FC Workshop 2015

Fuel cell systems for aircraft applications

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DLR

Aerospace Research Center and Space Agency of the Federal Republic of Germany (DLR)

- 7.700 employees
- 16 national facilities
- > 30 institutes and test facilities
- offices in Brüssel, Paris, Washington
- Test facilities in Almeria/Spain

- **ESI Energy System Integration, DLR**
  - Battery Systems and degradation
  - Fuel Cell Systems and degradation
  - Aircraft Applications MEA and AEA

University of Ulm –
Institute of Energy Conversion and Energy Storage

Department of Hybrid Concepts

- Power Electronic Hardware, Controls and FC/Battery Power Management Systems

Department of Propulsion Research

- High power E-Machines, Generators

Applications: Aircraft applications, ….

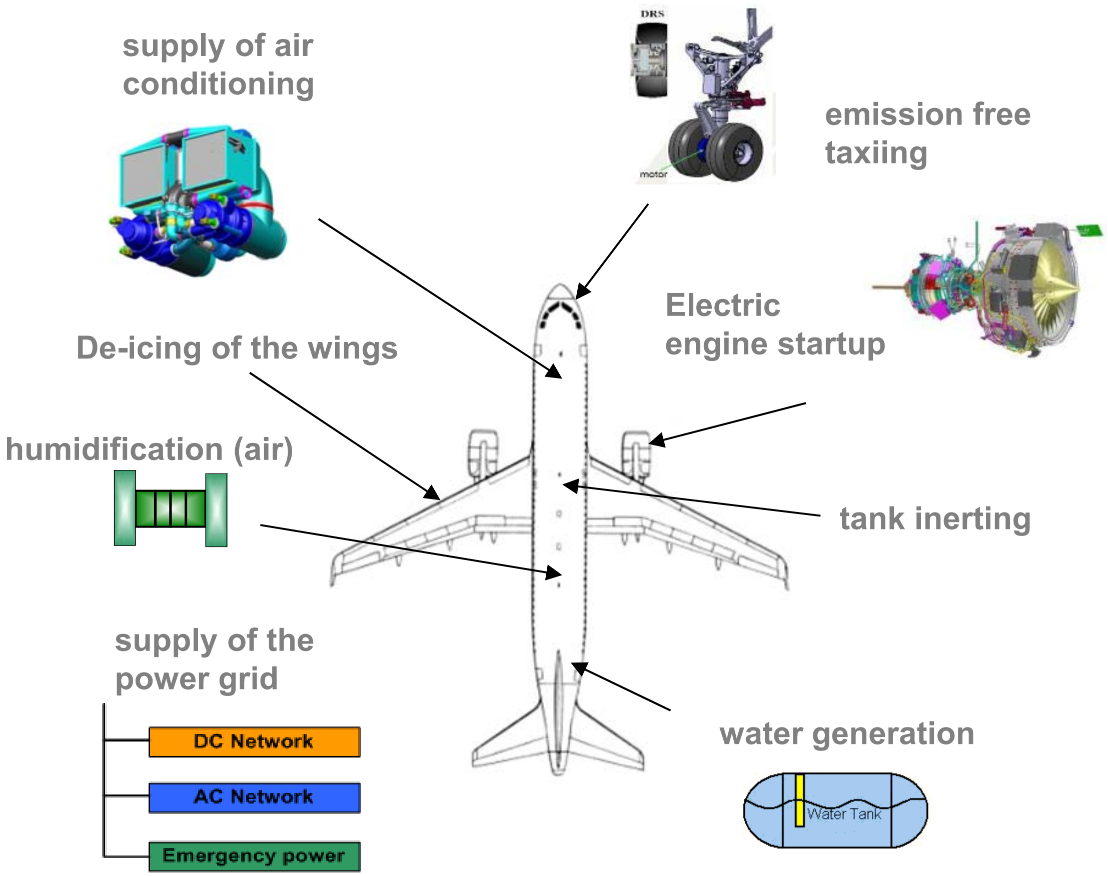
Hardware/Teststand:

- ICE-Battery-E-Machine Hybrid up to 250kW
- Hydrogen infrastructure
- Low Pressure and Temperature chamber for components and complete systems

Potentials of fuel cells in aviation applications

→ Multifunctional use of fuel cell systems in an aircraft

- **electric energy supply**
- **emmission free ground operation**
  → Autonomous Taxiing
- **electric Main Engine Start**
- **supply of air conditioning**
- **water production**
  (potable water and lavatory)
- **waste heat recovery**
  (de-icing, warm water generation)
- **prevention and suppression of fire and explosions**
  (tank inerting, cargo inerting)
- **humidification of Cockpit air and/or cabin air**



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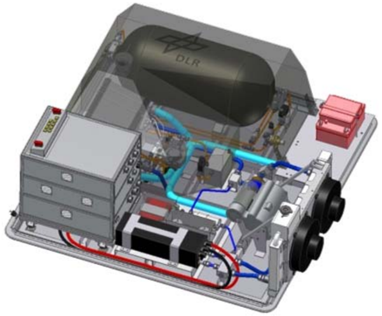
Fuel Cell Aircraft and Airport Applications at DLR
Institute of Engineering Thermodynamics

