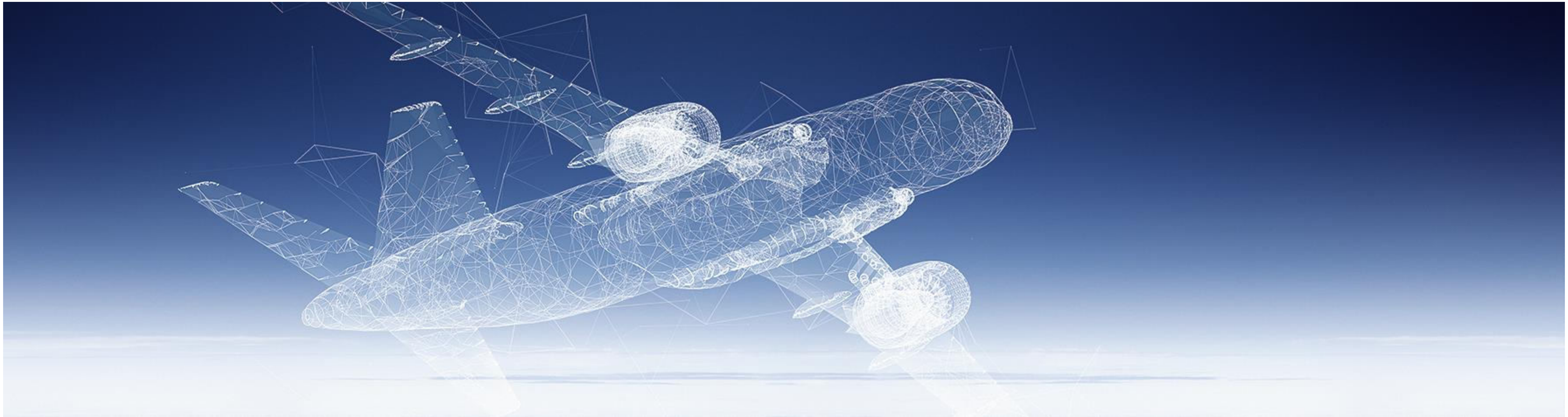


Wasserstoff - auf dem Weg zum emissionsfreien Fliegen

20. Brennstoffzellenforum Hessen 2021-10-28

Barnaby Law | MTU | Chief Engineer Flying Fuel Cell

Agenda

- MTU Aero Engines
- Produktstrategie und emissionsfreies Fliegen
- Das Flying-Fuel-Cell-Antriebskonzept
- Wie kommt der Wasserstoff zum Fliegen?

Our track record: partners and customers appreciate MTU's excellence

Commercial OEM business

Share of total revenues ~ 26 %

Balanced product portfolio in all thrust categories

Decades of partnership with OEMs

Military OEM business

Share of total revenues ~ 12 %

European and U.S. engine programs

Leading partner of the German Armed Forces

Commercial MRO business

Share of total revenues ~ 62 %

Services: maintenance, leasing and asset management

Direct customer business, partner of OEMs and airlines

MTU group fiscal year 2020: Revenue € 3.977 billion / EBIT € 416 million

MTU possesses unique capabilities and has a wealth of know-how

Technology

We are continuously expanding our technological lead by identifying and setting revolutionary trends

Processes

We deliver on time, with the right quality and at reasonable costs – digitalization opens up further potential for MTU, sustainability is our basic principle

Partnerships

We enter into sustainable partnerships – an essential prerequisite for MTU’s long-term success

People

We boast some 10,000 engine experts – innovative and competent

Locations

Through our 15 locations worldwide, we are close to our customers

Boasting comprehensive system expertise, MTU focuses on five core engine competencies - three core components and on unique manufacturing and maintenance processes

HPC: High-pressure compressor

CF6, JT8D, PW6000, PW1000G, PW800,
EJ200, RB199

Fan

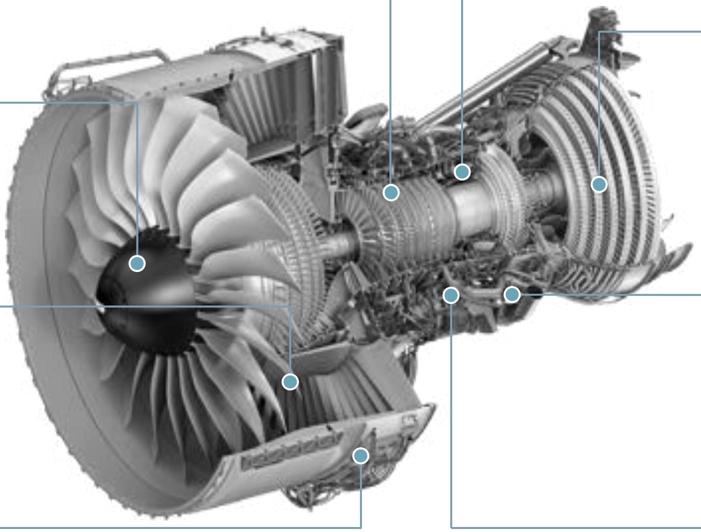
EJ200

IPC: Intermediate-pressure turbine

RB199, TP400-D6

Engine control and diagnostics

RB199, EJ200, TP400-D6



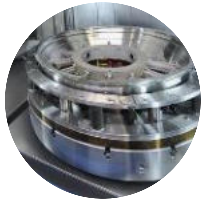
Military Engines   Commercial Engines

Combustion chamber

MTR390, T64,
Larzac, Tyne

LPT: Low-pressure turbine

V2500, PW1000G, PW2000,
PW4000, PW6000, GP7000,
PW300, PW500, PW800
F414, T408, Tyne



TCF: Turbine Centerframe

GP7000, GEnx, GE9X

IPT / HPT: High- and intermediate-pressure turbine

MTR390, RB199, TP400-D6,
CF6, JT8D, GP7000, PW2000

Agenda

- MTU Aero Engines
- Produktstrategie und emissionsfreies Fliegen
- Das Flying Fuel Cell Antriebskonzept
- Wie kommt der Wasserstoff zum Fliegen?

