Role of Fuel Cells and Batteries for Electric Propulsion Systems for Aircraft

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Motivation

Electric propulsion for aircraft systems is motivated by several factors driven by political, economic, social, technological and ecological interests.

Political factors

- The International Air Transport Association (IATA) and the International Civil Aviation Organization (ICAO) defined a global approach to reduce emissions caused by aviation.
- The Advisory Council for Aeronautics Research in Europe (ACARE) created a vision, the Flightpath 2050, for future research agendas.

Flightpath 2050

Climate change impact:
75 % CO_2 emission reduction

Exhaust gas health issue:
90 % NO_x emission reduction

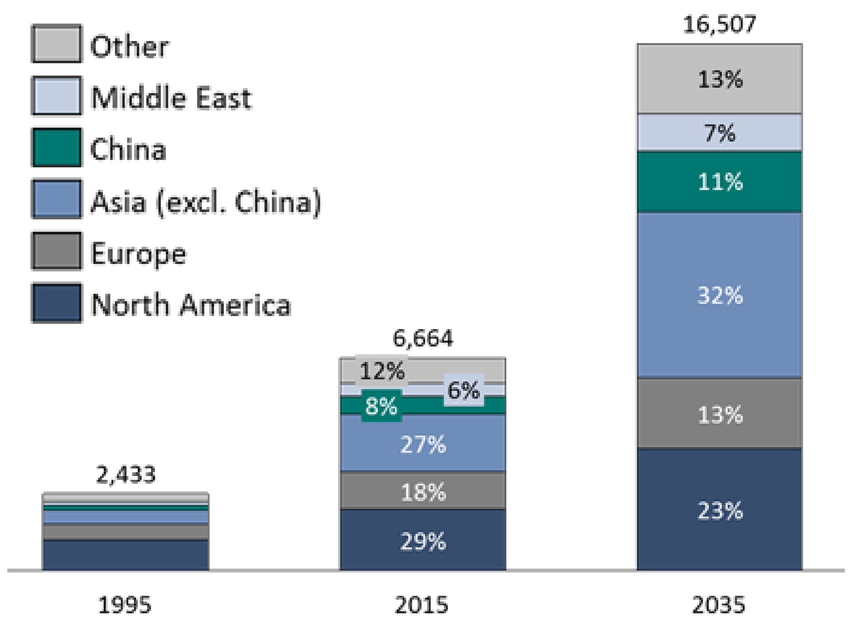
Noise health issue:
60 % noise reduction

Economic factors

- Fuel expenditures statistically represents a high share of operating costs.
- The oil price as a basic indicator for the aviation fuel price is forecasted to double within the next 15 years.
- A future shortage of CO_2 certificates of the emission trading system increases cost significantly.

Social factors

- Growing economies and populations in emerging markets lead to increasing demand for air transportation. Revenue passenger kilometers (RPK) are predicted to double in less than 20 years.
- The rising environmental awareness of air travelers is another driver for a paradigm change in the aircraft design.



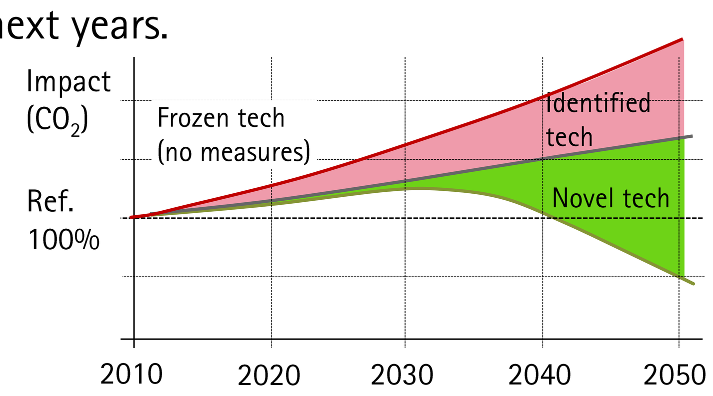
Development of RPK until 2035 according to Boeing

Technological factors

- Increased research focus and the progress of electric mobility lead to electric propulsion components with a higher performance for lower cost.
- Huge improvements have been achieved in the battery technology in the last two decades and are predicted to last for the next years.