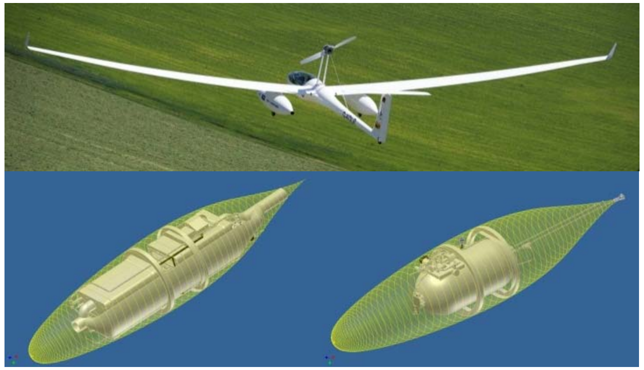
Fuel Cell Technology Development Platform



Electric Energy, ODA, Water Source (→ MFFC)

Energy Source for Emission Free Taxi

Modular Hybrid Development Platform EASA CS.22 and CS.23.Light



Flying Testrig for Fuel Cells and Hybrids,

Emission Free Propulsion for UAV and General Aviation (4-6 Pax or 200 kg Payload)

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Aircraft flight profile

$$0{,}25bar < P_{in\_air} < 1bar$$

Impact of feed gas humidification to the water manage-ment of a PEMFC under aviation relevant conditions

Assumptions:

- Pressure difference between cathode inlet and outlet is neglected
- Water drag between cathode and anode is neglected
- O_2 – Concentration of cathode inlet gas is assumend to be 21 Vol.-%
- $T_{in} = T_{Exhaust} - 10K$

$$\lambda_{Cathode} = \frac{0{,}21 \cdot rH_{Exhaust} \cdot p_{Sat\_H_2O\_Exhaust}(T_{Exhaust}) - p_{Exhaust}}{\Psi \cdot p_{Exhaust} - rH_{Exhaust} \cdot (1+\Psi) \cdot p_{Sat\_H_2O\_Exhaust}(T_{Exhaust})} \quad with \quad \Psi = \frac{p_{H_2O\_In}}{p_{In} - p_{H_2O\_In}} = \frac{rH_{In} \cdot p_{Sat\_H_2O\_In}(T_{In})}{p_{In} - rH_{In} \cdot p_{Sat\_H_2O\_In}(T_{In})}$$

$rH_{Exhaust}$ = Relative humidity of cathode exhaust gas

rH_{In} = Relative humidity of cathode inlet gas

p_{In} = Pressure of cathode inlet gas

$p_{Exhaust}$ = Pressure of cathode exhaust gas

$p_{H_2O\_In}$ = Water vapor pressure of cathode inlet gas

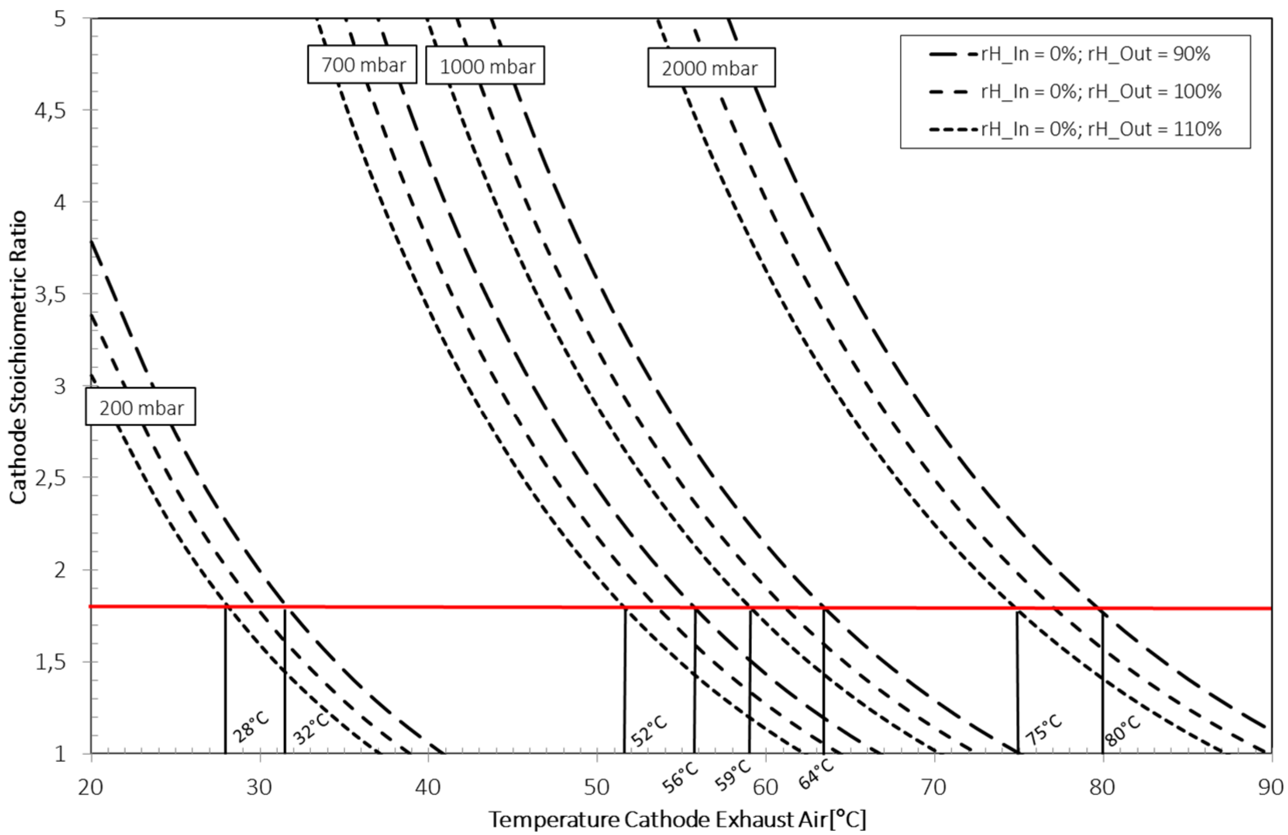
$p_{Sat\_H_2O\_In}$ = Saturation vapor pressure of cathode inlet gas