Motivation Emission und Klimawirkung

- Die Luftfahrt arbeitet kontinuierlich an verbrauchsärmeren Triebwerken.
- Die Auswirkungen von Emission auf das Klima sind teilweise sehr komplex und müssen ganzheitlich betrachtet werden.
- Einige der selbstgesteckten Emissionsziele erfordern einen Technologiesprung und nicht „nur“ Technologieevolution.
- Weiterhin müssen die Nachhaltigkeit des eigentlichen Systems und die Verfügbarkeit der Rohstoffe die Technologie ermöglichen.

	Effekte durch CO_2	Effekte durch NO_X	Aerosol-Effekte	Kondensstreifen, Zirrusabdeckung	Indirekte Wolkeneffekte
Aktuell	=	=	=	=	=
SAF, PtL	↘	=	↘	=	↘
H_2 Gasturbine	0	→	↘	↗	↘
H_2 Brennstoffzelle	0	0	0	↘	0
~~Batterie~~	0	0	0	0	0

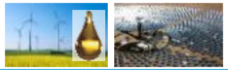
Technology roadmap towards “emission-free flying”

Application range

Gas turbine

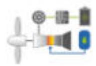

Evolutionary Gen2 GTF development


Revolutionary engine concepts


drop-in – no infrastructure change: SAF

not drop-in – new infrastructure required: LH2

Electric propulsion


Parallel hybrid electric concepts:
