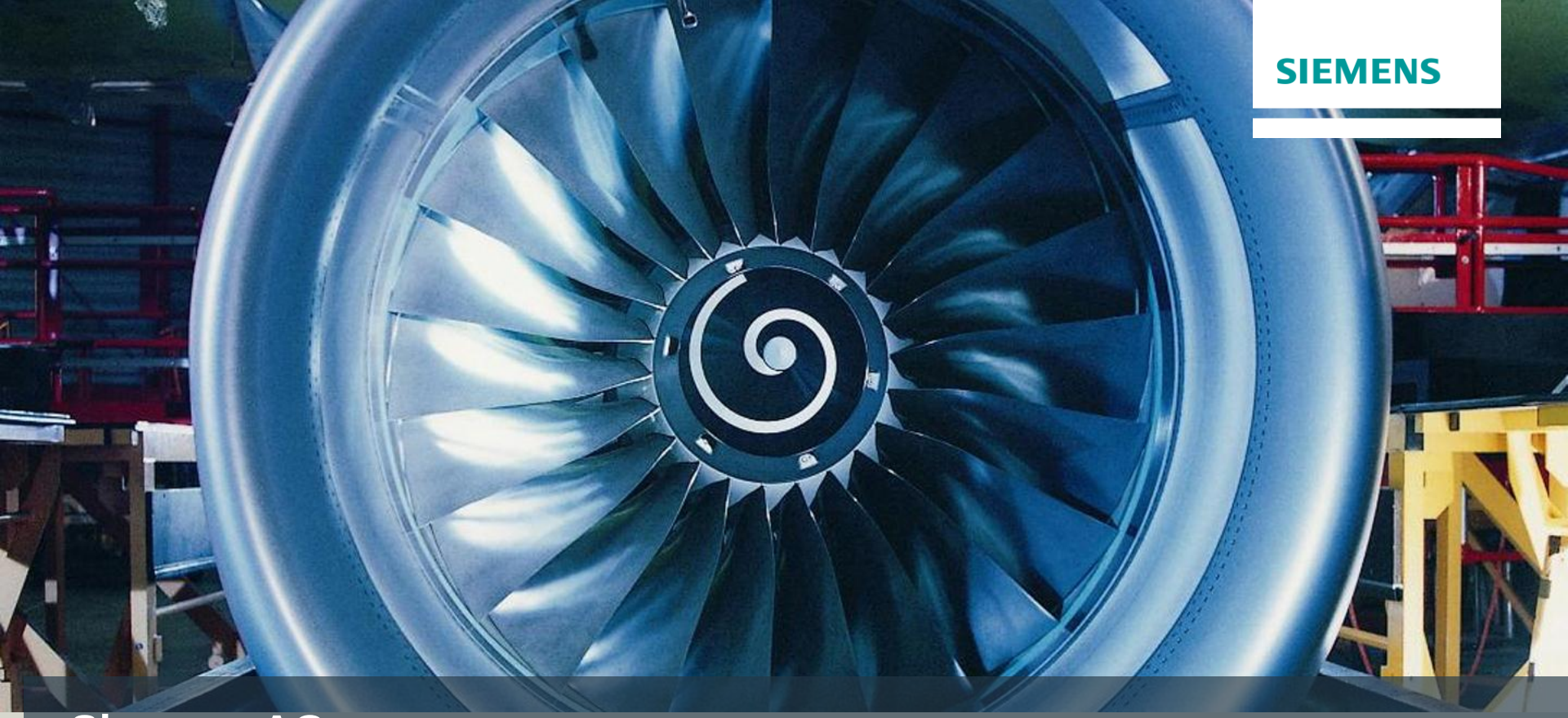

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Anforderungen an E-Motoren im Elektroflug

CT NTF AIR AI

Dr. Marco Schramm

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Ultra light weight Integrated Drive Trains for Aircraft

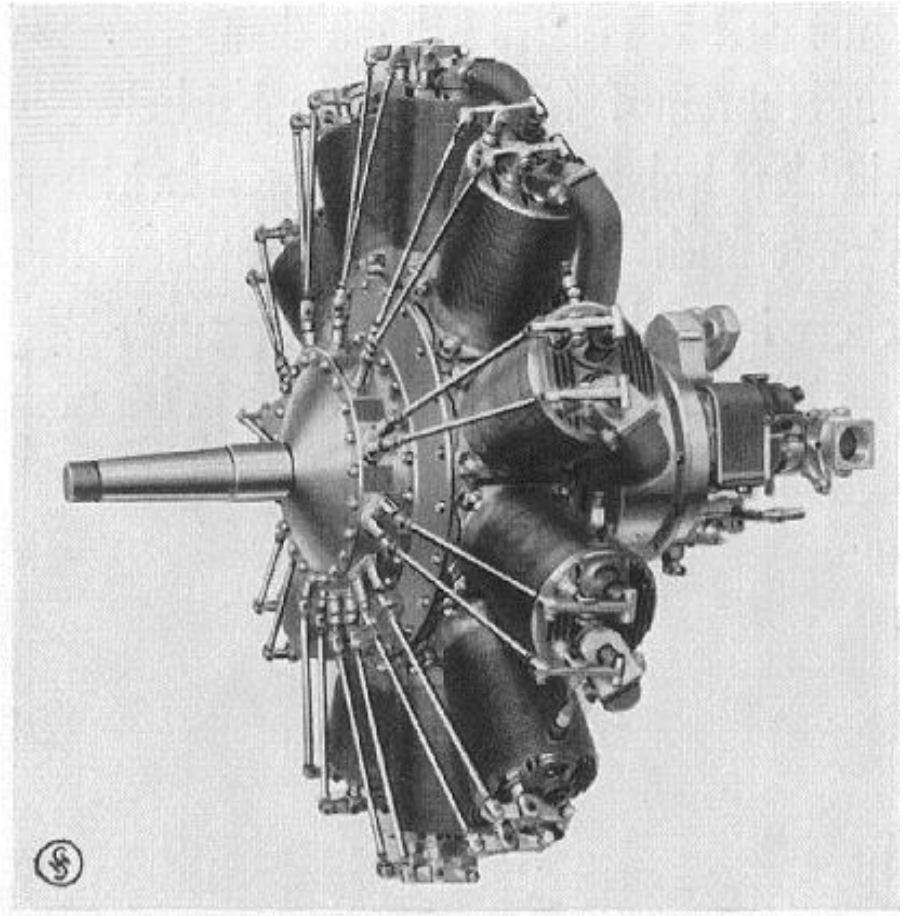

Bild 3. 160/240 PS-Siemens-Umlaufmotor, Type Sh 3

- Motivation
- Propulsion System Configuration
- Key Requirements on Component and System Level
- Scalability Aspects
- Summary

