6th Dutch National Hydrogen Congress, 11 December 2008
Hydrogen and Fuel Cells - Inspiration by Demonstration
Congress Centre Papendal, Arnhem, The Netherlands

Fuel Cells and Hydrogen – an Aircraft Industry View

John Price - Head of Energy & Propulsion
- EADS Innovation Works

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- Overview of EADS business fields
- Innovation Works - Energy and Propulsion
- Present fuel cell activities and opportunities at EADS
- Comparison with other industries
- Fuel Cell technologies of interest and fuel cell types
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Overview of EADS Business Fields

DIVISIONS

Airbus

Military Transport Aircraft

Eurocopter

Astrium

- Astrium Satellites
- Astrium Space Transportation
- Astrium Services

Defence & Security

- Defence and Communications Systems
  - Professional Mobile Radio
- Defence Electronics
- Military Air Systems
- Test & Services
- MBDA

Fuel Cells and Hydrogen may be relevant for all divisions

Innovation Works is the EADS Corporate Research Organisation, operating across all divisions

EADS Innovation Works Geographical Locations

A worldwide network

Innovation Works Means

A workforce of more than 600

Staff in France and Germany
Headcount : 524
PhD/Thesis : 62

IW Spain
Target = 75 people

IW Singapore
Target = 25 people

IW UK
Target = 120 people

Foundations
- Fondation d'Entreprise EADS
- Bauhaus

Academic partnerships

. . .

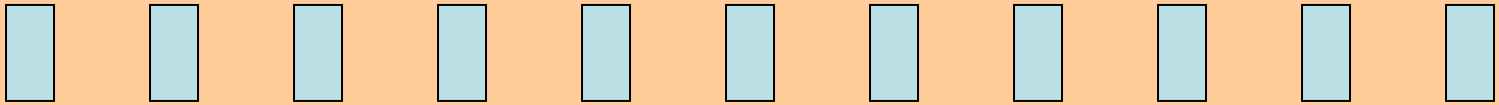
A System Level Approach to Energy & Propulsion

Technology Capability Centre Energy & Propulsion

Energy & Power Management Architectures

- Electrical Power & Actuation
- Propulsion Systems
- Power Generation
- Fuel Systems
- Alternative Fuels

Enabling Technologies



Other TCC's, BU's, Suppliers, Universities

Power Generation Topics

Hydrogen and Fuel Cells are options within Power Generation Systems

Electric Power

hydrogen generation from fuels
- PDh technology
- fuel processing
- reforming

alternative electric power sources
- fuel cells
- generators
- etc.

Energy Storage

electric storage
- batteries & supercaps
- energy harvesting
- power management

hydrogen storage
- chemical (solid)
- physical (gas, liquid)
- etc.

EADS Business Unit Support and Integration

Airbus - fuel cell lab & multifunctional fuel cell system

Power System Integration

Space Missions

Present fuel cell activities at EADS include:

- **Airbus: multifunctional fuel cell system on mid to long term, for more and all electric airplane**

- **Astrium: work on Alkaline technology rfcs for lunar and Mars missions**

- **Innovation Works: partial dehydrogenation of Kerosene**

Fuel cell opportunities at EADS Business Units

business unit	opportunity	typical power / kW
Airbus	**- RAT substitute** **- emission free ground operation**	**10 - 50** **100 - 300**
Military Aircraft	**- RAT substitute** **- secondary power in flight**	**10 - 20** **50 - 200**
Astrium	**- telecon satellite power (rfcs)** **- rfcs for lunar and Mars mission** **- life support system for submarines**	**20** **20** **20**
Eurocopter	**- secondary power**	**20**
Defence & Security	**- electric power for special products** **- telecommunication products**	**40** **< 1**

Partial Dehydrogenation of Kerosene

- **principle:** partial “extraction” of gaseous hydrogen from liquid hydrocarbon by catalytic reaction (H_2 -> fuel cell; residual liquid -> engine or tank)
- **opportunities:**
  - low complexity (no H_2O or O_2 to be added)
  - high H_2 purity (no CO, CO_2, N_2 impurities)
- **challenges:**
  - catalyst lifetime
  - conversion rate
  - formation of H_2S
  - integration
- **status:** TRL 2

