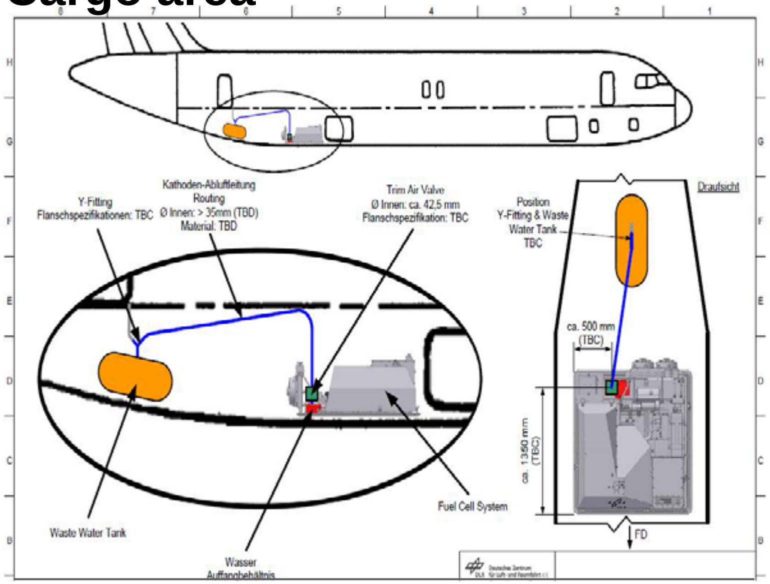
Fuel cell driven nose wheel drive of an Airbus A320

→ Test on A/C 2011

System Installation of DLR Fuel Cell System in Airbus A320 ATRA

(Advanced Technology Research Aircraft)

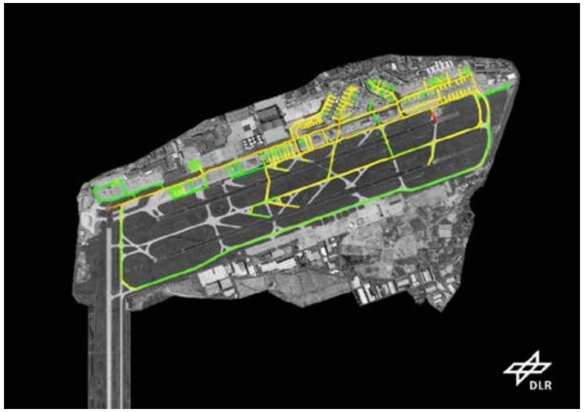
Installation of fuel cell in the Cargo area



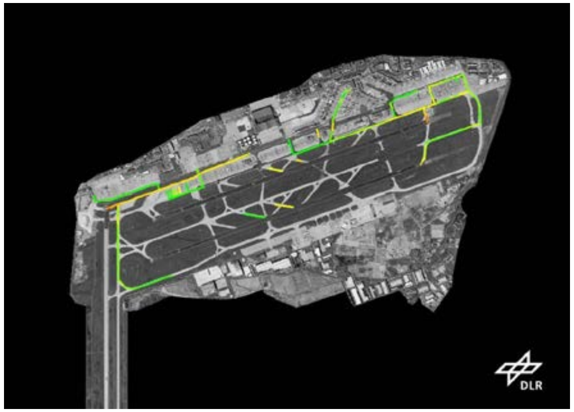
Electrical drive in nose wheel

Savings Potential (calculated for Frankfurt – Airport)

fuel consumption A320 + B737 conventional



fuel consumption A320 + B737 electrical drive



	Saving by fuel cell technology	
Jet fuel	44.267 kg/d	(-18,2 %)
CO_2 emissions	- 135.919 kg/d	(-18,7 %)
H_2O emissions	- 53.375 kg/d	(-18,7 %)

Reduction of acoustic noise
120 dB(A) < 60 dB(A)
(ref: A 320)

Development of system concepts for multifunctional A/C applications

QFCS – theoretical analysis for inerting (ODS)

System Req

primary

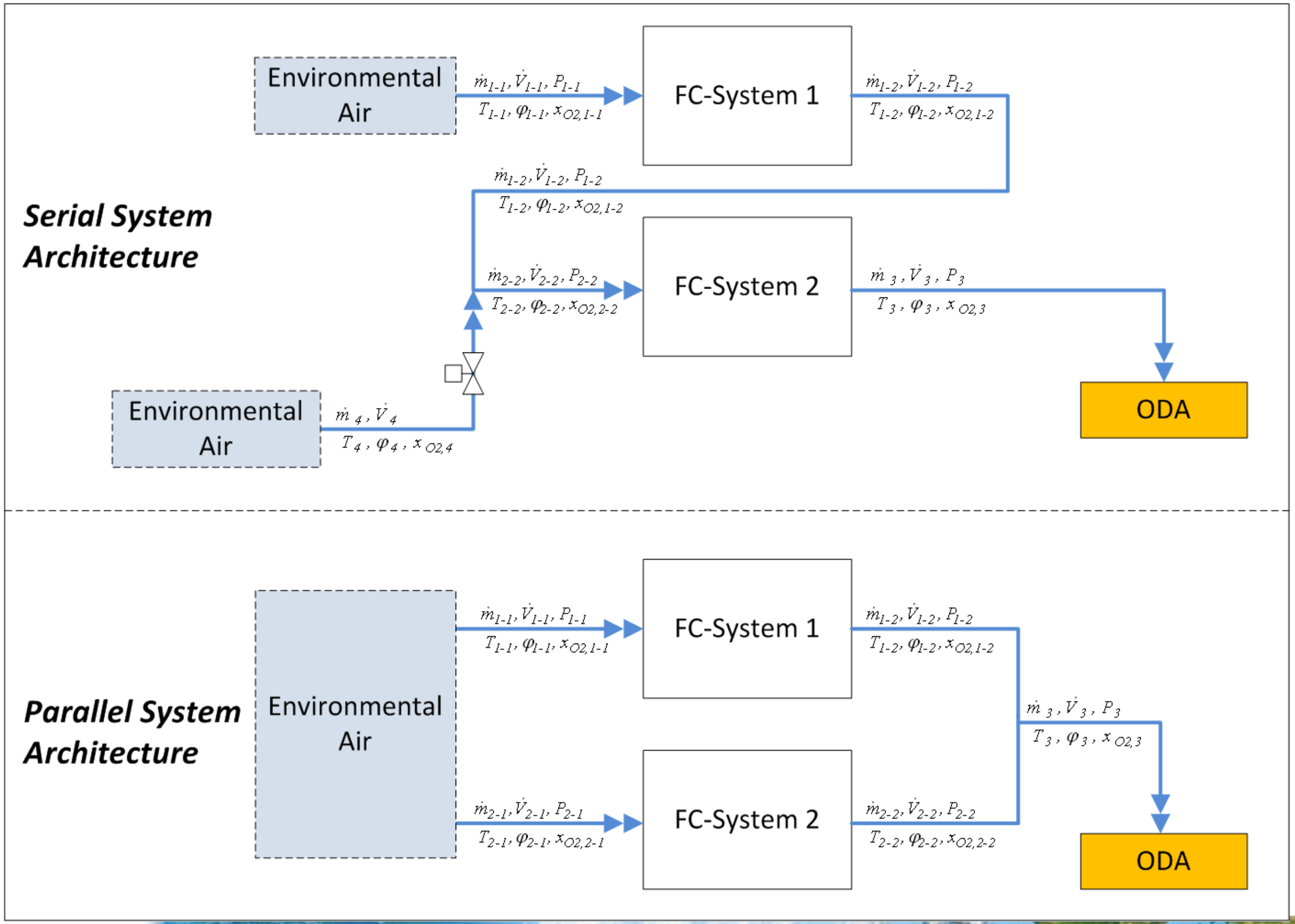
- Generation of O2 depleted air (ODA)