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Motivation

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E-Aircraft Hybrid Electrical Drive System for Aircraft

Problems

Aircraft manufacturer (OEM) and operator

Solutions

Siemens hybrid-electrical drive system for aircrafts

Airscrew Aircrafts

Helicopter

Turbo Fan Aircrafts

Benefits

A **more efficient** combustions engine optimized for permanent operation - peak load provided by battery - **efficient piston engine** will replace turbine

reduced Kerosene costs - 20 %

lower CO2 emission - 20 %

More quiet optimized integration in the fuselage

→ Acoustic emission in free space to the top

quiet piston engine instead of loud turbines

Low Life Cycle Cost low-wear electrical drive engineering

Improved flight dynamics

small E-drive motor actuate air-screw

optimal distributed hybrid components

Improved safety

redundant generators and additional battery charge controller

Market

1“ $/a

Turbo Prop, incl. MRO[1)]

> 2“ $/a

To 10 t, incl. MRO

20” $/a

with A320, incl. MRO

MRO[1)] = Maintenance, Repair, Overhaul

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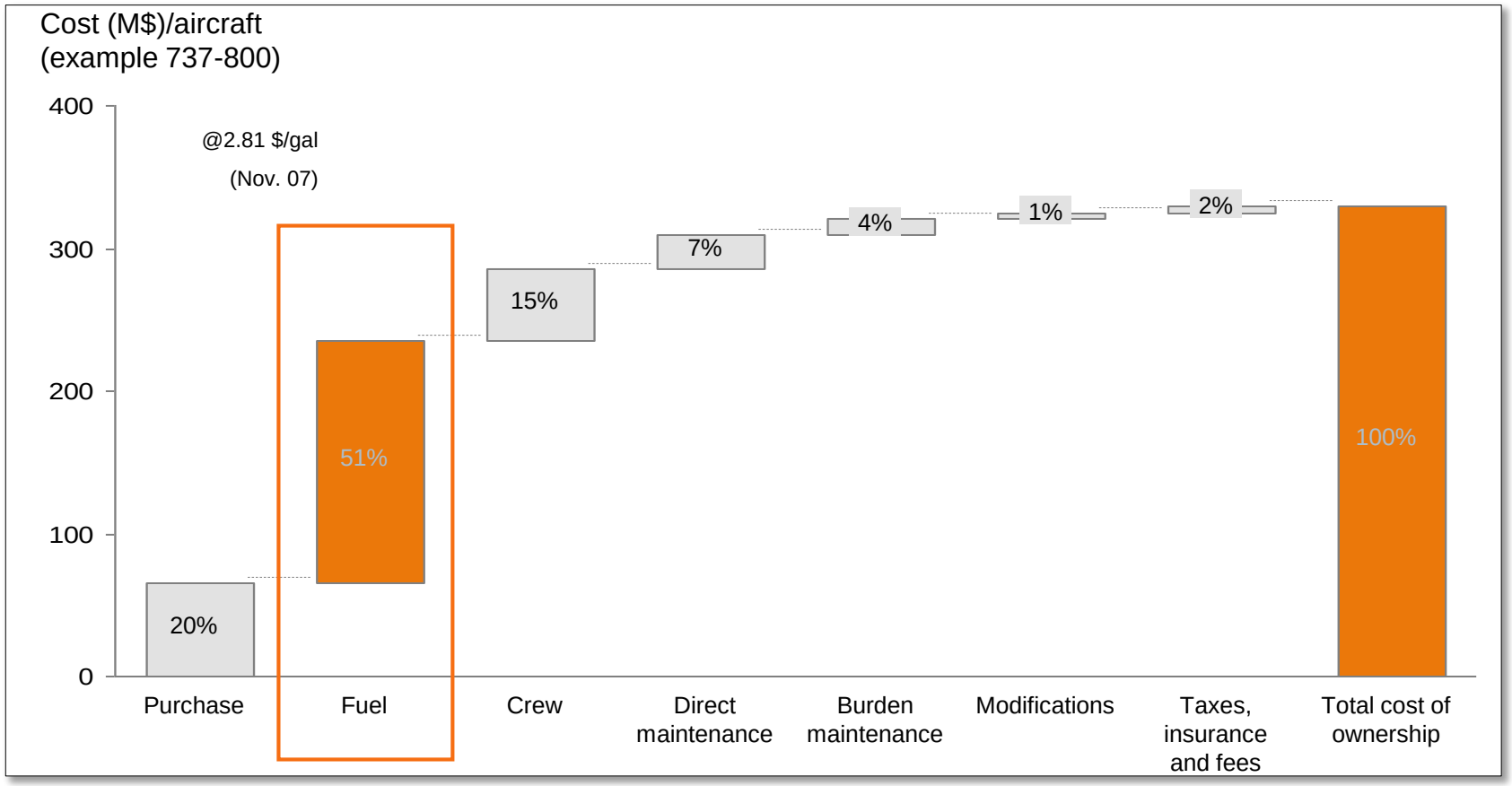
Fuel consumption has high share (~ 51%) of aircraft total cost of ownership



Reduction of fuel consumption is main lever to reduce aircraft TCO

Note: Calculated using hourly operational costs from September 2007 Form 41 data for all US carriers currently operating 737-800s (Continental, American, Delta, Sun Country, ATA, Alaska). Assumes uptime avg. 10.3 block hrs/day, 20-year lifecycle, and 8-10 year modification cycle.