Aircraft / Other industries – Fuel Cell differences and synergies

- globally, fuel cell development is focusing strongly on automotive
- there was a paradigm shift in June 2004 from gasoline to H_2 as a fuel initiated by DoE which decided to stop on-board fuel processing activities
- accordingly efforts on processing of hydrocarbons were abandoned almost completely and only H_2-fueled fuel cell cars were pursued
- in aeronautics Kerosene will be the one and only fuel for the next decades (no matter if it is made from oil, coal, biomass or whatever)
- while potential niche applications for H_2-fueled fuel cell systems exist on airplanes, large fuel cell systems have to run on Kerosene in the foreseeable long term
- thus fuel processing is a necessity and the most important challenge
- this also holds for military applications (Diesel instead of Kerosene with a lower sulfur content)

Aircraft / Other industries – Fuel Cell differences and synergies contd

- the choice of fuel marks the difference for stationary applications, for example using natural gas
- stack development has made significant progress with respect to specific power and power density during recent years (weight and volume are of critical importance for aircraft application)
- stacks have achieved the level of ruggedness used in cars; however, additional requirements are imposed by an aircraft scenario:
  - operation: extreme g-loads, tilting, lower air pressure …
  - safety: reliability, need for redundancy …
- SOFC has also made progress although its specific power and power density are lower than PEM; however, the fuel processing for SOFC is substantially simpler

Summary for EADS Products

- power density and specific power are of ultimate importance for aeronautic applications
- in aeronautics Kerosene is difficult to replace
- for ground defense application Diesel appears to be in a similar position
- processing of fuel with high Sulphur content is a key issue
- we see paradigm shift and acceleration in the automotive business
- for small communication devices or environmental control systems for defence, DMFC might be an option
- space application is a different story
- an integrated approach on system level is required to enable the biggest benefits of the new technology - utilization also of the by-products

Fuel cell technologies of interest for EADS

AFC	**space (rfcs)**
PEM	**aircraft, ground units, space**
DMFC	**small communication devices**
PAFC	**(potentially for ground units)**
SOFC	**aircraft, ground units, small communication devices**

special interest: fuel processing technology for (high sulphur content) Kerosene/Diesel

……..
long term fuel processor requirements:
- specific power: min. 2.0 - 2.3 kW kg^{-1}
- power density: ca. 1.3 - 1.5 kW L^{-1}
- efficiency: ca. 76 – 80 % (incl. desulphurisation)
……..

Airbus Drivers for Fuel Cells and Hydrogen

The four ACARE GOALS 2020 for the Environment:

- To reduce fuel consumption and CO2 emissions by 50%
- To reduce perceived external noise by 50%
- To reduce NOX by 80%
- To make substantial progress in reducing the environmental impact of the manufacture,
  maintenance and disposal of aircraft and related products.

EADS CEO Louis Gallois at Airbus ISO14001 Certification in Paris, 14 June 2007:

'We have to increase our efforts in other research areas… **Airbus has accumulated significant experience in hydrogen technology** ... We also need to consider fuel cell technology to power ground operations at airports. Eliminating CO2 emissions on the ground is a concrete vision I have and I believe there is huge potential. We can't afford to miss a single opportunity.'

BDLI Technologieforum mit Airbus CEO Dr. Thomas Enders in Berlin 11. Oktober 2007:

„.. Wir wollen unsere Flugzeuge noch sauberer, noch sparsamer, noch leiser machen und damit natürlich auch unsere Chancen am Markt erhöhen...Wir werden die **Öko-Effizienz unserer Produkte** zu einem bestimmenden Maßstab machen, an dem wir unsere Forschung messen."