secondary

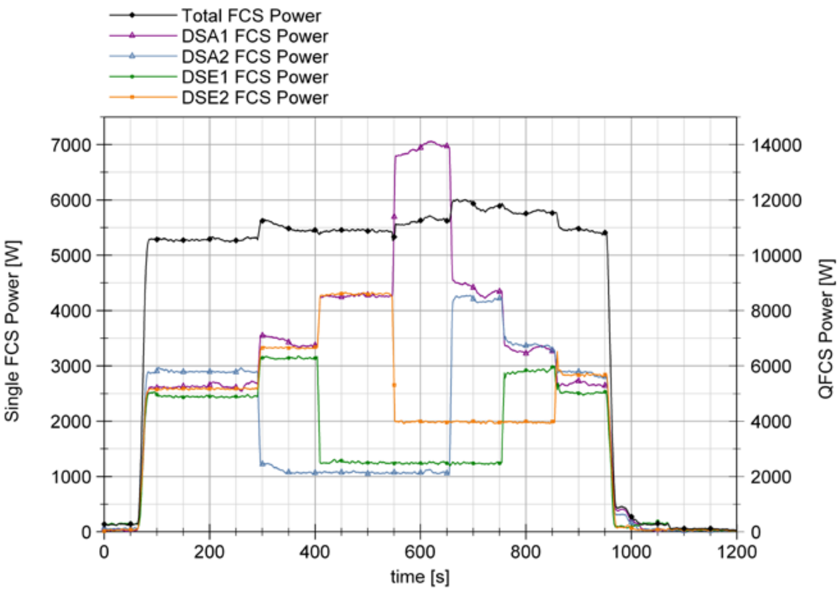
- P_{el}
- Water generation

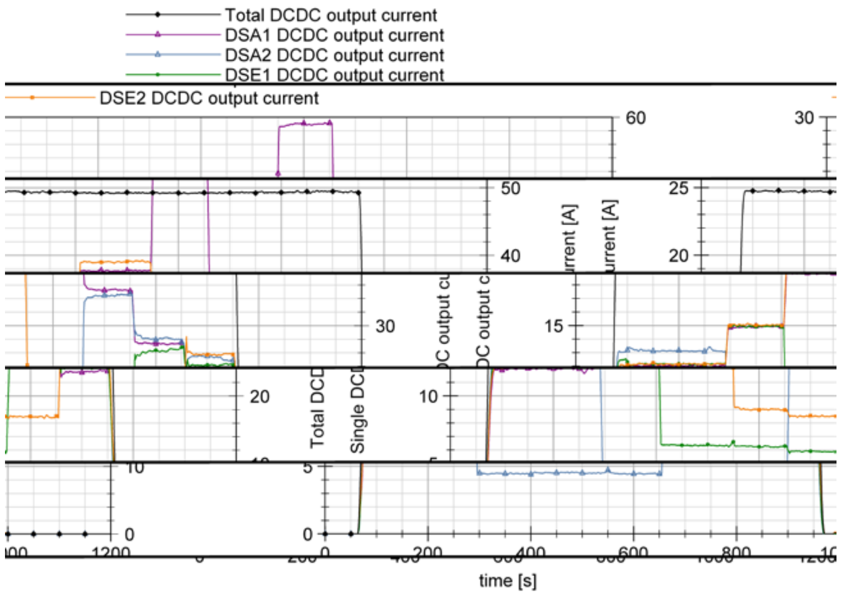
Architecture Req

- high P_{el}
- redundancy
- „Fail safe“ concept
- reliability
- flexibility
- Multi-functional capability



Demonstration of prototypes - multiple system coupling;