$p_{Sat\_H_2O\_Exhaust}$ = Saturation vapor pressure of cathode exhaust gas

T_{In} = Temperature of cathode inlet gas

$T_{Exhaust}$ = Temperature of cathode exhaust gas

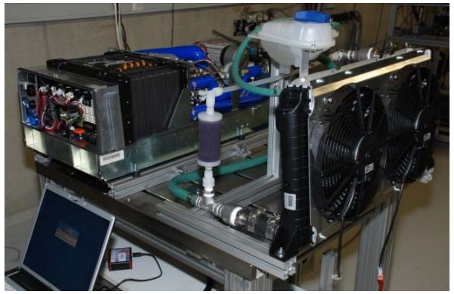
Impact of aviation relevant operating parameters to the water management of a self-humidified PEMFC



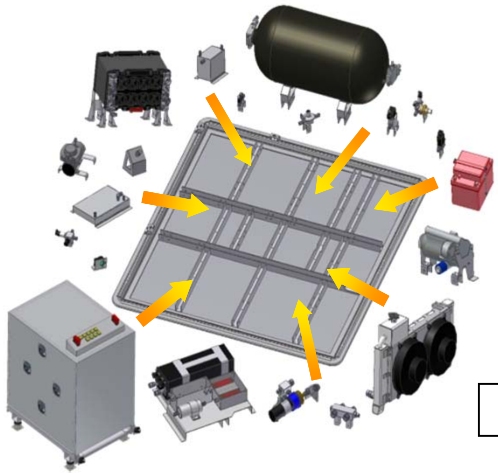
System temperature control crucial for humidification

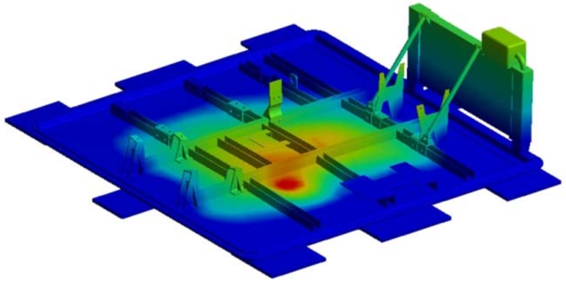
System build up:
Fuel Cell Technology Transfer to Aircraft Application

FC System from Transport Application



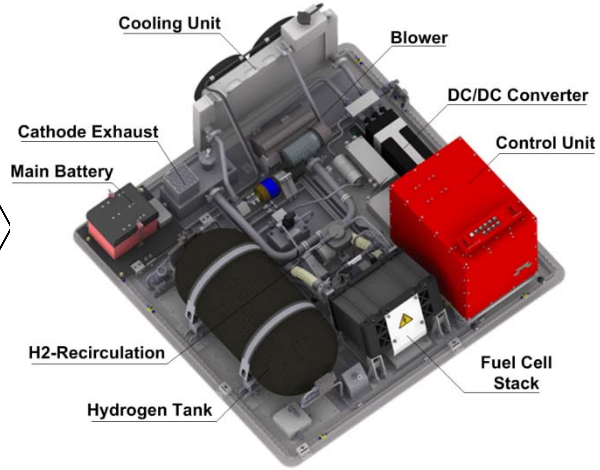
Aircraft Application (DO16xX)
Functionality, Architecture, BOP