Source: Carrier Form 41 reports, IATA, airfinancejournal.com, TeamSai, Aerostrategy; BCG

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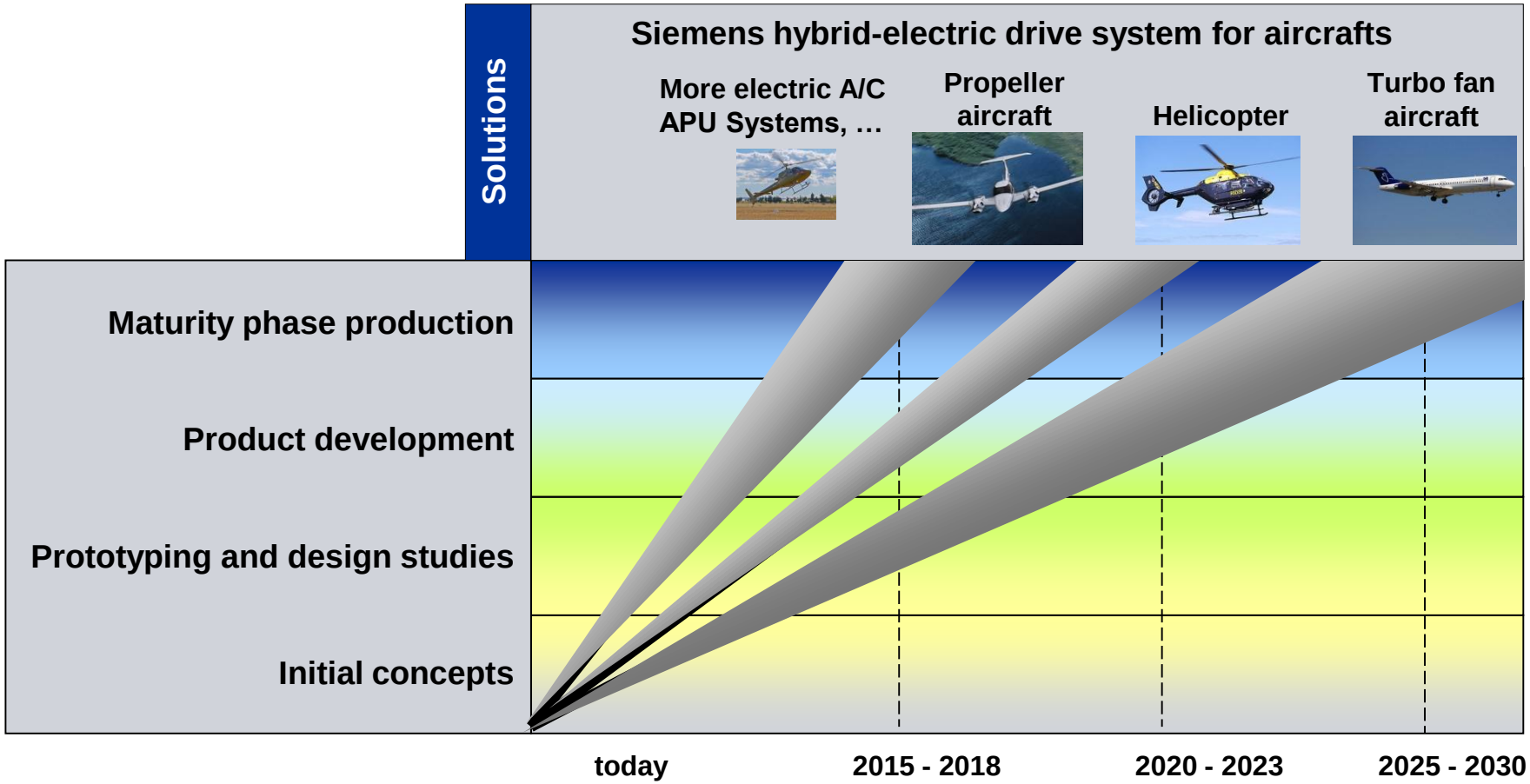
Concept designs and feasibility studies for all main applications already started



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Propulsion System Configuration

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Serial Hybrid Electric Propulsion System for Small Planes – One Engine Concept with ELOS of 2-MOT

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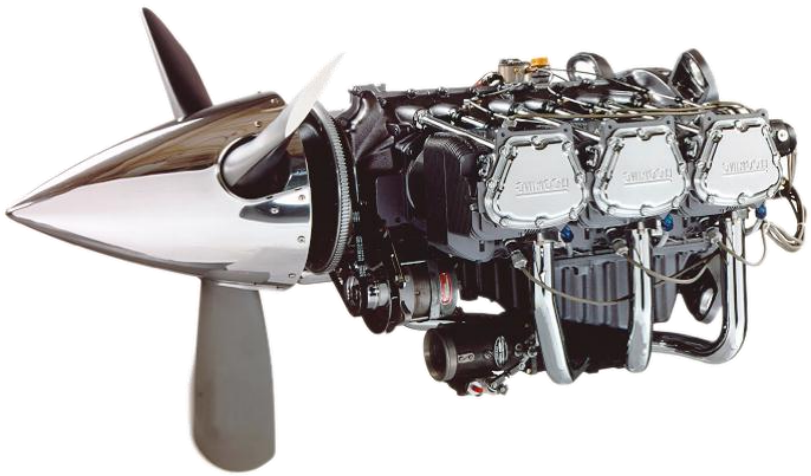
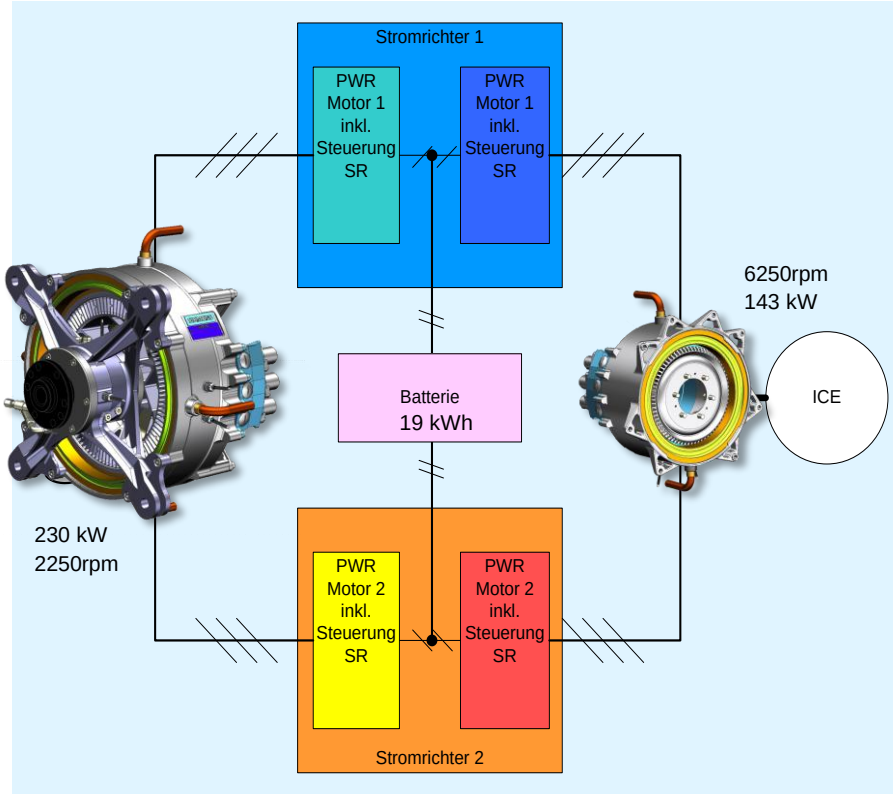
Today's combustion engine from 150 to 230 kW power

4-6 Cylinder direct ICE
2000…3000rpm



Serial hybrid electrical propulsion system with Two redundant power paths



Source: Lycoming Inc.