Example: Power output of 3 systems defined, 4. system „floating“

→ load distribution of subsystem can be controlled in a flexible way

→ „floating“ system provides the necessary load for power output

→ high redundancy

Demonstration of Prototypes

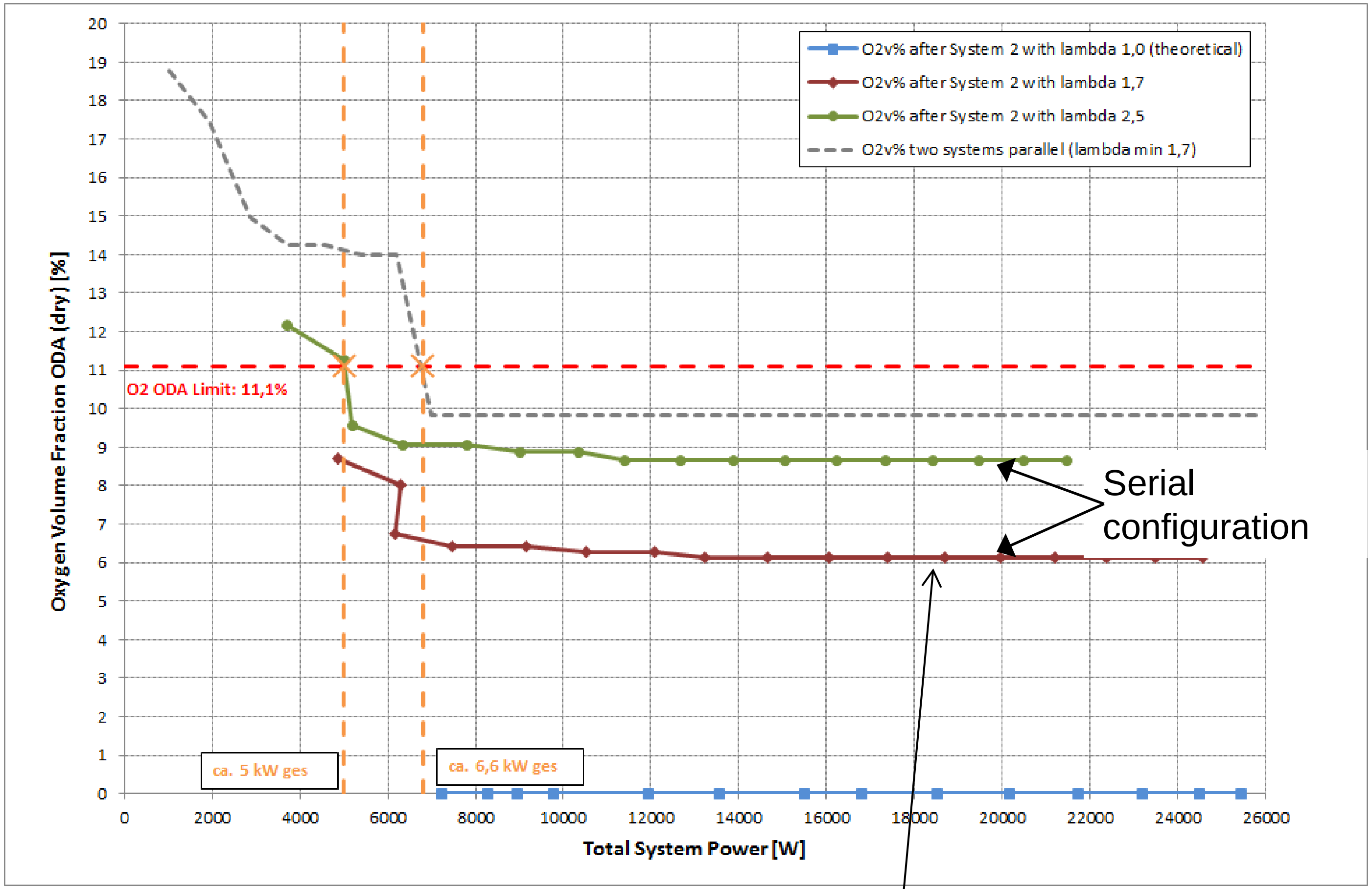
QFCS – conception² Architecture – Experimental Analysis for Inerting

Serial Architecture

- More flexibility for system control
- Low minimum power for ODA generation with <11.1%-O_2
- Optimal adaption of λ_{cath} for operation possible

Parallel Architecture

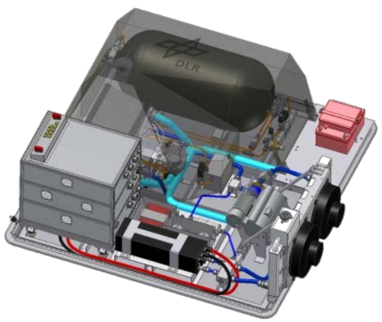
- ODA x_{O2} stoichiometry limit of λ_{cath}=*1.8* is possible
- So far no optimization of ODA generation with dynamics and water management possible



ODA – gas composition with < 11%Vol O_2

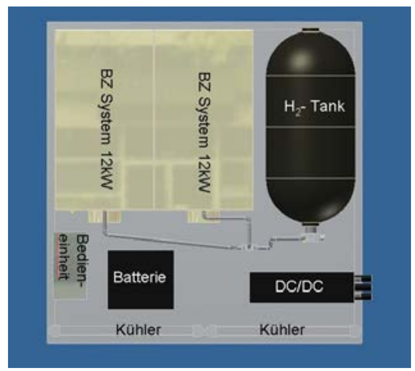
Fuel Cell Aircraft and Airport Applications at the DLR

Airworthy technology development platform for A320



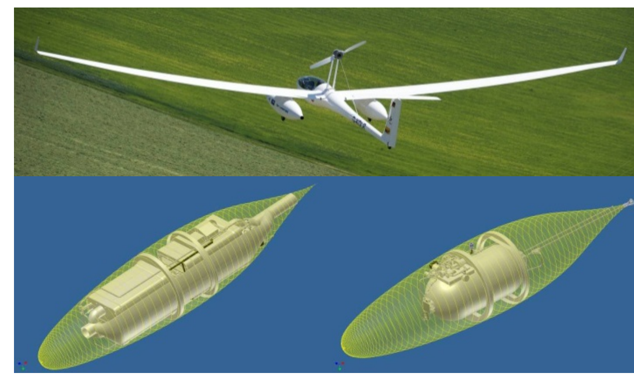
- for emergengy power
- for multifunctional use
  → APU
- energy source for nose wheel drive