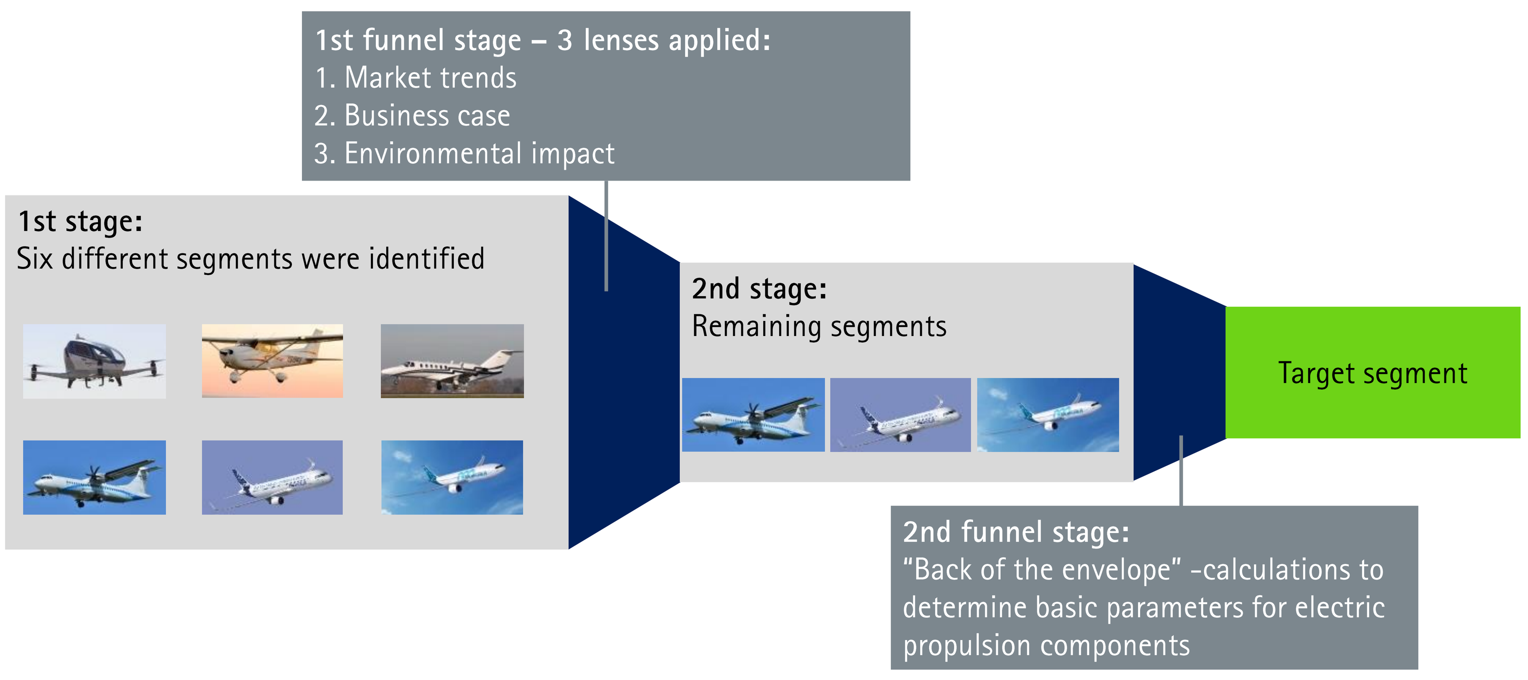
Environmental factors

- Aviation causes the most emissions of all transportation modes.
- Including cirrus cloud effects, the share of emissions made up 4.9 % of global radiative forcing in 2005.