Mechanical Strenght Simulation
Vibration, EMC, H2 Safety, Controls

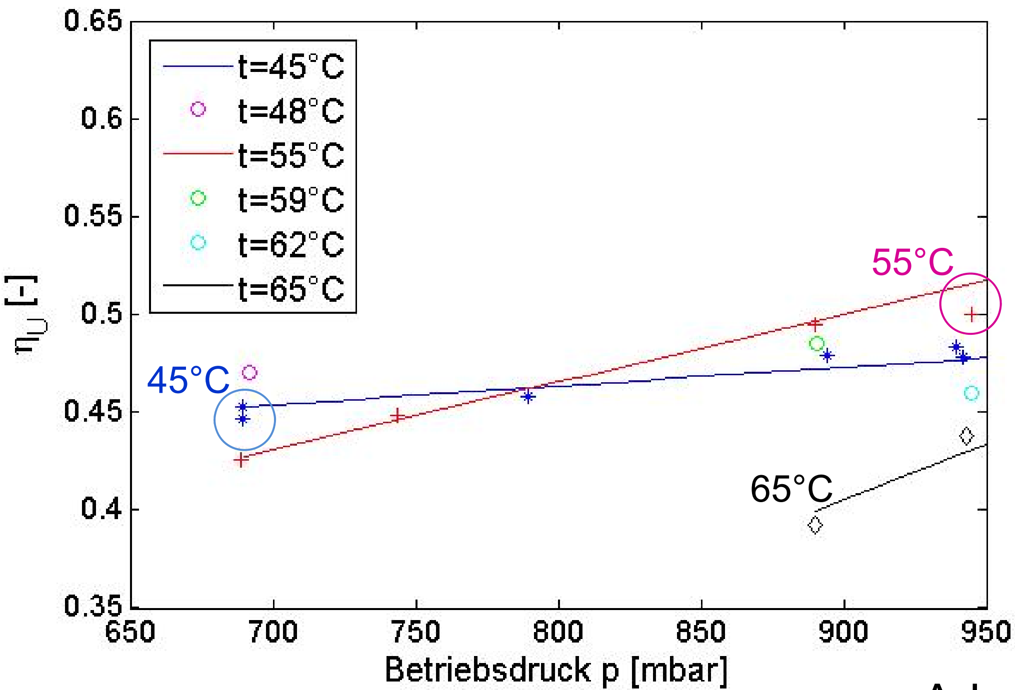
Airworthy technology development platform



- **Fuel cell**
- **DC/DC**
- **hydrogen storage**

Fuel cell system efficiency as a function of cathode inlet pressure and relative humidity at the cathode outlet

System efficiency



Temperature (cath out)	rHout (%) 950 mbar	rHout (%) 700 mbar
45	161	108
48	139	93
55	98	65
65	62	41

Adequate system temperature for optimal system efficiency (I_{Stack} = 0,5 I_{max})

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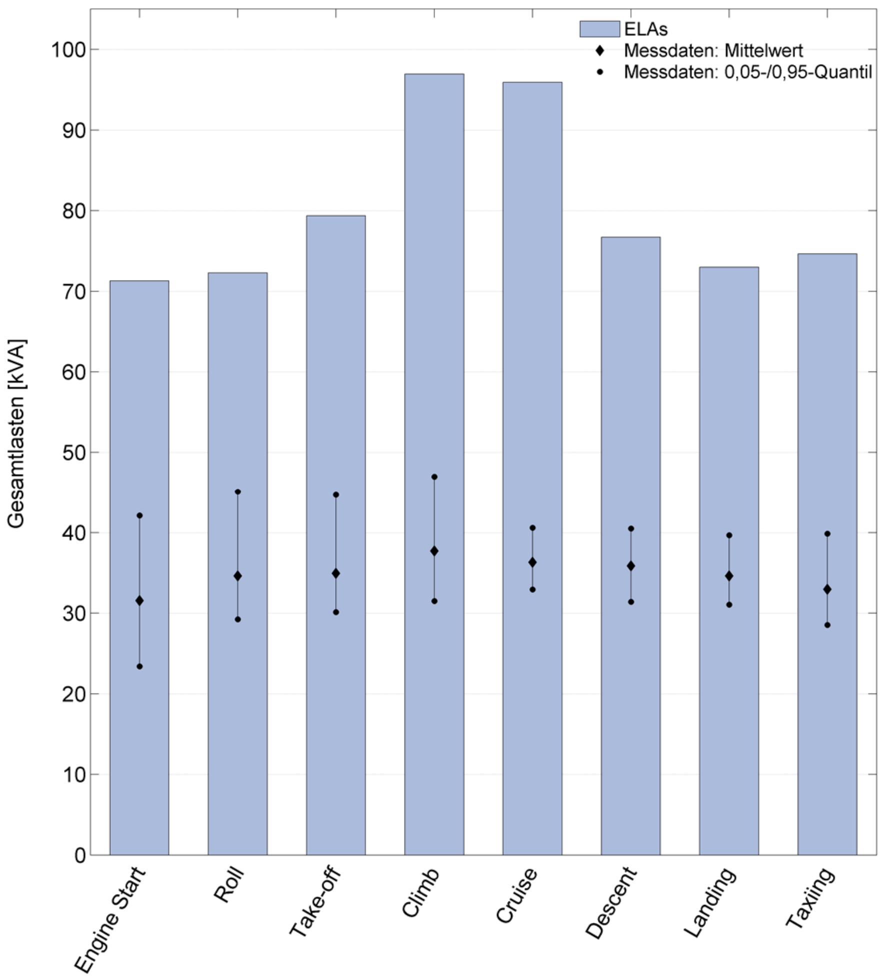
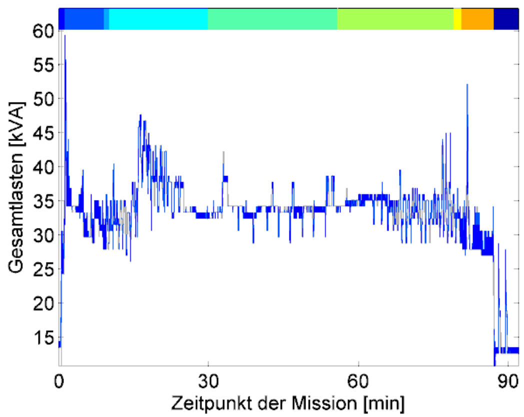
Fuel Cell System Topology
Electrical power assessment A320 (681 flights, 5 different A320)