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Serial Hybrid Electric Propulsion System for Small Planes – Twin Engine Concept

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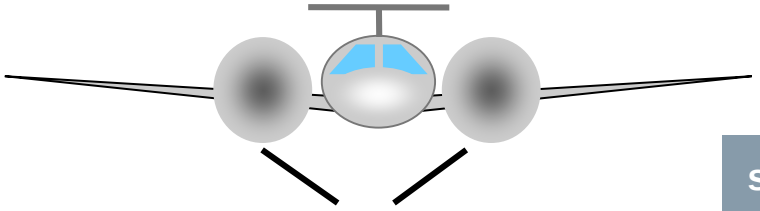
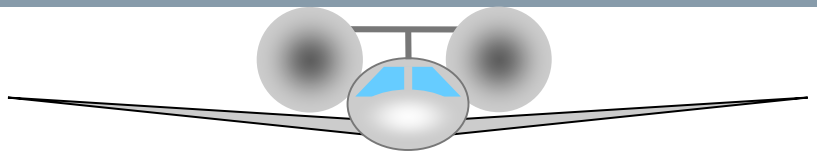
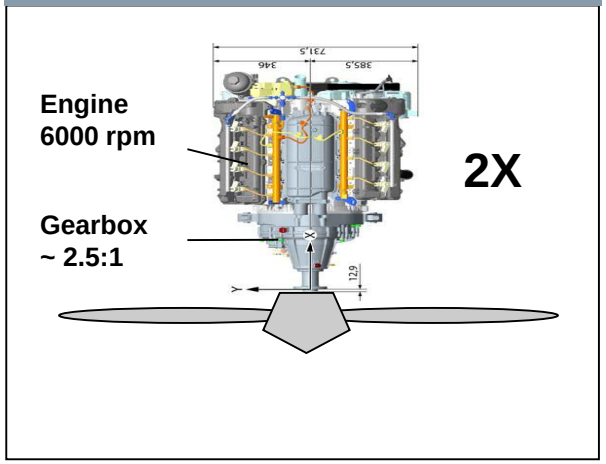
Replacement of conventional combustion engine linked via gear box with propeller by serial hybrid electric system

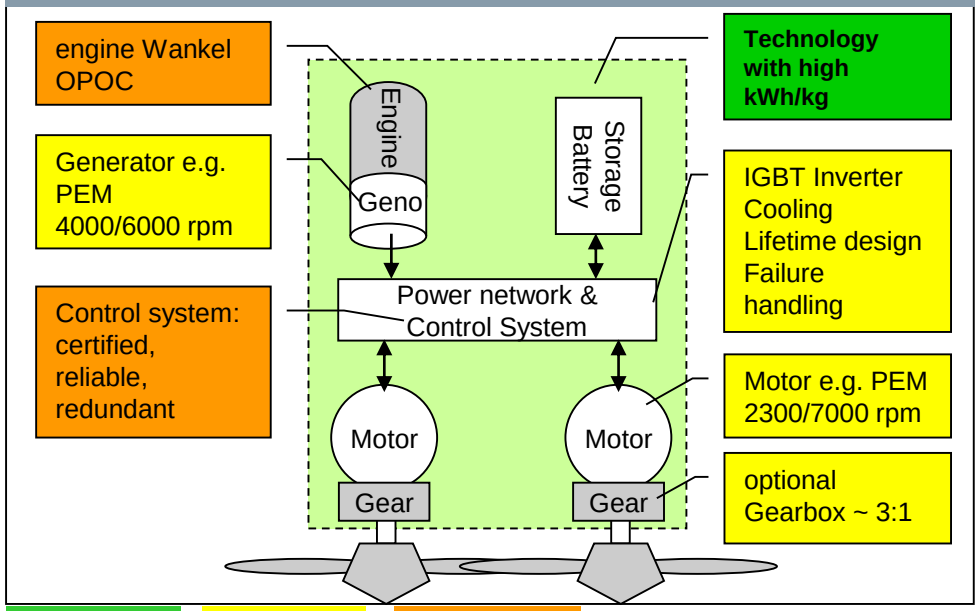




Today's combustion engine each 100 to 300 kW power



serial hybrid electrical propulsion system



market driven **technology** **architecture**

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Key Requirements on Component and System Level

Highest Power Density

Target: > 6 kW/kg

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Electric machine power density kW / kg compared to Industry Standard machines, Hybrid bus and e-Aircraft machines