enabling technology only


Batteries

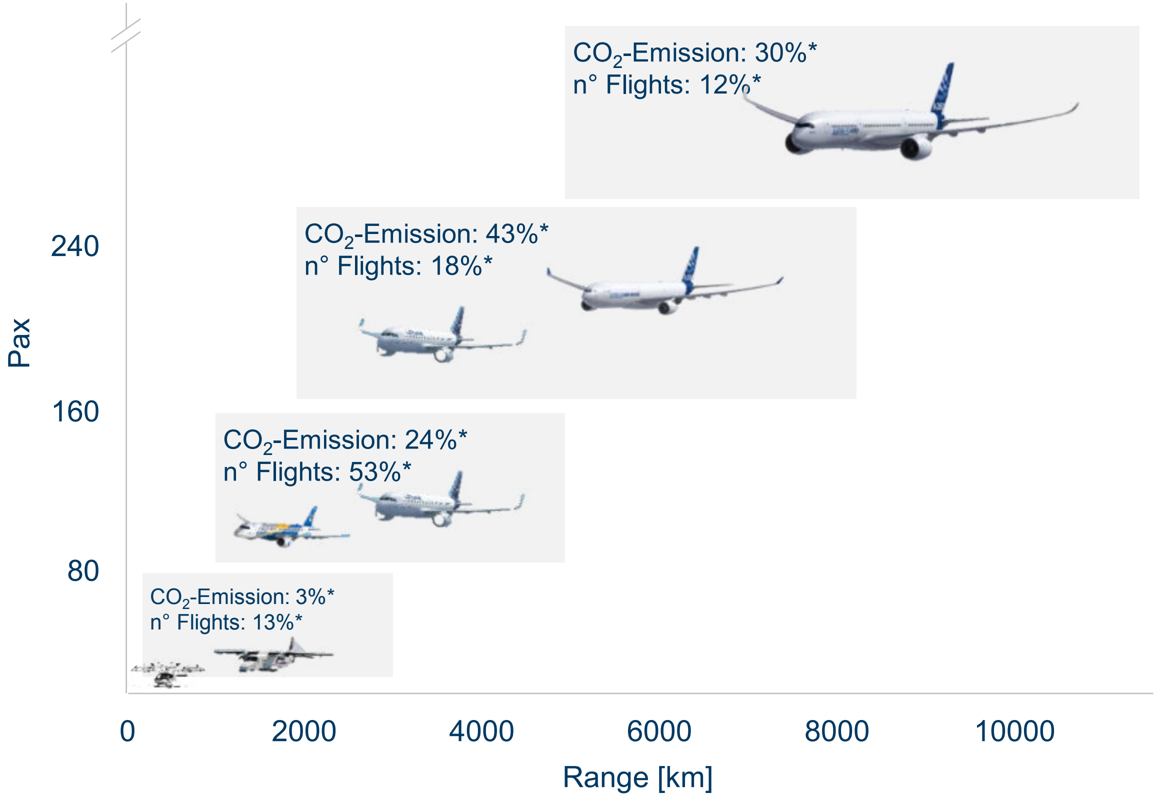

Flying fuel cell

Today — 2030 — 2050

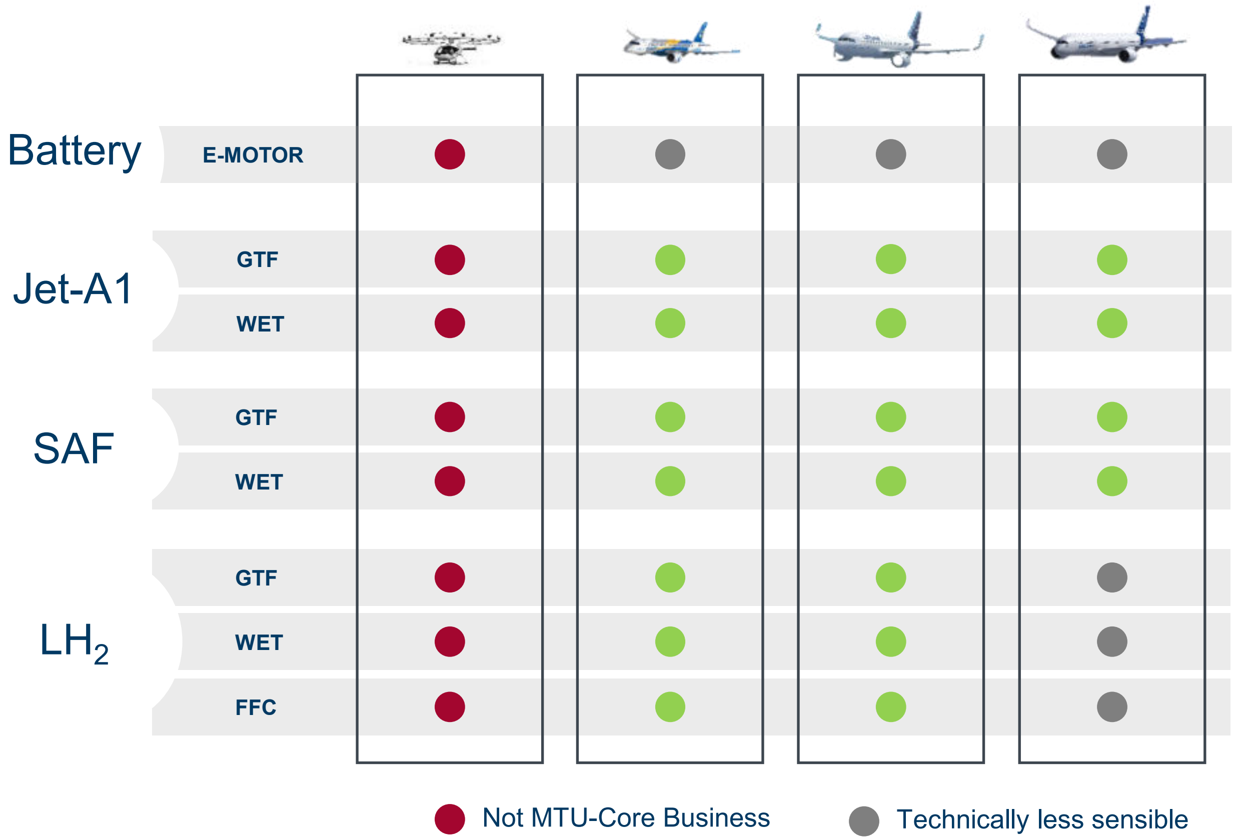
Application

Technology				
Evolutionary Gen2 GTF development		Short-range	Mid-range	Long-range
Revolutionary engine concepts		Short-range	Mid-range	Long-range
drop-in – no infrastructure change: SAF			Mid-range	Long-range
not drop-in – new infrastructure required: LH2		Short-range	Mid-range	
Parallel hybrid electric concepts		Short-range	Mid-range	
Batteries	Urban mobility	Short-range		
Flying fuel cell	Urban mobility	Short-range	Mid-range	Long-range

Which markets need to be addressed with which technology?



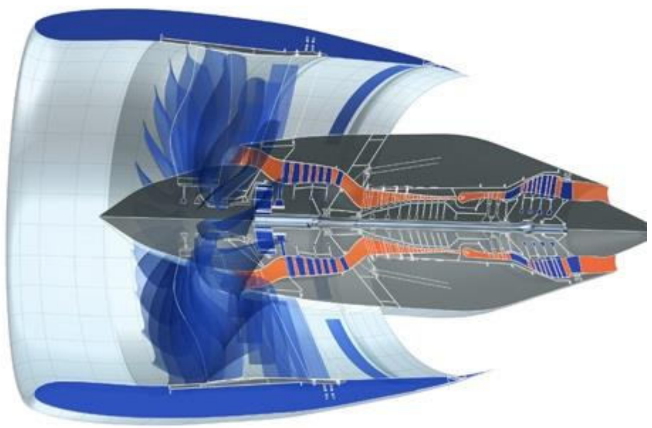
*aus „Hydrogen Powered Aviation“ McKinsey, 2020 (bezogen auf weltweiten Luftverkehr)



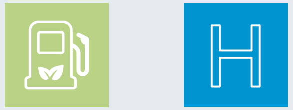
New Concepts

Evolutionary → **Revolutionary**

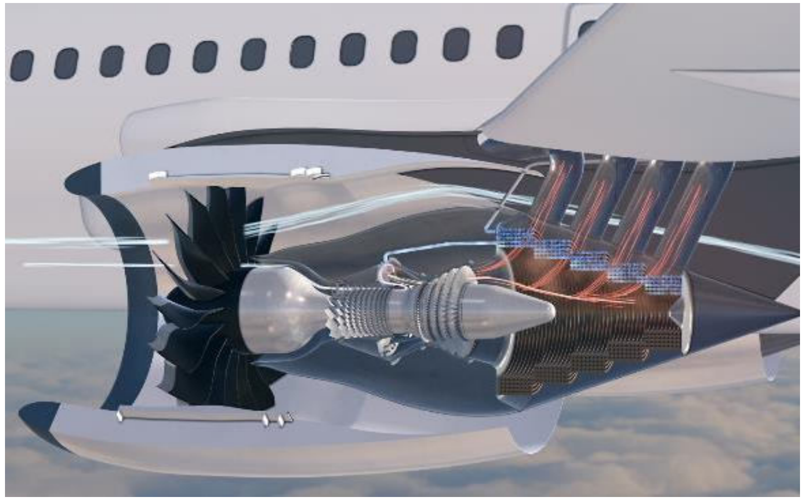
Gen2 GTF



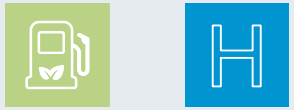
Minimum 10% reduction in fuel burn resp. energy consumption, -10EPNdb noise (cumulated) 1)