Development of emissions

Funnel approach on the example of HEA



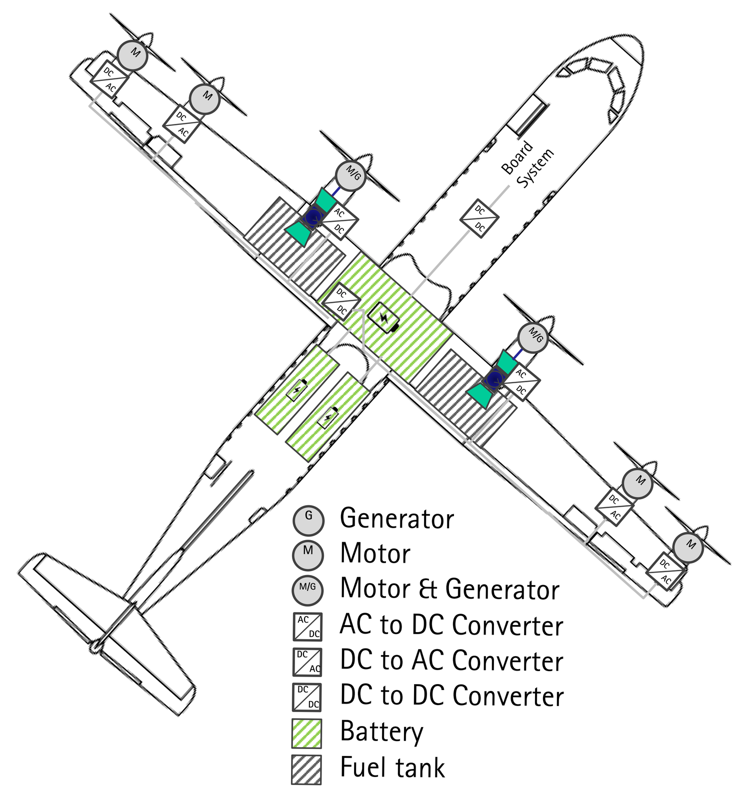
Results of funneling

- Regional and short-haul flights, represented by the ATR 72 and the Airbus A320, respectively, are suitable for battery electric propulsion.
- For the long-haul distance, e.g., flown by the A330, energy of hydrogen and fuel cells are feasible alternatives.

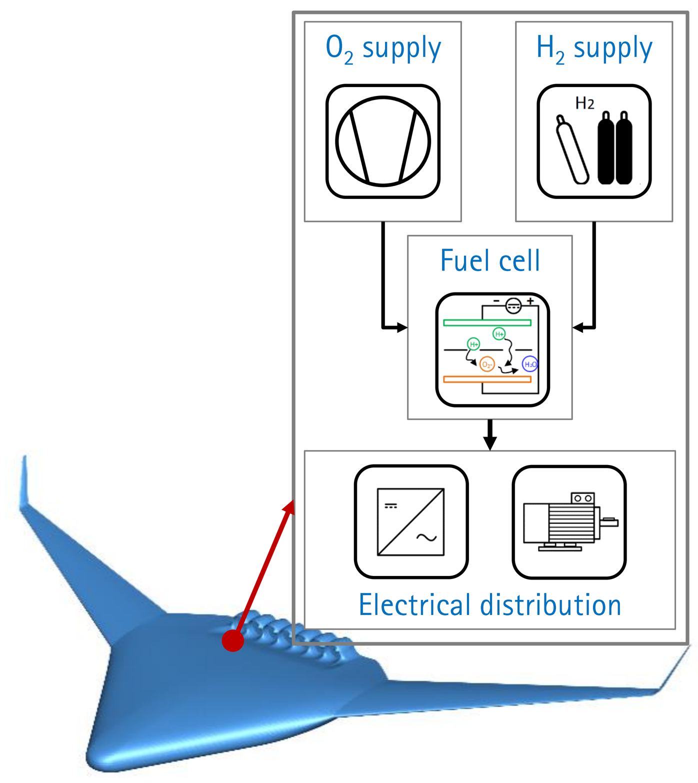
Segment	Power rating	Available weight for energy[1]	Flight profile (exemplary)	Flight energy needed[4]	Required battery energy densities: 50 % of energy by battery delivered[5]	Required battery energy densities: Full electric aircraft[5]
ATR 72 	2x 2 MW	22.3 t – 13.5 t – 5.3 t[2] = **3.5 t**	Regional (HAM-FRA) Cruise: 45 mins	Total: **2.4 MWh**	0.2 t fuel burn **0.5 kWh/kg battery needed**	**0.9 kWh/kg battery needed**
Airbus A320 	2x 11 MW	66 t – 43 t – 12.2 t[3] = **10.8 t**	Short-haul (MIA-JFK) Cruise: 1h 35 mins	Total: **20.7 MWh**	2.7 t fuel burn **2.3 kWh/kg battery needed**	**3.4 kWh/kg battery needed**
Airbus A330 	2x 30 MW	182 t – 120 t – 20 t[3] = **42 t**	Long-haul (FRA-NBO) Cruise: 6h 45 mins	Total: **181 MWh**	23.4 t fuel burn **8.7 kWh/kg battery needed**	**7.7 kWh/kg battery needed**