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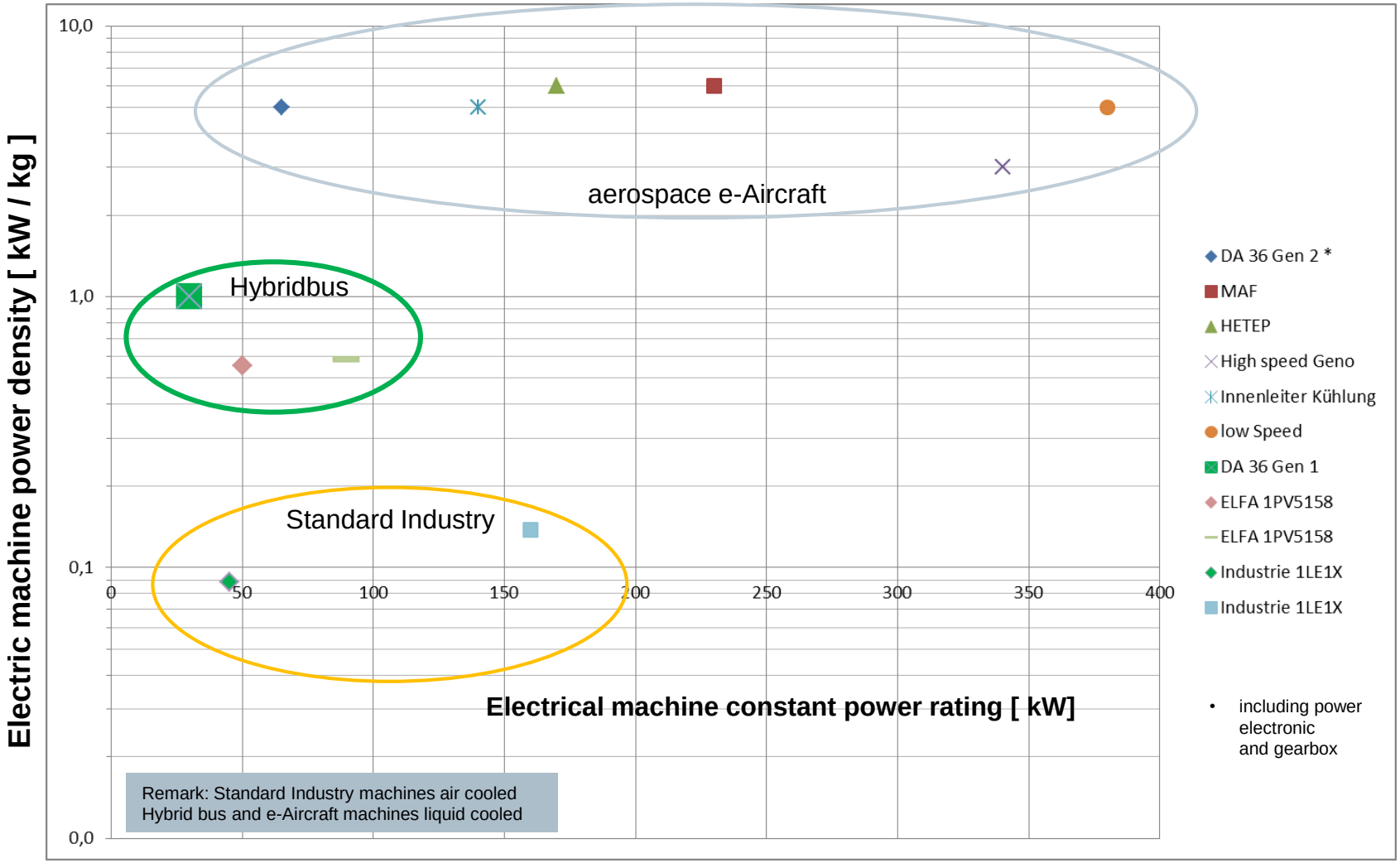

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Application DA 36 e Star 2nd Generation Motor Glider Propulsion System – Maiden Flight 01.06.2013

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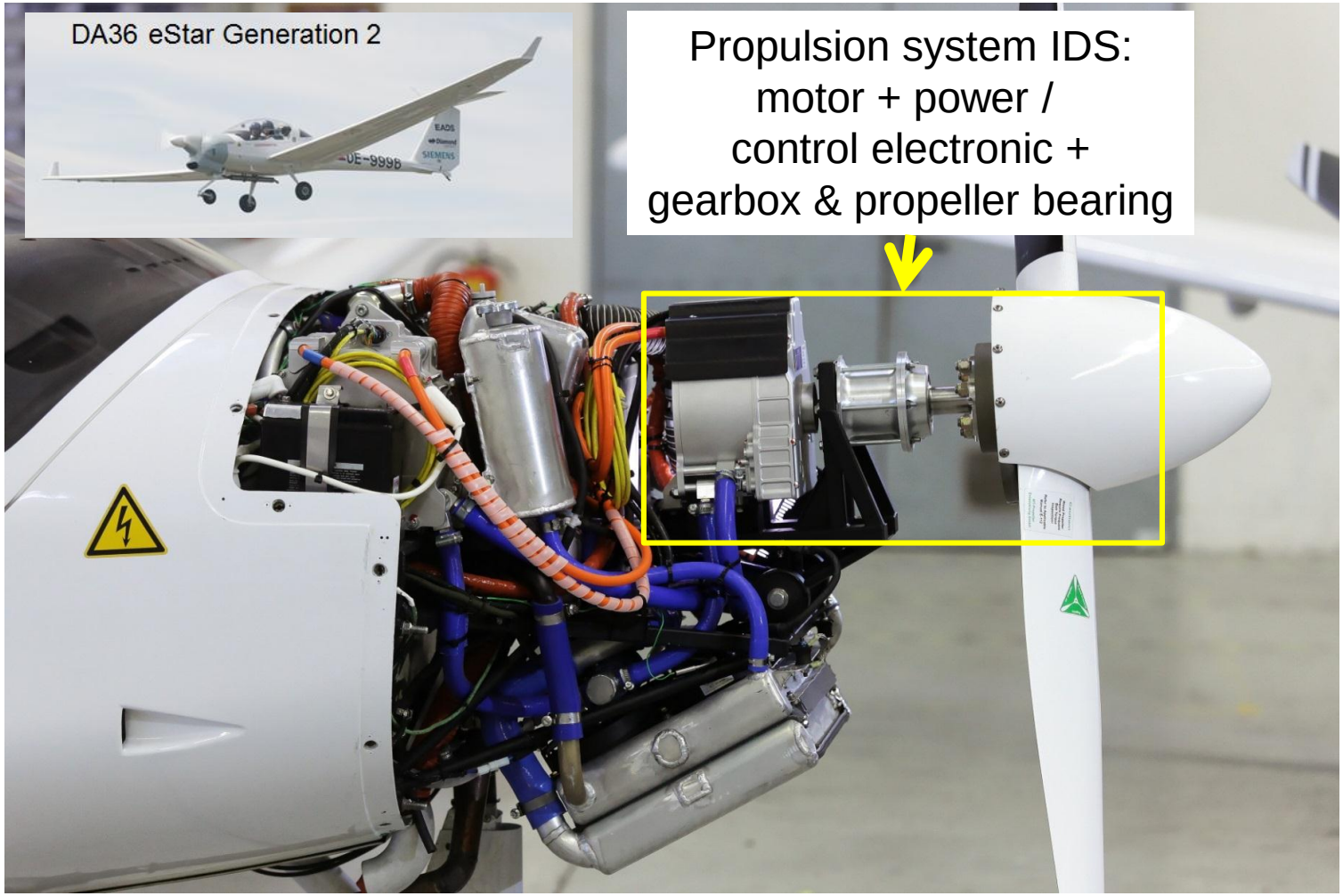