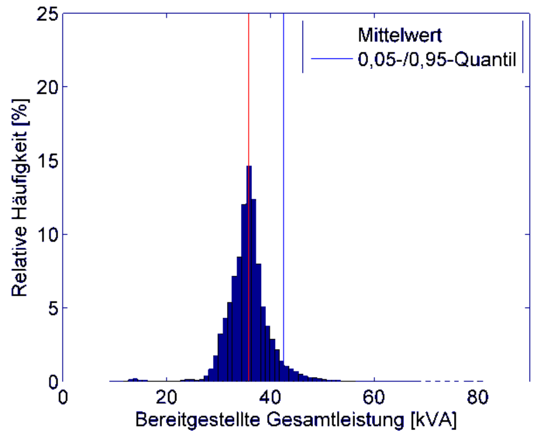
Average real world consumption lower than 50% of ELA

Electrical power data catalogue A320

Profiles electrical power

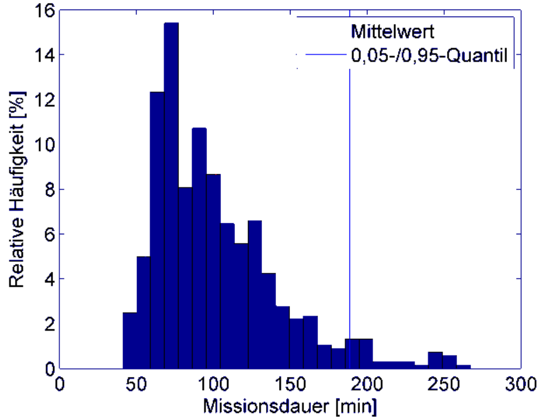


Overall Electrical power catalogue



- 681 Flights
- Flightphase definition based on ELA

Mission duration catalogue



Average mission duration: ca. 100min
Average electrical power: ca. 36kW

→ Average 3,6kg H_2 /mission
(at 50% system efficiency)

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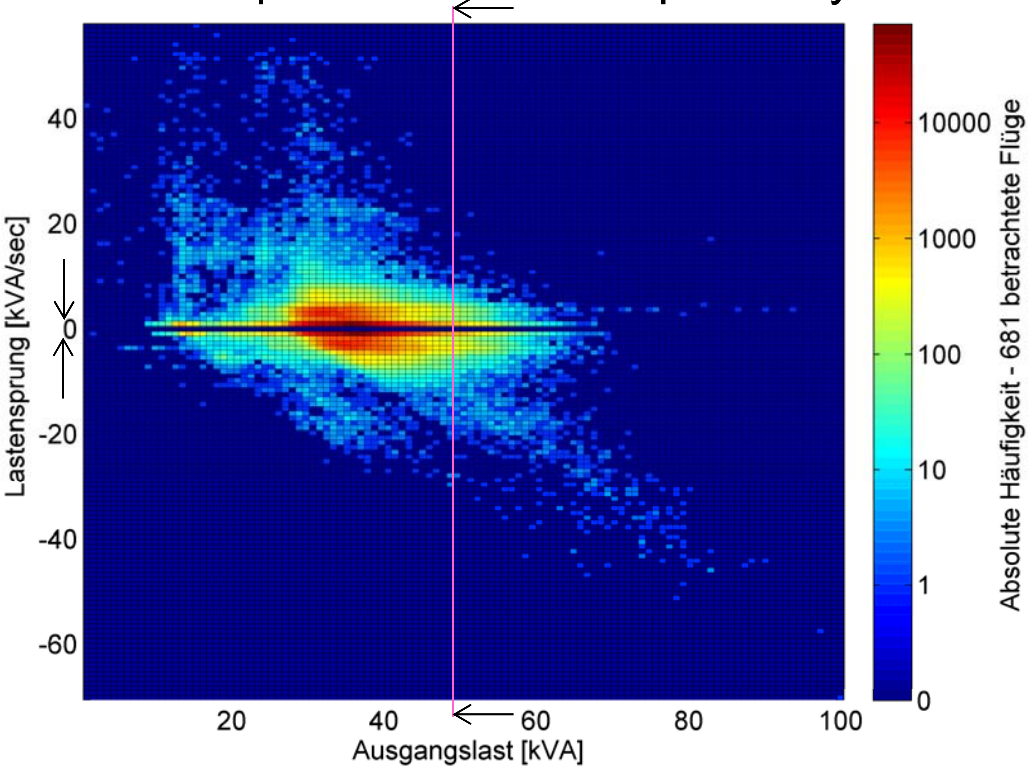
Specific electric power distribution and dynamics A320