Electric propulsion system design

Battery



Fuel cell



Results of HEA

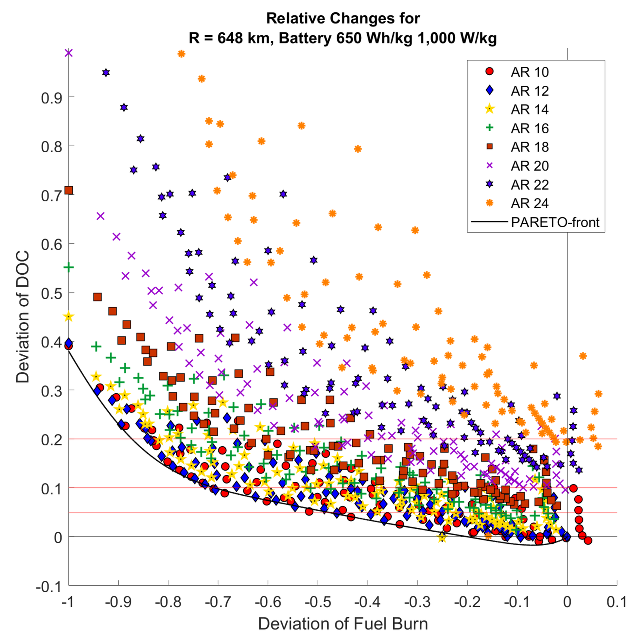
Battery electric propulsion (BEP) [1]

Advantages

- HEA with BEP shows significant fuel burn savings while competitive in cost.
- More efficient propulsion system achieves overall emission reduction.

Challenges

- Battery weight is the limiting factor for feasibility of BEP.
- Optimum battery operating depends highly on P/E-ratio. Tailored batteries in terms of P/E-ratio lead to an optimal battery design.



DOC and fuel burn deviation of HEA [1]

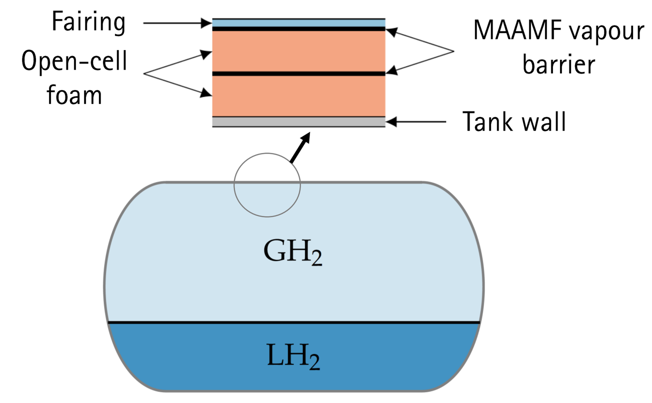
Fuel-cell electric propulsion (FCEP) [2]

Advantages

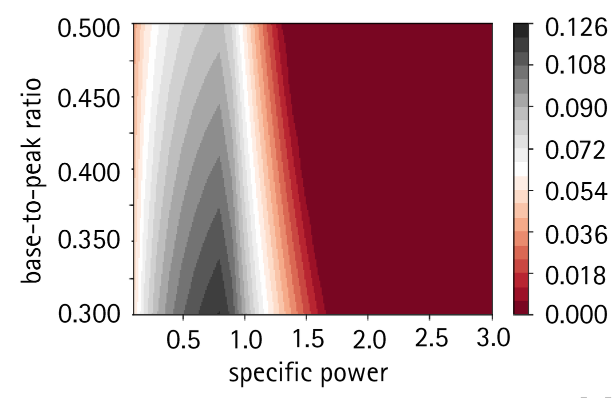
- Liquid hydrogen tanks achieve significant higher gravimetric energy than kerosene (20 kWh vs. 10 kWh).
- Fuel-cell systems for aircraft propulsion show high mass savings for long-haul flights [4].

Challenges

- A sufficient heat management as well as the integration of large hydrogen tanks determine among others the feasibility of FCEP.
- System modelling is necessary for optimal component design.



Liquid hydrogen tank design [2]



Mass savings by hybrid propulsion system [4]

Project overview

- This contribution is elaborated as part of the Project "Energy Transformation in Aviation".
- A multidisciplinary team of researchers develop a holistic approach to tackle the challenges associated with the necessary changes in air transport system.
- This approach covers non-technical disciplines, such as economical and social sciences, as well as technical disciplines, such as aeronautical, power, process and industrial sciences.

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