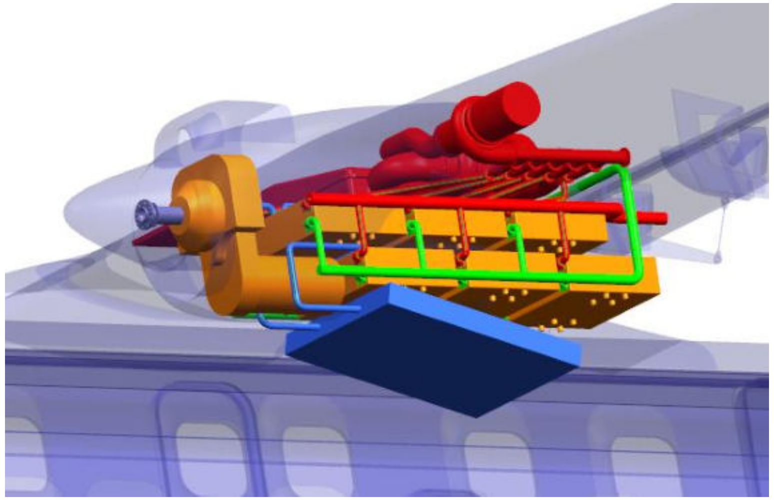
Water Enhanced Turbofan (WET) Engine



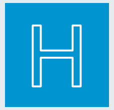
Minimum 25% reduction in fuel burn resp. energy consumption, significant reduction of the climate impact, -80% NO_x 1) and contrails



Flying Fuel Cell



-100% CO_2 and NO_x 1) and further reduction of contrail formation => almost climate neutral



1) Compared to 1st generation

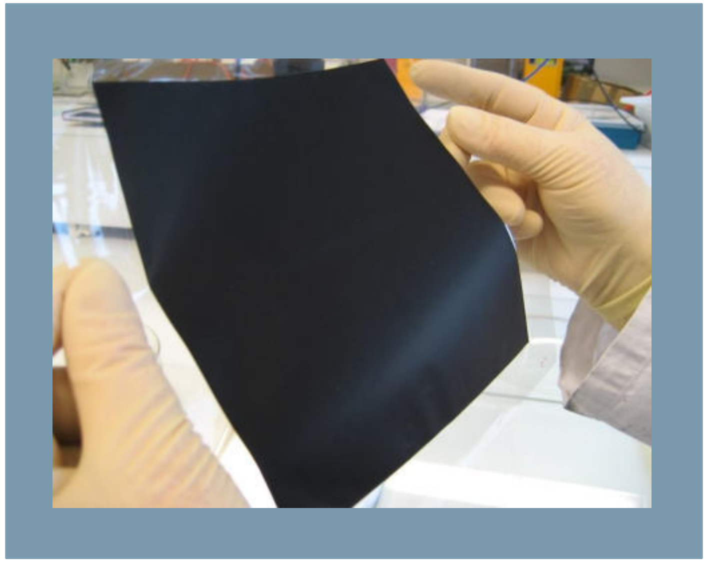
Agenda

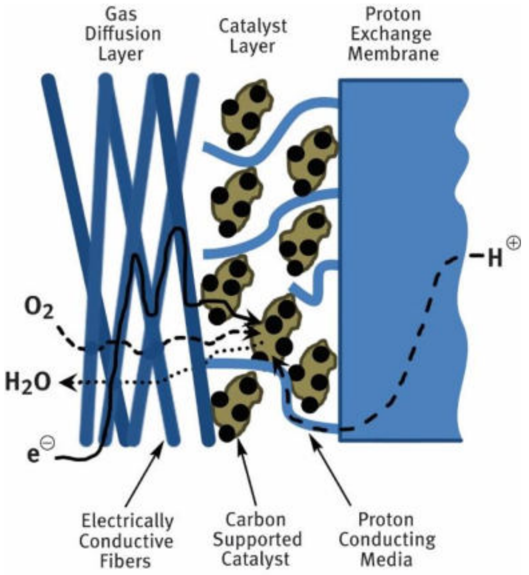
- MTU Aero Engines
- Produktstrategie und emissionsfreies Fliegen
- Das Flying-Fuel-Cell-Antriebskonzept
- Wie kommt der Wasserstoff zum Fliegen?

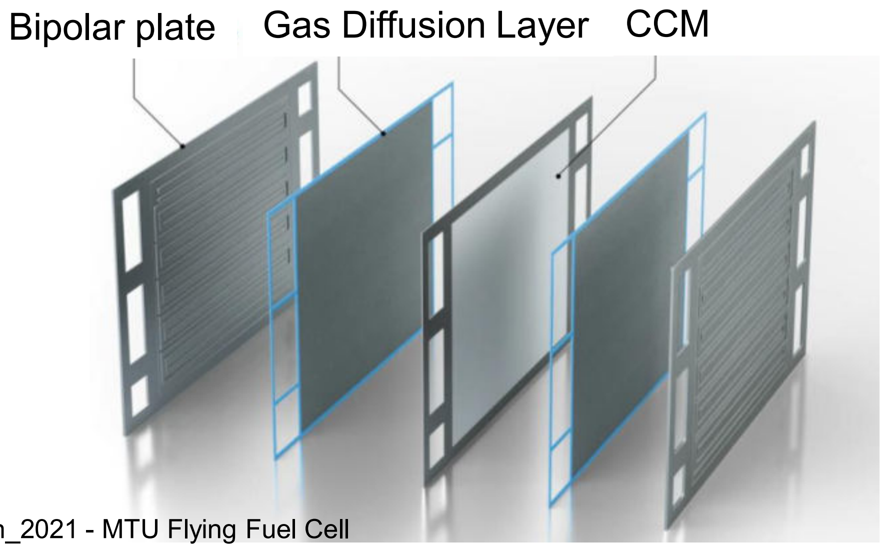
Catalyst Coated Membrane
the core component for performance