Modular architecture development platform



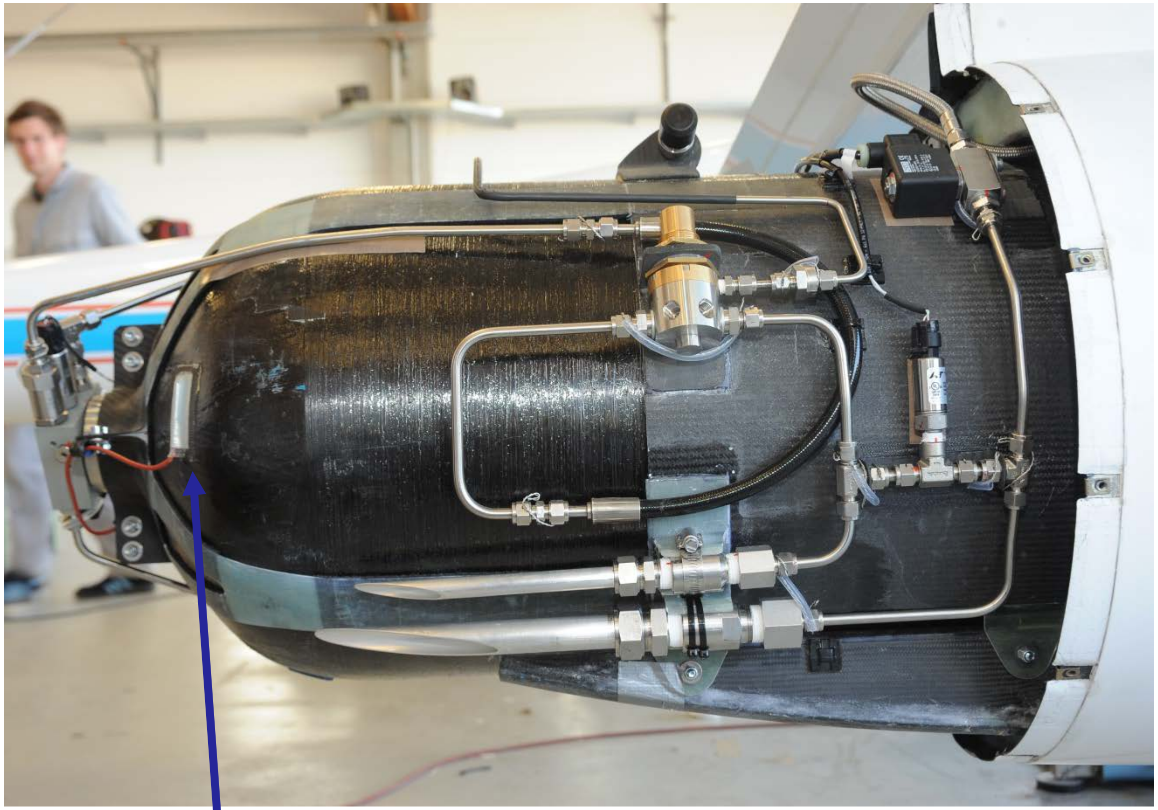
- for GPU applications
- for high torque airport applications (transport)

Modular airworthy propulsion platform Antares DLR H2



- for UAV applications
- for general aviation (up to 6 Pax or utility)

Hydrogen storage system



In-tank valve

2 in-tank valves:
- 1 operation
- 1 emergency bypass

Pressure regulator:
- 350 bar → 8 bar

Temperature measurement unit

Tank:

Dynetec W205
Dimensions 415mm x 2110 mm
Weight 99,5 kg
Volume 74 Liter,

H_2 capacity 4.89 kg at 350 bar → max. 5 h flight time

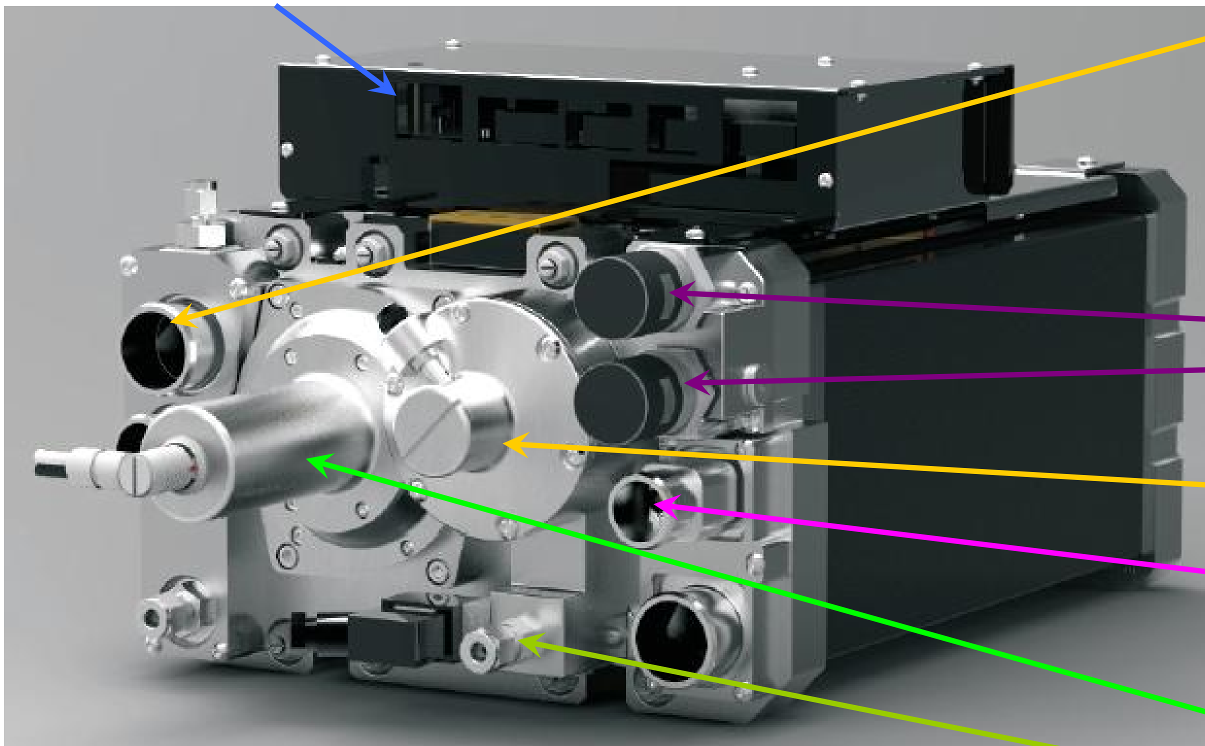
Fuel cell technology Antares DLR H2

Modular fuel cell system with cooling booster

Fuel cell system power up to 33 kW_{net}

→ modular system 3 x 11 kW
→ liquid cooled

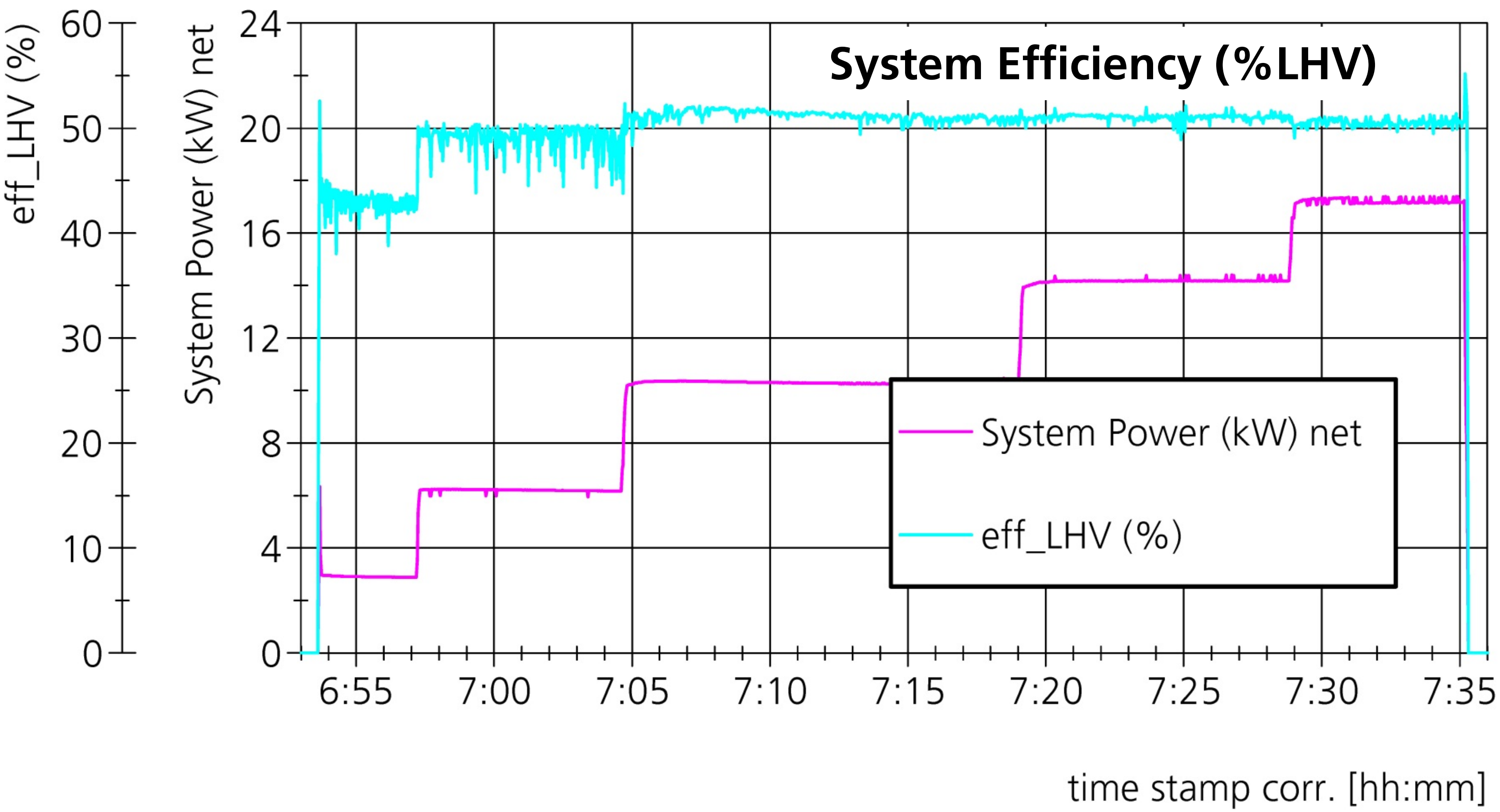
LT - Next generation medium area fuel cell system Hydrogenics



Base unit 100 cells, metallic insulated connectors up to 360V
Medium active area → up to 11 kWnet per module
Temp up to 80° C, low pressure drop (ca. 150 mbar at max. power)