Electric power and electric power dynamics

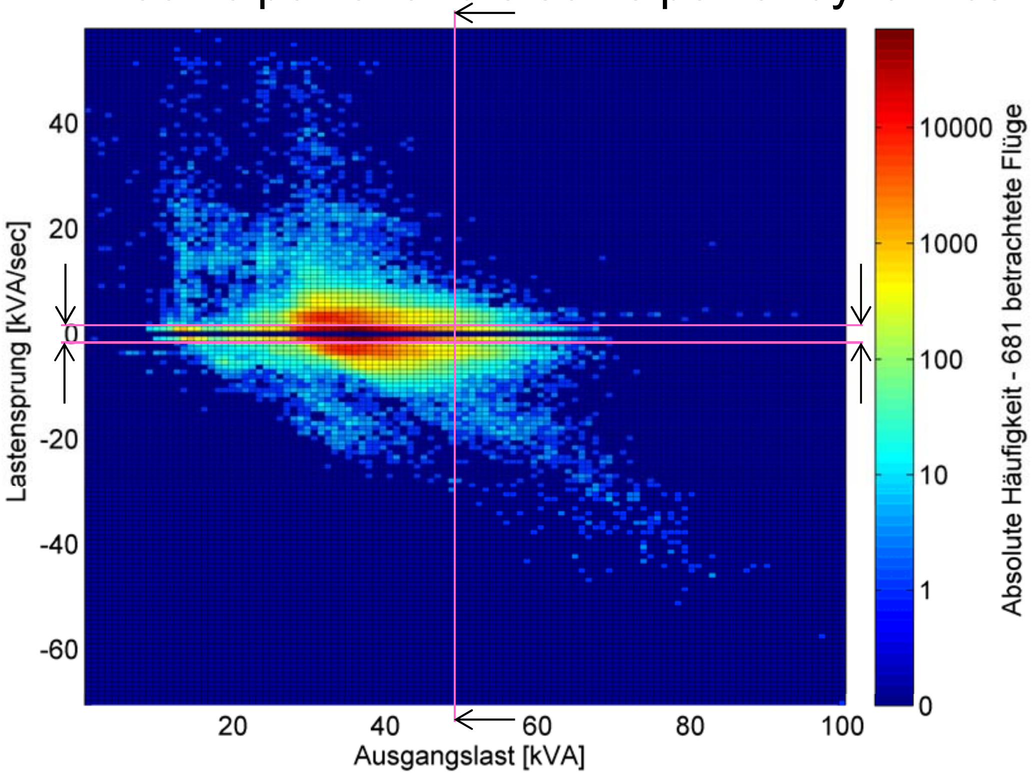


- Power slopes up to +/- 50kW/s
- Minor absolute power case > 50kW

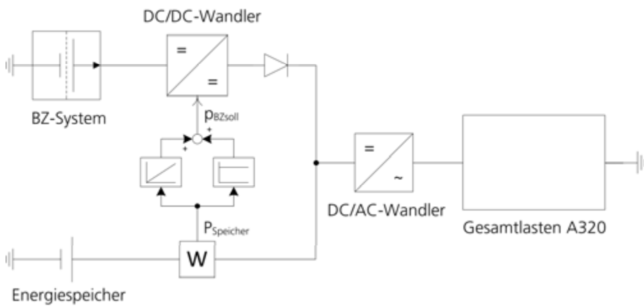
→ ***Hybrid System***

Customized hybrid system for A320

Electric power and electric power dynamics



Hybrid System – 50 KW FC



Hard boundaries FC dynamics
→ **1kW/s** power slope

Expected power from fuel cell system?
Power and capacity of used battery ?