<u>Catalyst Coated Membrane (CCM)</u>
- determines performance and life-time of stack
- Pt loading and distribution

<u>„Comfort Parameters“ for CCM:</u>
- Supply with reactants
  - homogeneous over ACA
  - sufficient supply per time
- defined, homogeneous temperature
- high degree of hydration
- minimal contact resistance to other components
- no „foreign“ atoms/molecules

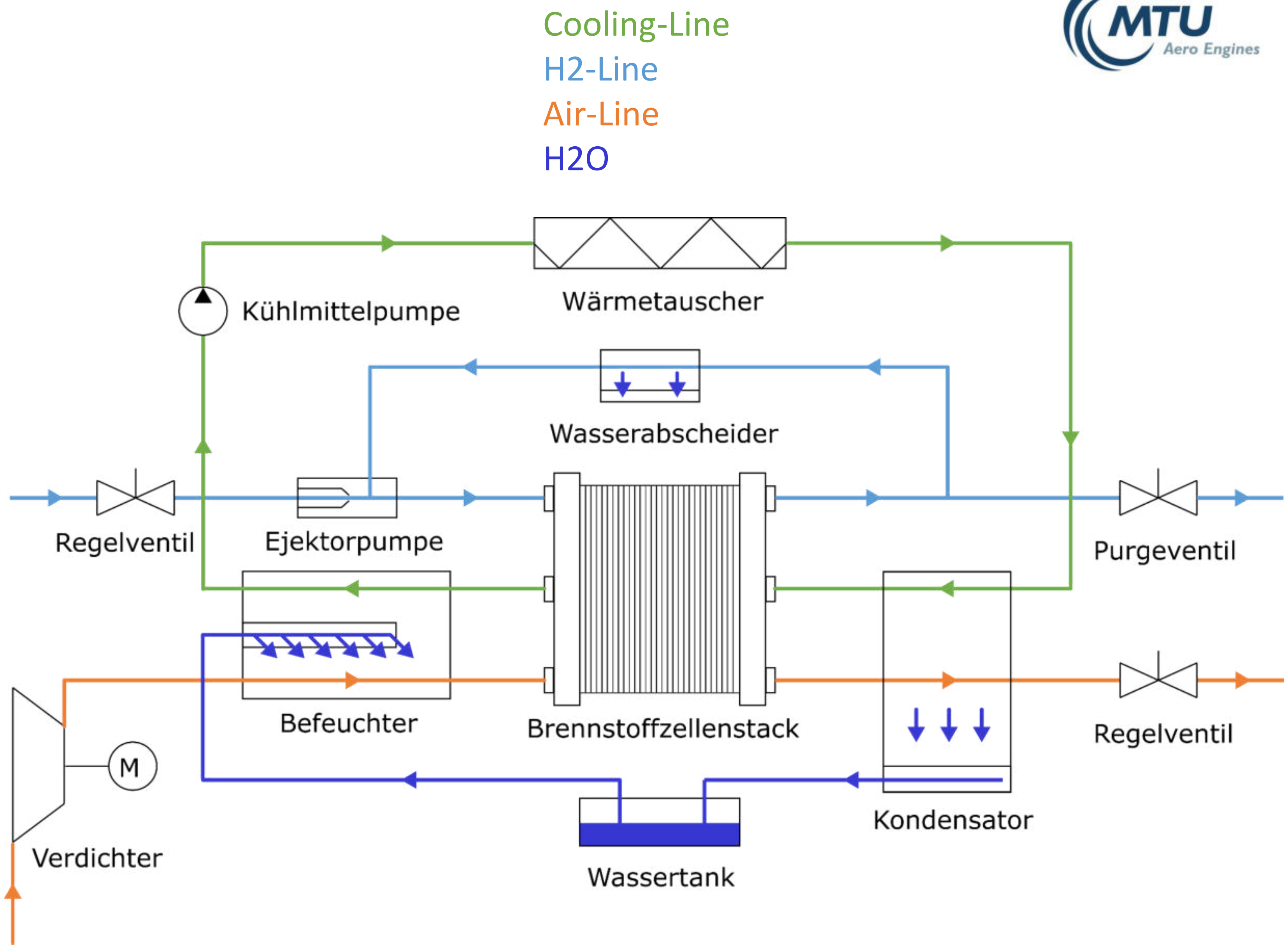