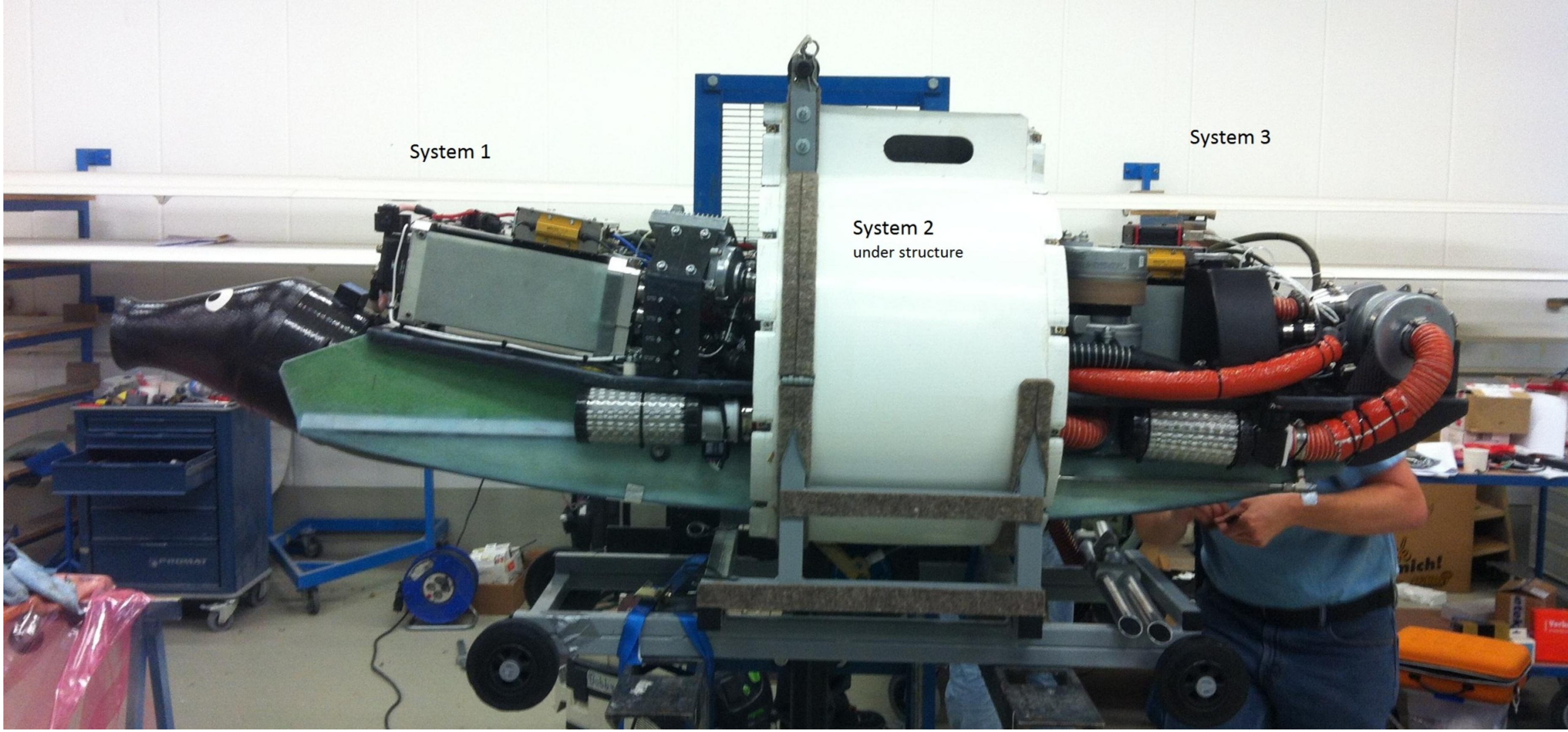
LT - Next generation medium area fuel cell system

Lab Test – system efficiency 3 modules

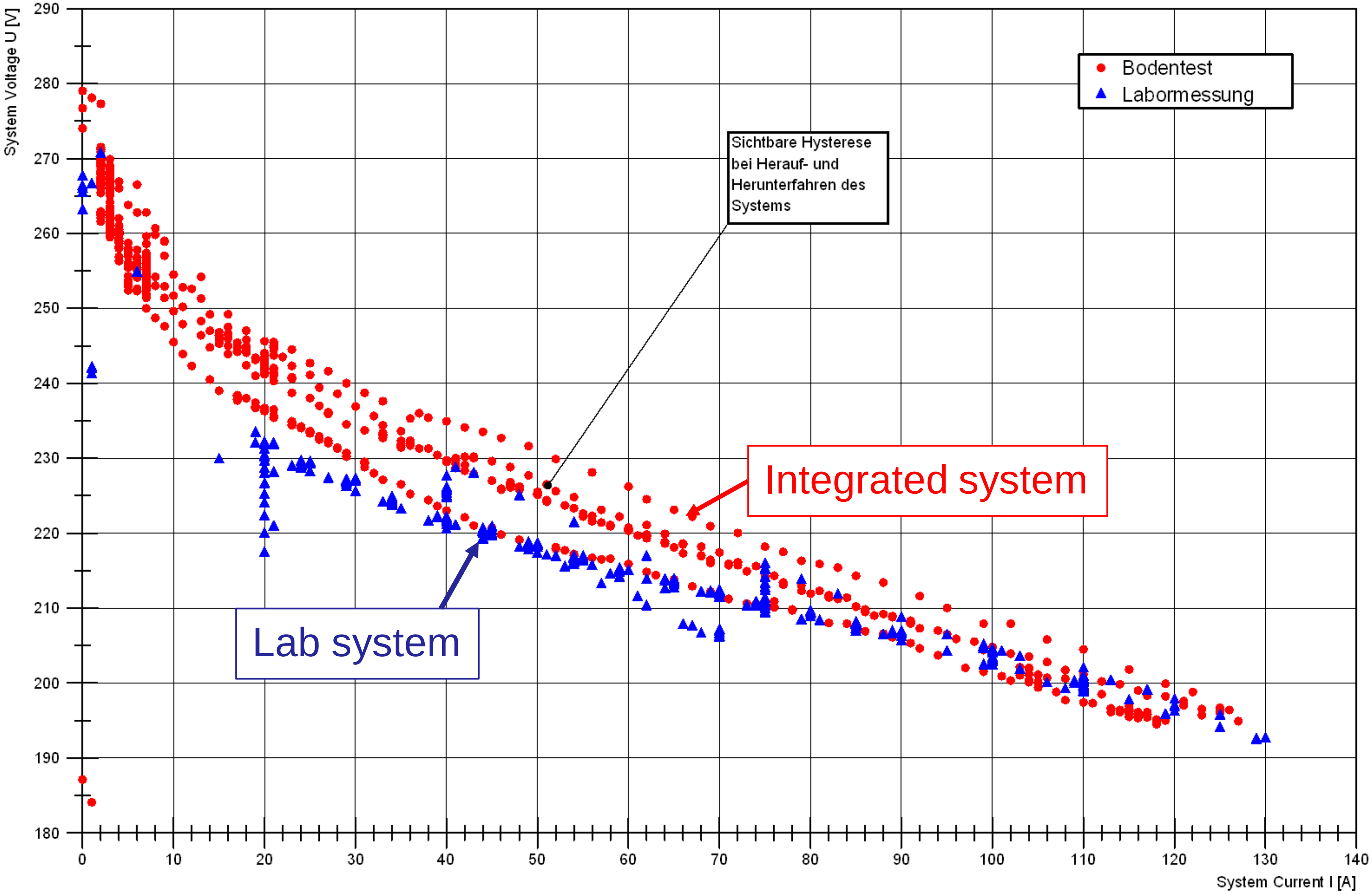


- System efficiency including cathode blower > 50% LHV (without cooling pump)