Delivering the Goals

Fuel cell technology offers some opportunities to approach these goals:

- enhanced energy efficiency
- emission free ground operation
- emission reduction during whole flight cycle
- additional synergy benefits through fuel cell by-products (inert gas, water)

…however, fuel cells will only be part of a system level solution

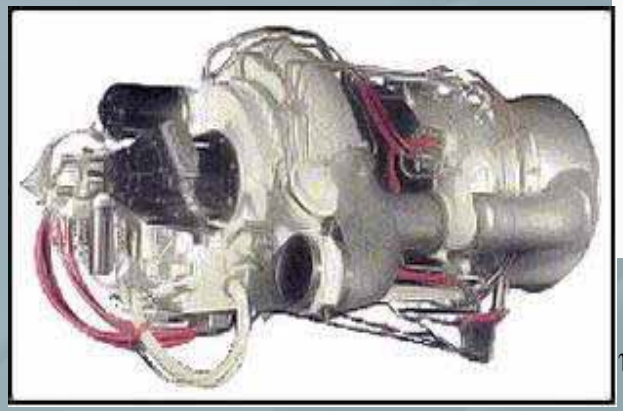
Airbus – Demonstrating the Benefits from Multi-Functional Fuel Cell Application

Ecological Aspects:

- Reduction of Fuel Burn
- Reduction of Greenhouse Gases ($CO_{2,}$)
- Reduction of Noise Emission and Pollutants (NOx, SO2, CO, HC)

Economical Aspects:

- Weight Reduction
- Lower Maintenance Cost
- Substitution of Ram Air Turbine and APU
- Substitution of Inert Gas System
- Reduction of Ground Support



$\eta_{Engine,\ idle}$ ~ 22%

η_{APU} ~ 18%

Michelin Fuel Cell

η_{FCS} ~ 50%

Higher Efficiency in Comparison with Conventional Electrical Generation

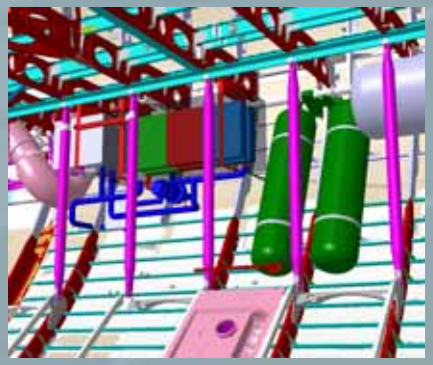
Airbus – Demonstrating the Benefits from Multi-Functional Fuel Cell Application

Increased Benefit on Aircraft Level

Function:

✈ Emergency Power

Flight Test successfully performed



Additional Functions

✈ Flammability Reduction (Inerting)

✈ Continuous Supplemental Power

Vision 2020

Multifunctional Fuel Cell

✈ Power for all loads on ground

To enable low or even no emission ground operation

✈ Water Generation

Increased Service Readiness

Low Emissions System : Fuel Cells

Hydrogen supplied fuel cell

Fuel and CO2:
Reduced fuel burn
= lower CO_2 emissions

No pollutions :
(HC, NOx, CO, SO2)
Less noise

Batteries

Emergency Power

Auxiliary Power

Ground Support Equipment

Fuel Tank inerting system

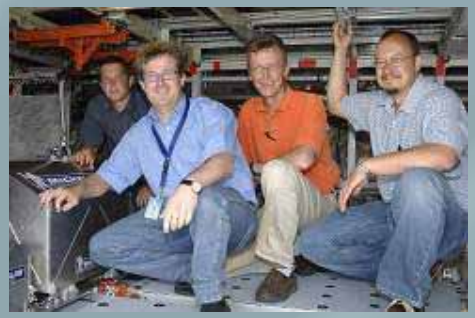
Water Refilling Truck

Fuel cell technology will initiate a step change in aircraft systems architecture

AIRBUS Achievements

First time ever:

- Hydrogen supplied fuel cell system operation on-board of commercial aircraft
- Hydrogen supplied fuel cell system integrated into electric and hydraulic network
- Successful flight tests performed 27 July 2007 in Hamburg
- Toulouse, 15 February 2008: Flight controls powered by fuel cell in flight