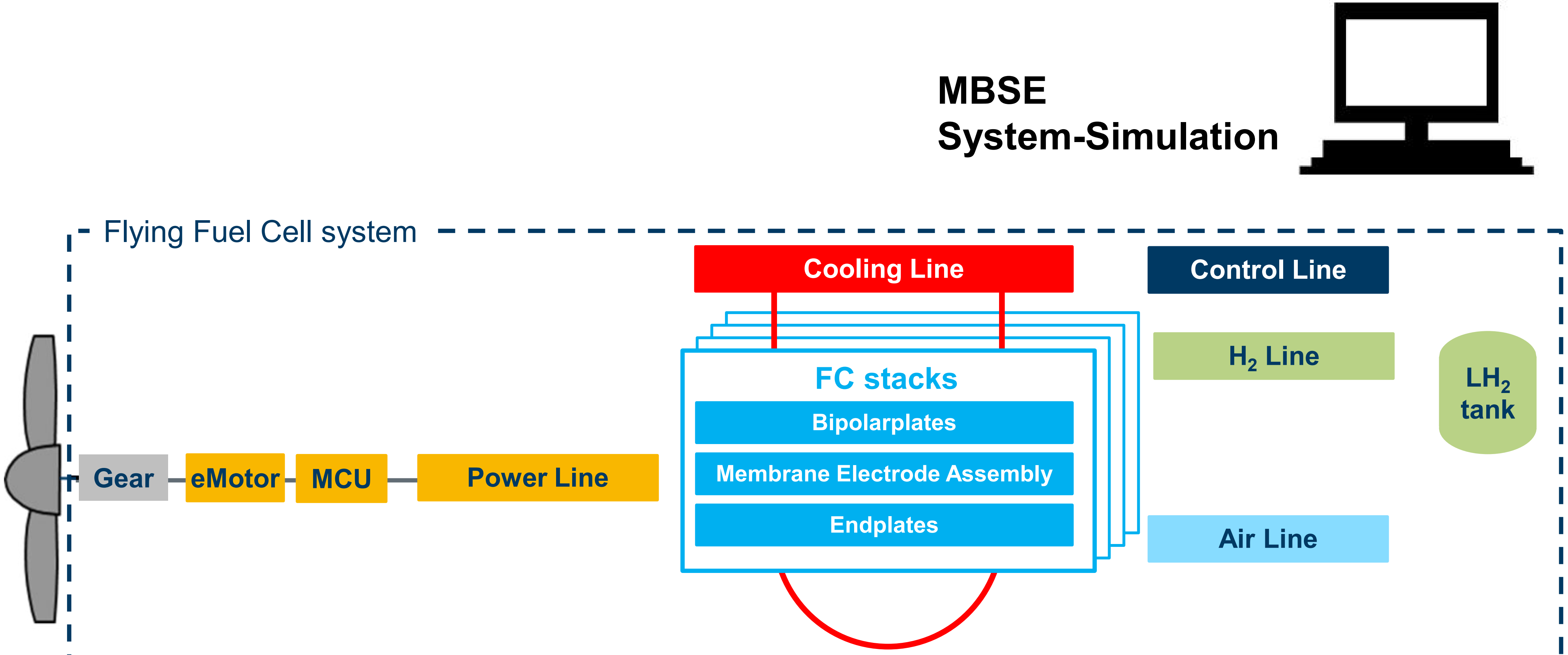


FFC Simple PID

- The „Lines“ / subsystems fulfill all necessary stack input and output functions
- Many different system architectures are possible
- Evaluation of system performance and subsystem interaction - especially with transients – is key for smart integration
- All lines have a high degree of interaction between each other
- This requires rigour in system engineering, modelling, simulation and testing