Highly integrated fuel cell system with customized parts



Startup of integrated system on ground



Highly integrated fuel cell system in flight

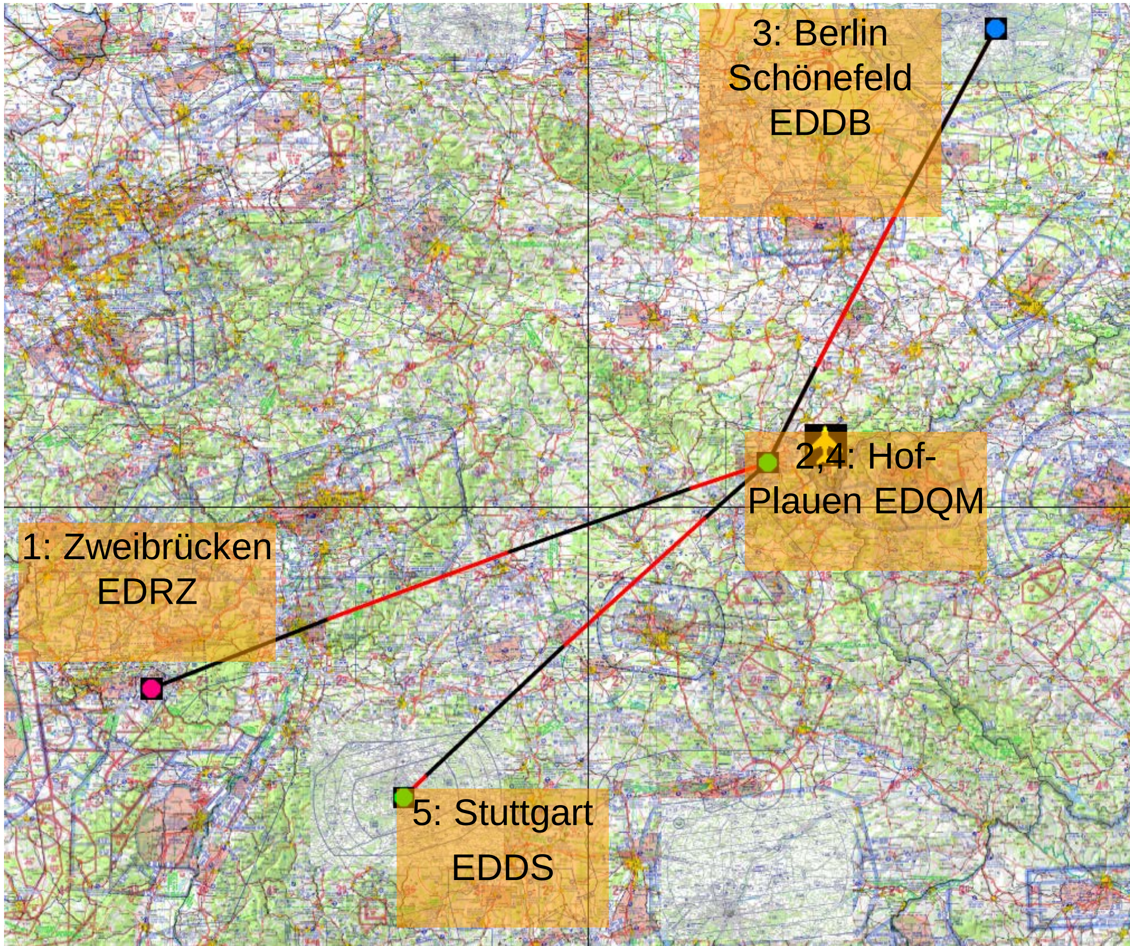
First flight on fuel cell with new systems → 7.09.2012