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Performance DA 36 e Star 2nd Motor
Maiden flight 01.06.2013

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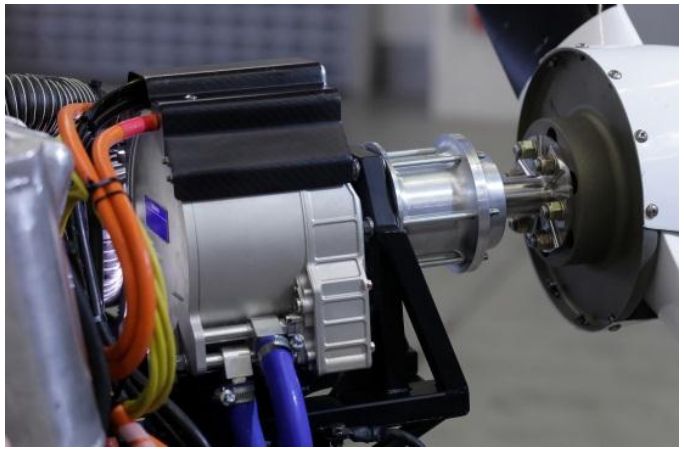

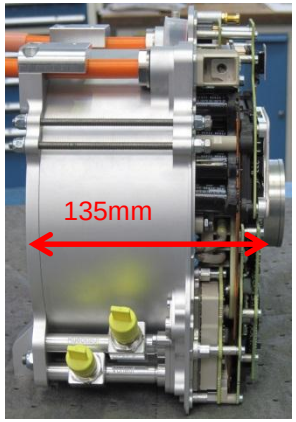

Key data:

P_{180s} = 80 kW
$N_{max\ intern}$ = 11000 rpm
$N_{max\ shaft}$ = 2400 rpm
M_{180s} = 70 Nm
Liquid cooled
Water / Glycol

$P_{cont.}$ = 65 kW
weight = 13 kg
~ 5 kW / kg
including inverter & gearbox

- R&D partner Compact Dynamics
- double-PWR for two galvanic separated winding systems
- Power semiconductors customized Infineon chips (600V) direct liquid cooling
- DC link - Elkos double sided cooled
- Compact design by specific components boards / plastics / direct connections

Time line CY

△:Start, ◆:End, ⬆:1st flight

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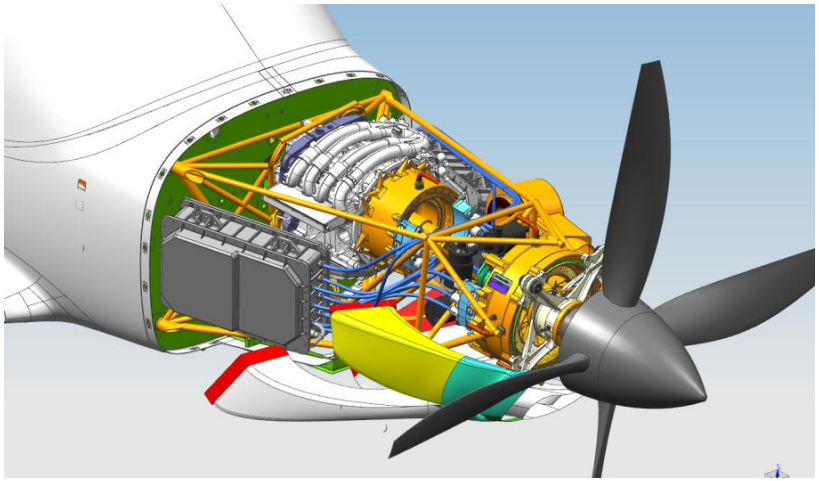
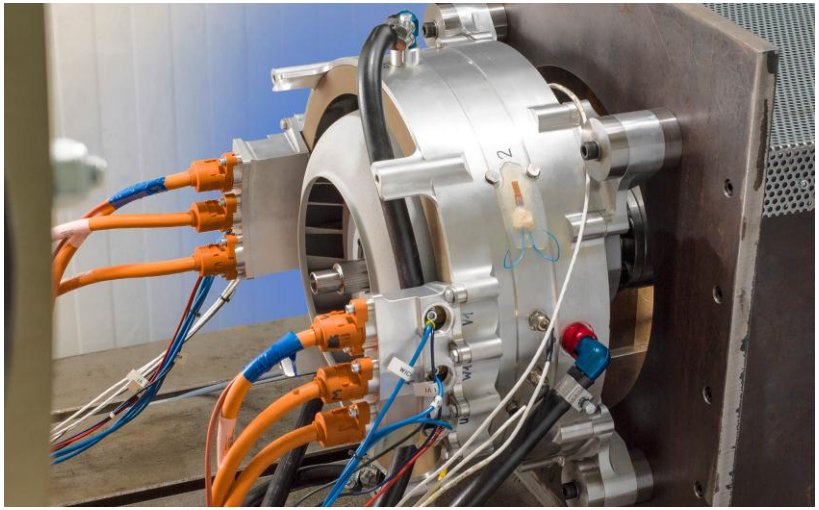
Performance „MAF“ Motor Lab approval





Key data:
$P_{cont.}$ = 230 kW
N_{nom} = 2250 rpm
M_{cont} = 977 Nm
U_{ZK} = 580V, I = 2*218A
η_{230kW} = >95 %

Tested on bench:
$P_{cont.}$ = 261 kW
N_{max} = 2500 rpm
$M_{cont.}$ = 1000 Nm
η_{260kW} = 94,5 %

- 2 redundant winding systems
- Direct conductor surface cooling with Silicon oil
- Mechanical design for Aerobatic loads
  +6,8g / - 4,8g & 28 kg Propeller (D = 2m, J = 2kgm²)
- Integrated Propeller bearing
- Motor weight w/o Prop. Bearing = 35kg
  -> 6,6 kW/kg
- Motor with prop. Bearing = 50 kg
  -> 4,6 kW/kg
- Dimensions: D = 418mm, L = 300 (w/o prop. bearing)