Fuel Cells for Military Aircrafts

Status and Way Ahead – H2Expo Hamburg, 25.10.2006

Stefan Roemelt, EADS Military Air Systems, Munich

Military Air Systems

Types of Military Aircrafts

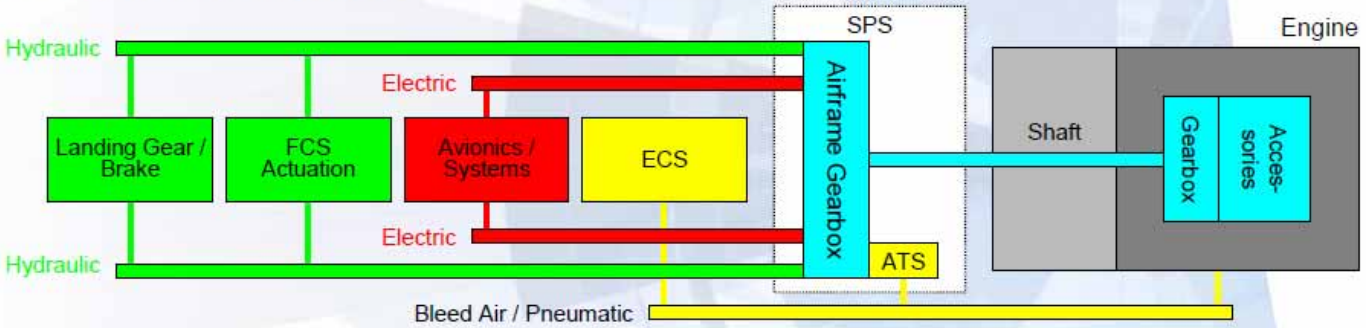
Unmanned Aircrafts (UAV)
e.g. HALE / MALE

Fighter Aircrafts e.g.
Eurofighter Typhoon

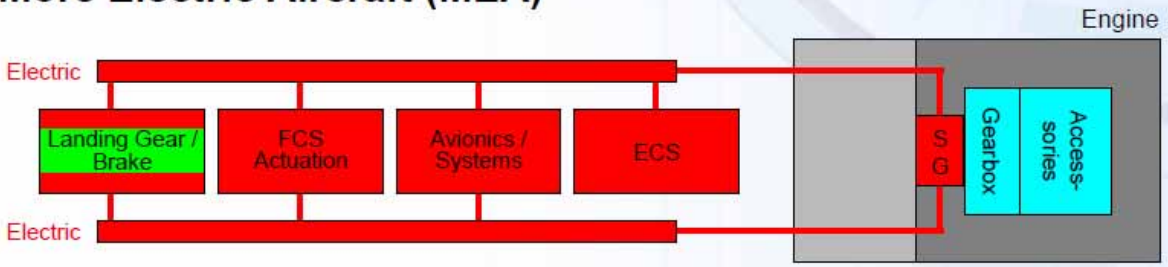
Mission Aircrafts
e.g. NATO AGS

Aircraft Power Architectures

Conventionell Aircraft



More Electric Aircraft (MEA)



ATS	Air Turbine Starter
ECS	Environmental Control System
FCS	Flight Control System
S/G	Starter/Generator
SPS	Secondary Power System

EADS DEFENCE & SECURITY

Motivation for More Electric Aircraft (MEA)