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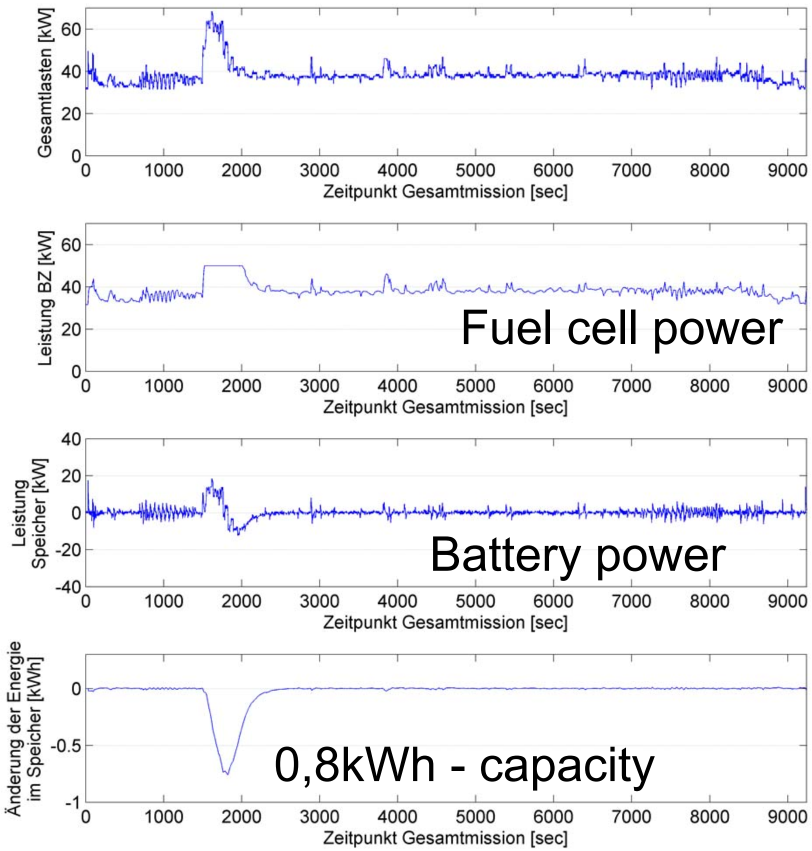
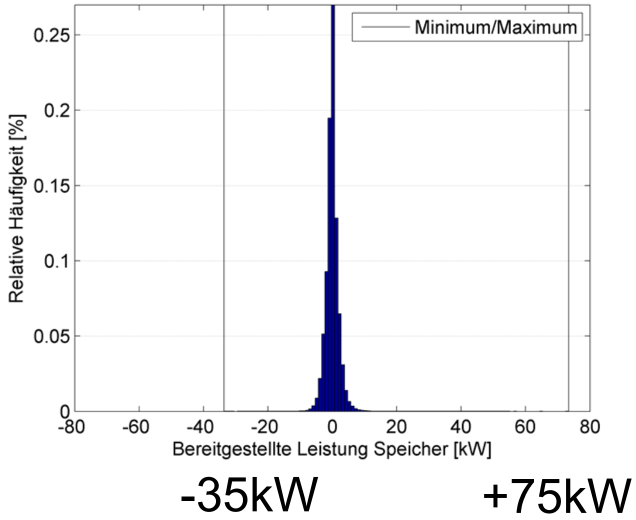
FC Hybrid system impact on battery power

A/C Power, fuel cell and battery power profile



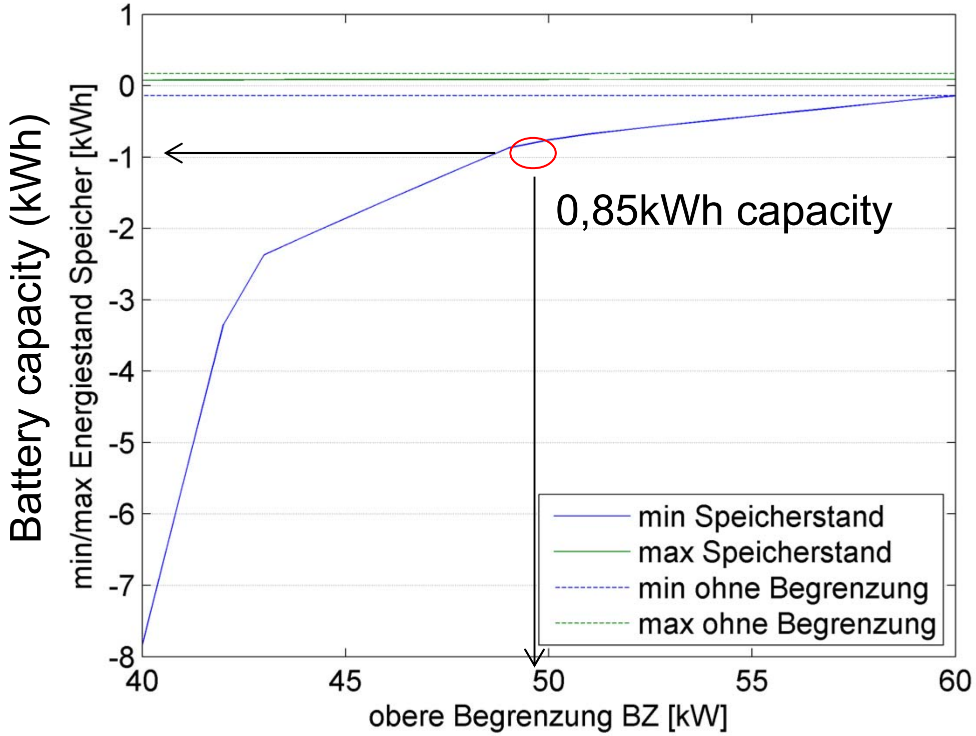
FC Hybrid System - 50 KW
- 1kW/s

Battery power: + 75kW ; - 35kW



FC Hybrid System impact on battery capacity

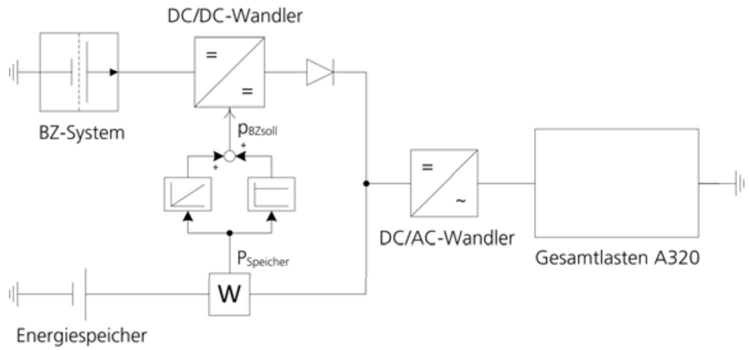
Battery capacity as a function of max. FC system power