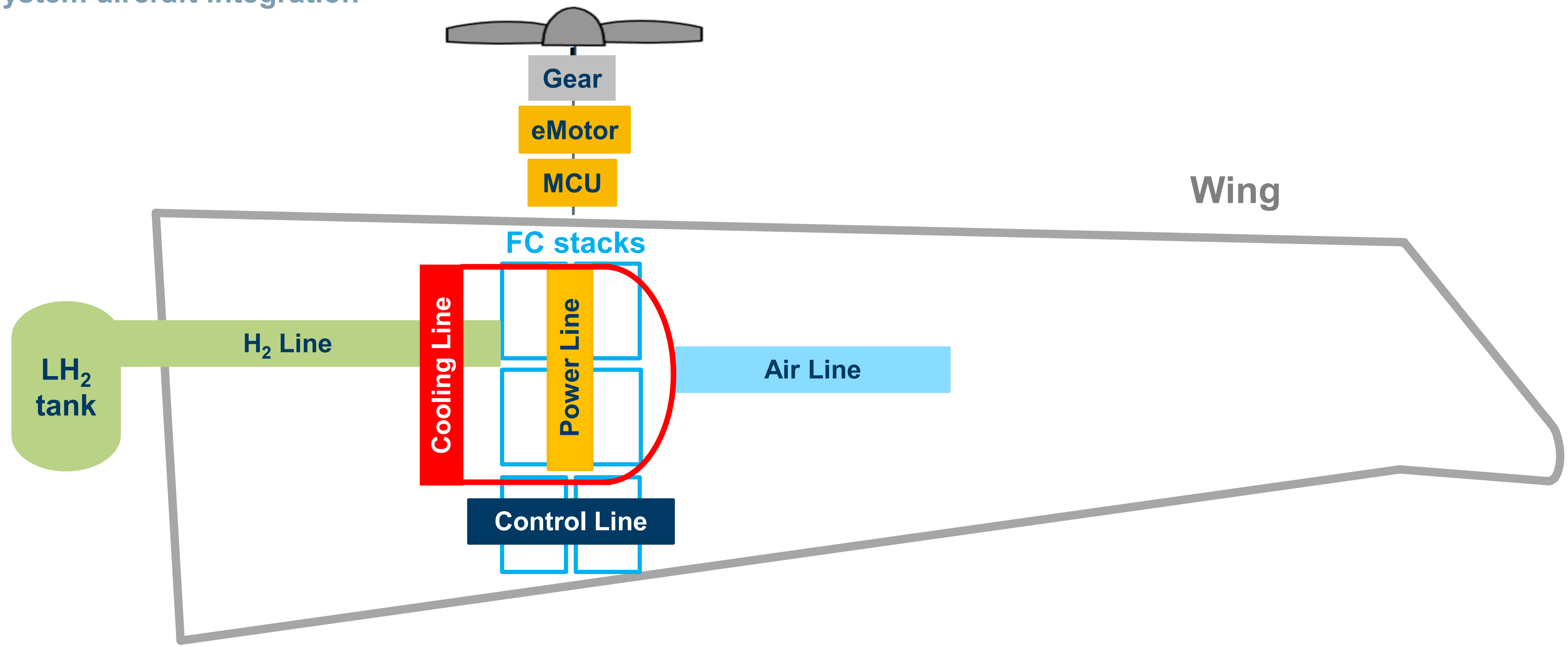


The Flying Fuel Cell Propulsion System



A flying fuel cell means an all-new integration challenge with multiple interfaces. Therefore, an even closer collaboration with the aircraft will be necessary.

FFC system aircraft integration



Wichtige „Zusatz-Anforderungen“ bei der Entwicklung der FFC

- Systemarchitektur
  - Ausfallsicherheit und Sicherheit durch Maßnahmen auf Equipment, Subsystem und Systemebene
  - Regelungsfähigkeit für unterschiedliche Leistungsanforderungen ohne Hybridisierung mit einer Batterie
  - Keine Notwendigkeit für „Low-level-TRL-Technologien“ wie „kV DC“, Supraleitung, Hoch-Temperatur-Membrane, etc.

- Smarte Integration
  - Geringe parasitäre Verluste durch Gesamtsystem-Optimierung => keine “COTS Melange”
  - Intelligente Kombination aus High-Tech- und Standard-Komponenten
    => “Power to weight” & “Power to cost” im Fokus

- Modularität großer Teile des Systems – aber nur wo sinnvoll
  => Skalierbarkeit großer Teile des Systems für höhere Leistungsklassen
  => hohes “Equipment-reuse”-Potential
  => Klare Definition von Nicht-Modularen Bauteilen (E-Motor, LH2-Treibstoffsystem, etc.)

Kühlkörperkomponente

Luftmassenstrom, Luftgeschwindigkeit,
$m_{dot,Luft}$, v_{air}

Benötigtes Volumen HEX, Dichte HEX
Rho_{HEX} , V_{HEX}

Masse HEX
m_{HEX}

Integration Kühlkonzept im Flugzeug

Dimensionen HEX (bsp. Länge Breite Höhe)
L, H, B

Einlaufdimensionierung, Auslaufdimensionierung,
$A_{Einlauf}$, $A_{Auslauf,}$, A_{HEX}

Masse Nacelle
$m_{Nacelle}$

Druckdifferenz HEX + Nacelle
$\Delta p_{HEX\text{-}Nacelle}$

Delta Druckwiderstand Nacelle+HEX
$\Delta c_{w,form}$

Bespülte Oberfläche Nacelle, Reibungswiderstand
ΔS_{WET}, $\Delta c_{w,reib}$

Interferenzwiderstand (bsp. Nacelle-Flügel)
$\Delta c_{w,Interf.}$

Komponenten-Ebene

System-ebene

Flugzeug-ebene

Kühlleistung, Kühlmitteltemperatur, Kühlmittelmassenstrom
Q_{dot}, T_{fluid} ,$m_{dot,fluid}$

Szenario:
- Hot Day Takeoff
- Cruise

Auswirkung auf Q_{dot}, $v_{air,avaiable,}$ $alpha_{angleofattack}$

OAD-Bewertungstool

Änderung Antriebsbedarf, SFC Gesamtflugzeug
$\Delta SFC_{aircraft,}$ $\Delta P_{aircraft}$