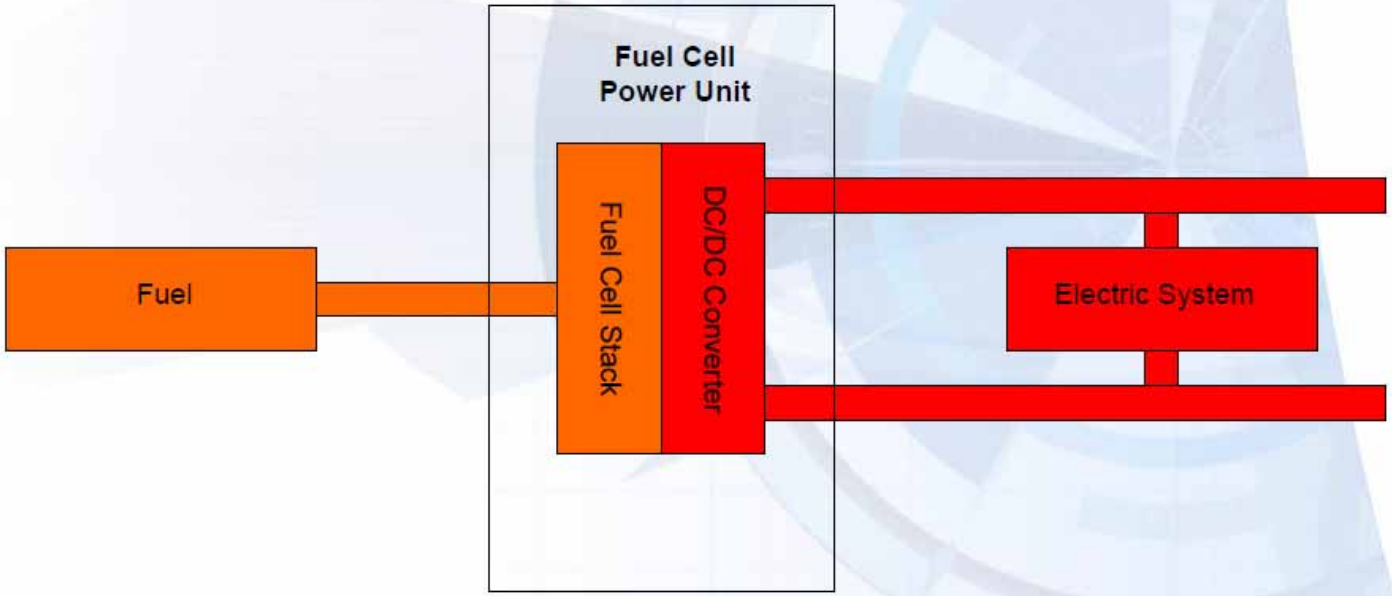
- Only one Type of Energy on Board (Electric)
  - Weight Savings
  - Less Complexity & Reduced Logistic Efforts
- Increased Efficiencies lead to
  - Increased Performance
  - Reduced Fuel Consumption
  - Reduced IR- and Radar-Signatures (Stealth Design)
- Load Management Capabilities
  - Increased Power Demand for new Sensors and Energy Weapons

EADS DEFENCE & SECURITY

Motivation for Fuel Cells

- More Electric Aircraft (MEA)
  - Increased electrical Power Demand
  - Replacement of Hydraulic and Pneumatic
- Independent Energy Source
  - Increased Safety for critical Systems (relevant for Certification)
  - Energy Source for assisted Relight in Case of Engine Flame-Out (important for single Engine Aircrafts)
- Clean Power Source

Aircraft Fuel Cell Architecture



Possible Fuel Cell Applications (1/3)
Fighter Aircrafts

- Replacement of Emergency Power Sources
  - NiCd Airborne Batteries (approx. 3kW Peak Power)
  - Thermal Batteries (approx. 10 kW Peak Power)
- Replacement of Secondary Power System
  - Auxiliary Power Unit (APU – approx. 15 kW electrical Power)
- Replacement of Ground Power Supplies
  - Ground Cart (approx. 50 kW electrical Power)

Possible Fuel Cell Applications (2/3)
Unmanned Aerial Vehicles (UAV)

EADS DEFENCE & SECURITY

- Support Engine Driven Power Generation
  - Engine Performance for HALE/MALE Aircrafts decreases with increasing Altitudes
  - Possible „Silent Flight" Phases with Engines switched off over Target Area (Relight Assistance)
  - Exceeding Engine Power-Off-Take Limitations for additional Payload

HALE: High Altitude Long Endurance

MALE: Medium Altitude Long Endurance

Military Air Systems

Possible Fuel Cell Applications (3/3) Mission Aircrafts

- Replacement of Emergency Power Sources
  - NiCd Airborne Batteries (approx. 3kW Peak Power)
  - Ram Air Turbine (RAT – approx. 5 kW electrical Power)
- Replacement of Secondary Power System
  - Auxiliary Power Unit (APU – approx. 100 kW electrical Power)

Concluding remarks

- EADS is committed to development of “greener” products
- Airbus committed itself to achieve ACARE 2020 goals
  - to reduce fuel consumption and CO2 emissions by 50
  - to reduce perceived external noise by 50%
  - to reduce NOX by 80%
  - to make substantial progress in reducing the environmental impact of the manufacture, maintenance and disposal of aircraft and related products.
- Hydrogen and fuel cells provide short term options for “greener” air transport
- Hydrogen and fuel cells are of key importance in space applications
- fuel cell systems based on hydrocarbon fuel offer potential improvement for aircraft (civil and military)
- there are synergies to exploit with fuel cells for car and stationary application