Bundesministerium für Verkehr, Bau und Stadtentwicklung

NOW Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie

DLR

Fuel cell „Germany Tour“ – Antares DLR H2



Hof - Stuttgart

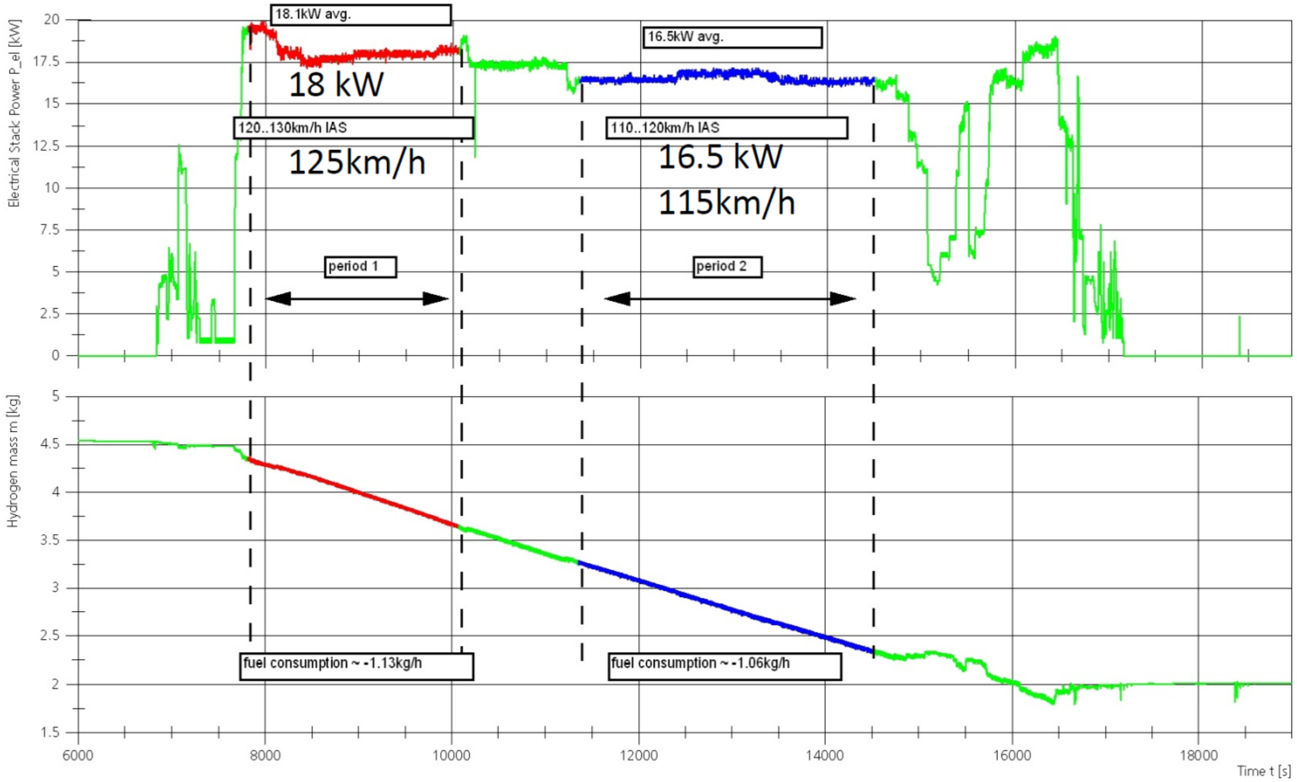
2 hours 18 minutes

295,5 km

ca. 2,2kg hydrogen

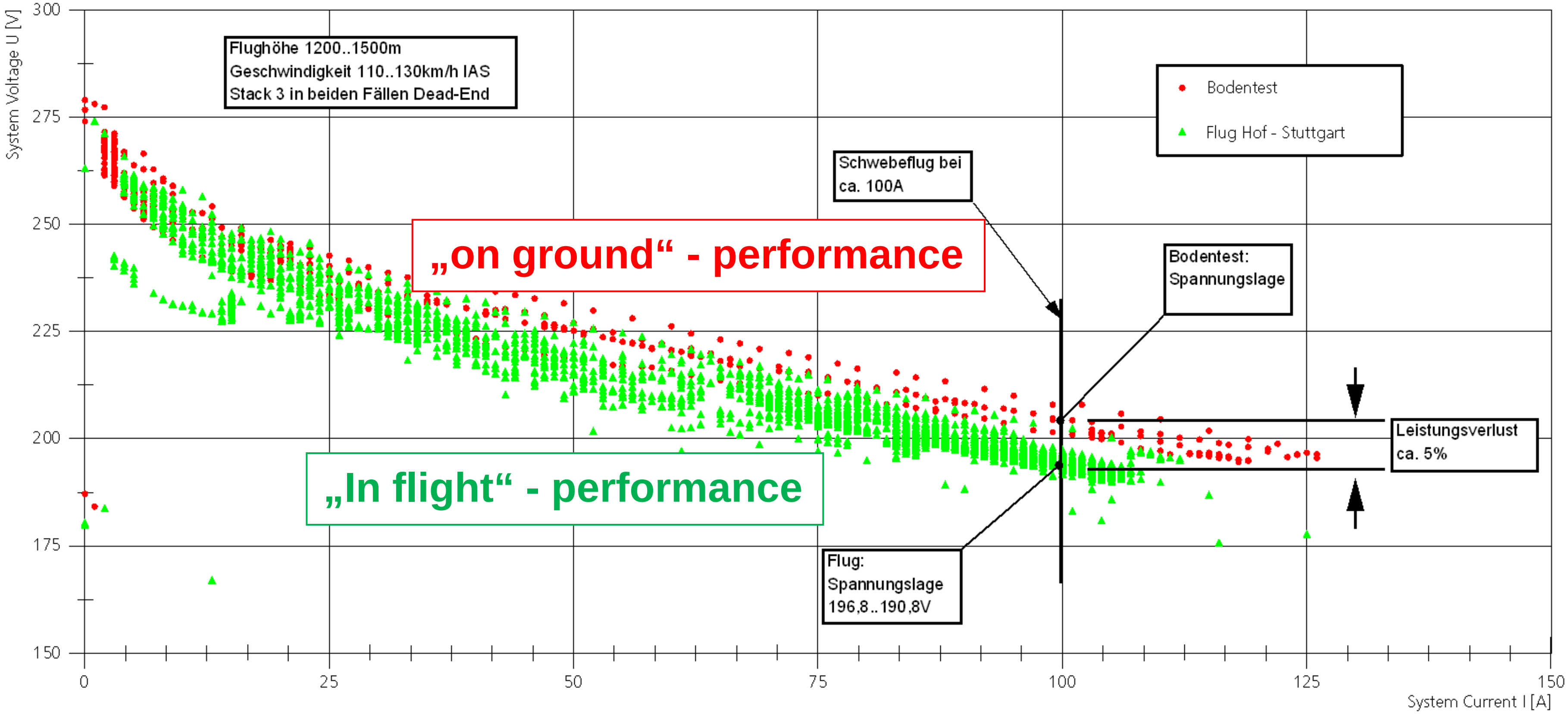
Total flight time during tour: 11:42 [hh:mm], 1483,9 km

Fuel Consumption during the Flights



- Power consumption approx. 1kg$_{H2}$ / 100 km
- Fuel cell system efficiency 48% – 52%

Fuel cell system performance „on ground“ (150m) vs. „in flight“ (1200-1600m)



Summarized performance loss „in flight“ due to altitude and cooling effects ca. 5%

Bundesministerium
für Verkehr, Bau
und Stadtentwicklung

Thank you for your attention !

NOW
Nationale Organisation Wasserstoff-
und Brennstoffzellentechnologie

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