Massenveränderung Gesamtflugzeug
$\Delta m_{aircraft}$

Widerstandsveränder-ung Gesamtflugzeug
$\Delta c_{w,aircraft}$

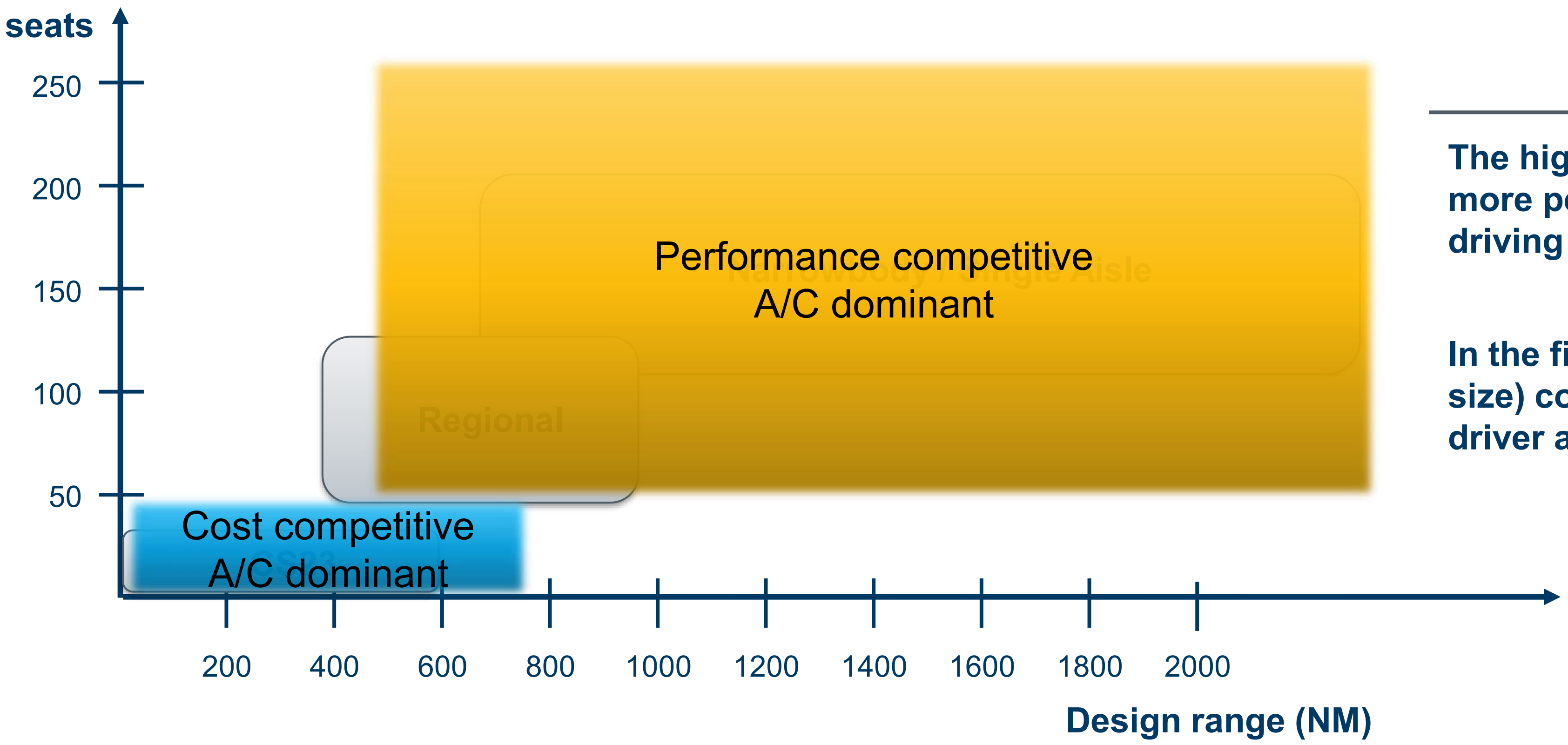
Flying-Fuel-Cell-Framework

Agenda

- MTU Aero Engines
- Produktstrategie und emissionsfreies Fliegen
- Das Flying-Fuel-Cell-Antriebskonzept
- Wie kommt der Wasserstoff zum Fliegen?

The FFC needs to address performance AND cost competitive A/C

Seat (payload) range diagram



Explanation

The higher Payload x Range the more performance becomes a driving factor for the A/C.

In the first application steps (CS23 size) cost competitiveness is a driver at A/C level.

MTU FFC – Main areas of action:

Fuel Cell & H2 System & Products

- System Engineering
  - Architecture
  - Scalability & Modularity
  - Simulation & Optimisation
  - Verification & Validation
- Business
  - Partnerships
  - IPR
  - Make / Buy
  - Hydrogen economy

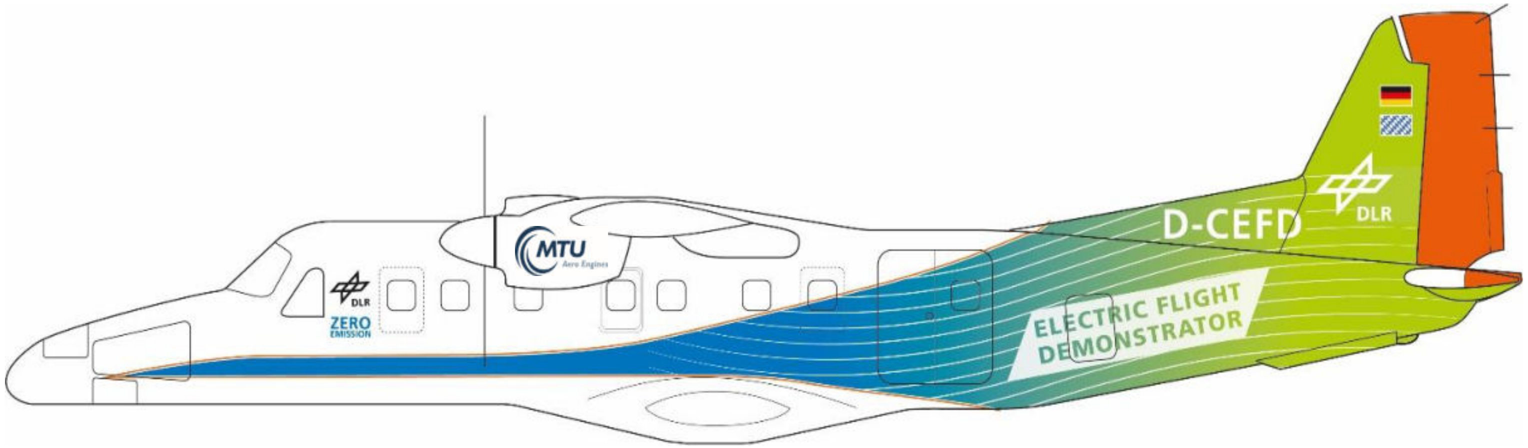
FC & H2 Aircraft Operations

- Climate impact sensitivities
- DMC/RC/NRC/NPV
- Operations
  - Airport
  - Airline
  - MRO
- Hydrogen infrastructure

FC & H2 Safety & Certification

- Rule making
- FHA, SSA, CMA, DFMEA, etc.
- Equipment and system qualification and certification
- Supplier qualification
- A/C integration & test
- Permit to fly (Do228FFC FTB)

The Do228FFC Flying Test Bed
a cooperation between DLR and MTU


MTU
Aero Engines
ZERO
EMISSION
DLR
D-CEFD
ELECTRIC FLIGHT
DEMONSTRATOR

Vielen Dank