Max power fuel cell (kW)

FC Hybrid System - 50 KW
- 1kW/s

Battery power: + 75kW ; - 35kW
Battery capacity: 0,85kWh (7kg)



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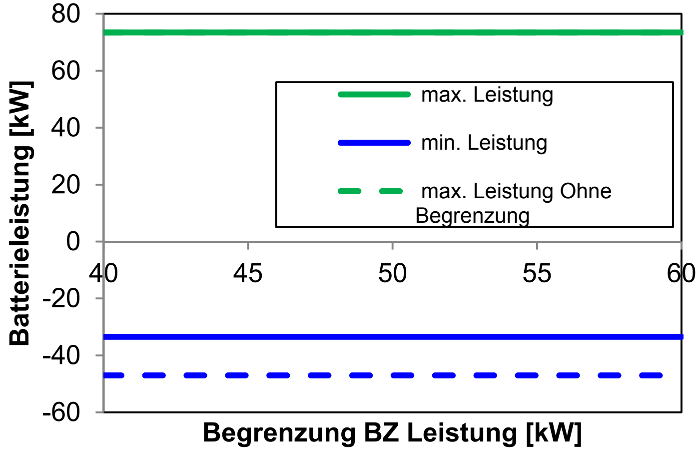
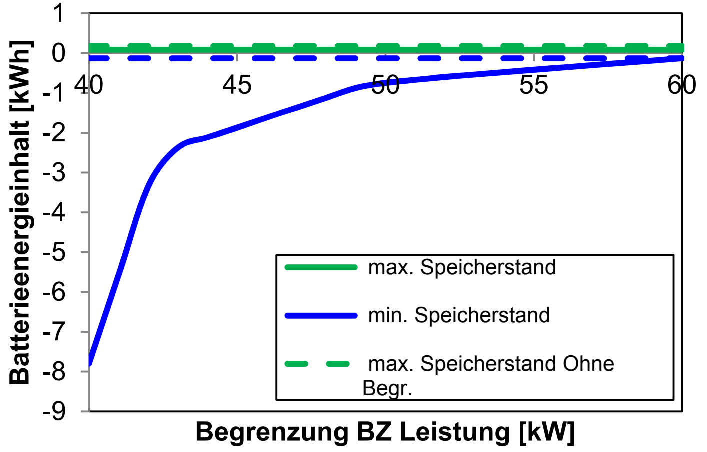
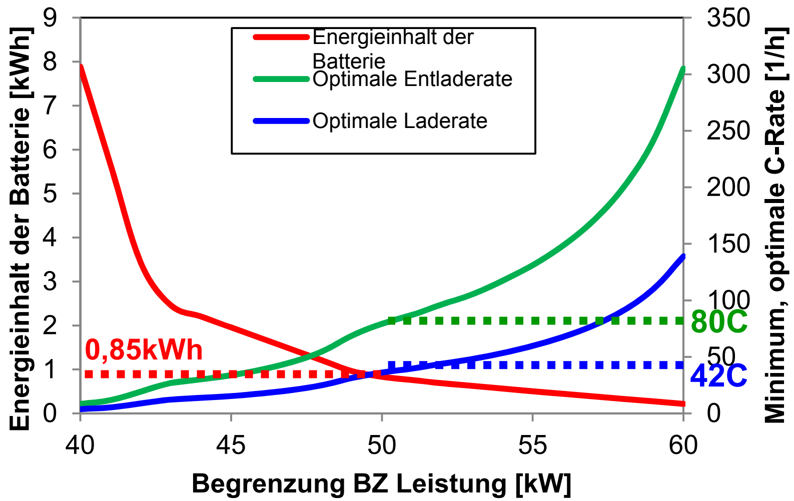
Abschätzung der idealerweise verfügbaren C-Rate





1. $E_{batt} \approx \overline{U_E} \cdot Q_{batt}, E_{Pack} = n_p \cdot n_s \cdot E_{batt}$
2. $P_{batt} = U(I,SOC) \cdot I(SOC), P_{Pack} = n_p \cdot n_s \cdot P_{batt}$
3. $\frac{P_{Pack}}{E_{Pack}} = \frac{P_{batt}}{E_{batt}} \approx \frac{U(I,SOC)}{\overline{U_E}} \frac{I}{Q_{batt}} = \frac{U(I,SOC)}{\overline{U_E}} \cdot I_{C-rate}$
4. $I_{C,opt} > \frac{\overline{U_E}}{U(I,SOC)}\Big|_{min,P_{Pack}=P_{Pack,max}} \cdot \frac{P_{Pack,max}}{E_{Pack}}$



Thank you for your attention!

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