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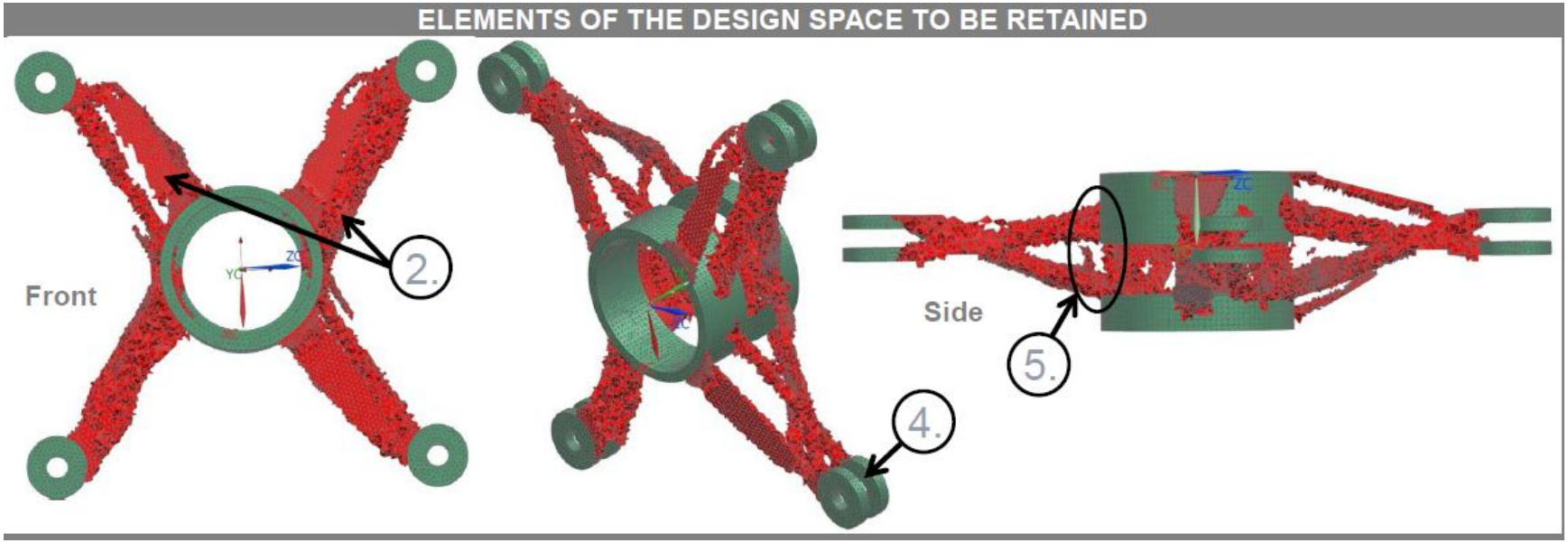
Optimization of Structure (Example: Bearing Shield)



1. Mass of retained material 2.9 kg
2. Optimizer suggests not rotational symmetric beams following the vertical direction of the maximum bearing forces
3. No outer ring structure necessary
4. No material between fixation flaps necessary

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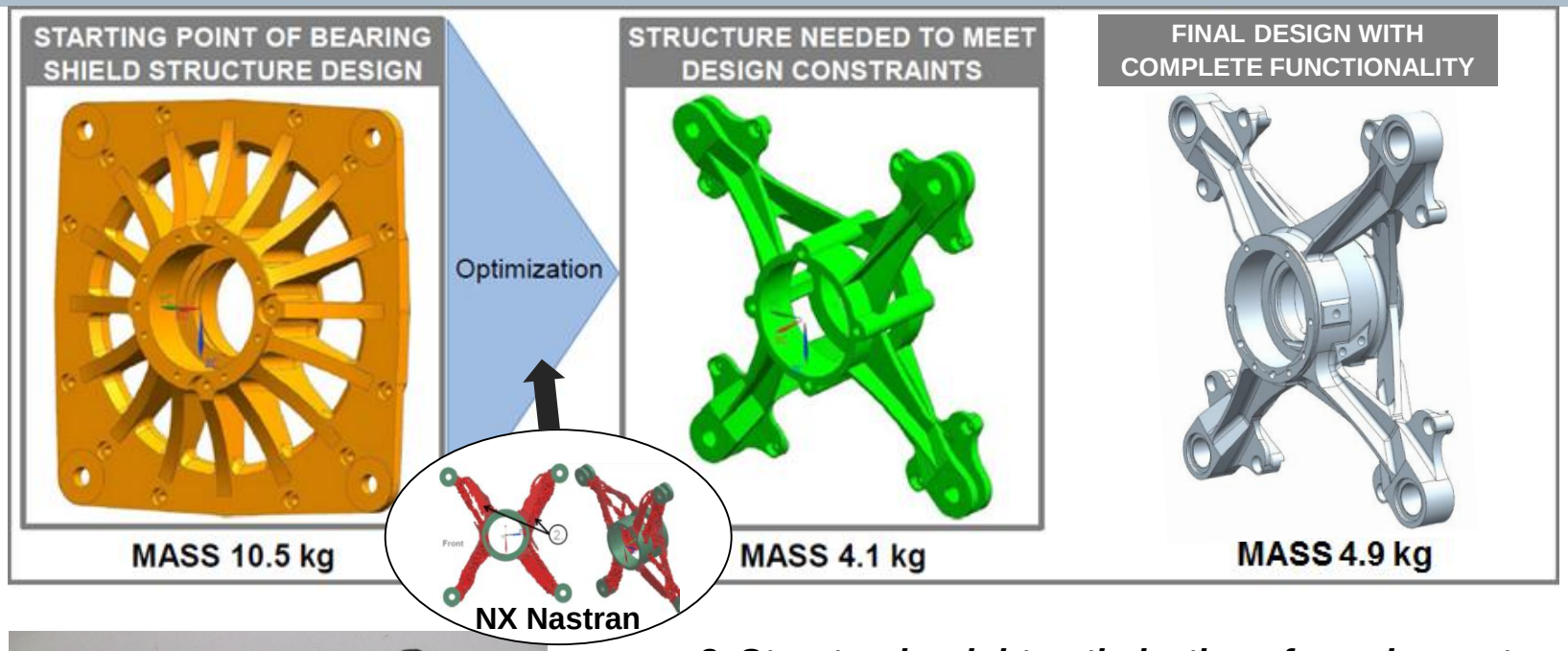
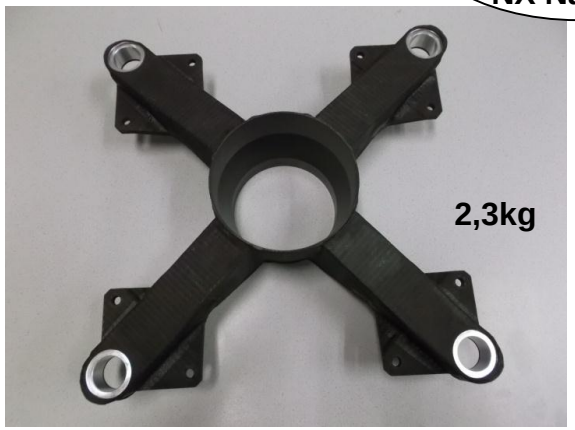
Mass Optimization Result (Example: Bearing Shield)





3. Structural weight optimization of passive parts

- e.g. bearing plate: from 10,5kg → 4,9kg
- Machined structural parts made of light weight materials (Aluminum) instead of iron cast design
- Strength calculations have to meet aircraft requirements which strongly differ from railway applications
- Use of CFK structural parts have potential of further weight reduction

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Performance Motor / Generator
Lab approval – next generation hybrid plane

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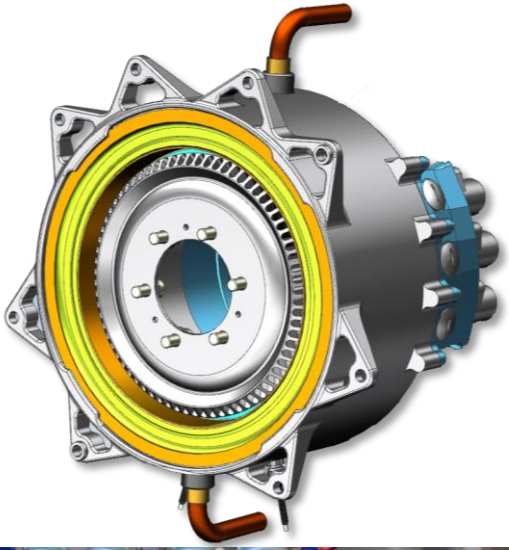

Key data:

$P_{cont.}$ = 170 kW @ 6250 rpm
P_{180s} > 170 kW
N_{max} = 6500 rpm
M_{cont} = 260 Nm
U_{ZK} = 580V, I = 2*131A
η_{170kW} = >95 %

- Redundant winding system
- Use as Motor or Generator
- Direct conductor surface cooling with Silicone oil
- Mechanical design for direct coupling to ICE or gearbox (including propeller bearing) mounting
- Dimensions: D = 308 mm, L= 150 mm
- Weight: 24,4 kg -> 7 kW/kg

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Under Evaluation:
Insulation Capabilities at High Altitude

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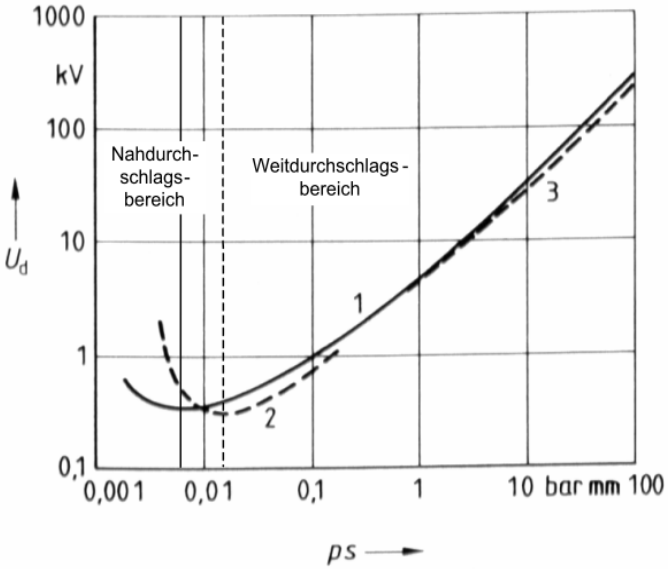
Low Pressure is a Specific Design Challenge

Low air pressure in the atmosphere: main effects

- Breakthrough voltage in homog. electr. Field
- < 330 V: no breakthrough
- Impact on cooling performance by reduced Mass flow via heat exchanger
- Thus system efficiency is key success factor



Paschenkurve von Luft bei 20 °C im homogenen Feld
1) experimentell ermittelte Kurve
2) für den Nahdurchschlagsbereich berechnet mit $\gamma = 0{,}025$ (s. Abschnitt 9.5.1)
3) für den Weitdurchschlagsbereich berechnet mit $\gamma = 2 \cdot 10^6$ (k = 13) (s. Abschnitt 9.5.1)

Source: Technische Universität Darmstadt

9 DER ELEKTRISCHE DURCHSCHLAG VON GASEN Seite 27
Fachgebiet Hochspannungstechnik Prof. Dr.-Ing. Volker Hinrichsen | Hochspannungstechnik WS 07/08 + SS 08 | TECHNISCHE UNIVERSITÄT DARMSTADT

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Scalability Aspects

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Scaling the Actual E-Machines to 600-1000 kW by increasing active length

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Target	Size	Technology
600-1000 kW 2000 to 2500 rpm 6 kW/kg Efficiency > 94 %	MAF E-Motor (400mm) m = ca. 112 kg Diameter = 418 mm Length = 500 mm	Direct Fluid Cooling Sealing at Stator (Can)
600-1000 kW 5000 to 6000 rpm 7.5 kW/kg Efficiency > 95 %	MAF E-Generator (292mm) m = ca. 80 kg Diameter = 310 mm Length = 280 mm	Cooling must be calculated and defined, Integration with the ICE

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Summary

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Requirements for Ultra light weight integrated drive trains for Aircraft

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General → Safety driven development process

light, efficient, reliable & safe, silent, operation in specific ambient conditions (temperature-/air pressure range)

<u>Subsystems and e-drive components:</u>

E-machine → light, small, reliable (redundant), high degree of efficiency (with regard to propeller-/ICE-efficiency), designed for flight loads (e.g. gyroscopic loads)

Inverter → reliable (redundant), operation in requested ambient conditions, EMC

Wiring & electrical connectors → safe [voltage], EMC, suitable for high altitudes

Cooling system → light, small, reliable, operation in requested ambient conditions

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… We have the Competence to Contribute to the Next Aircraft Generation …

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… let's take-off for a Green Future!

Thank you for your attention!

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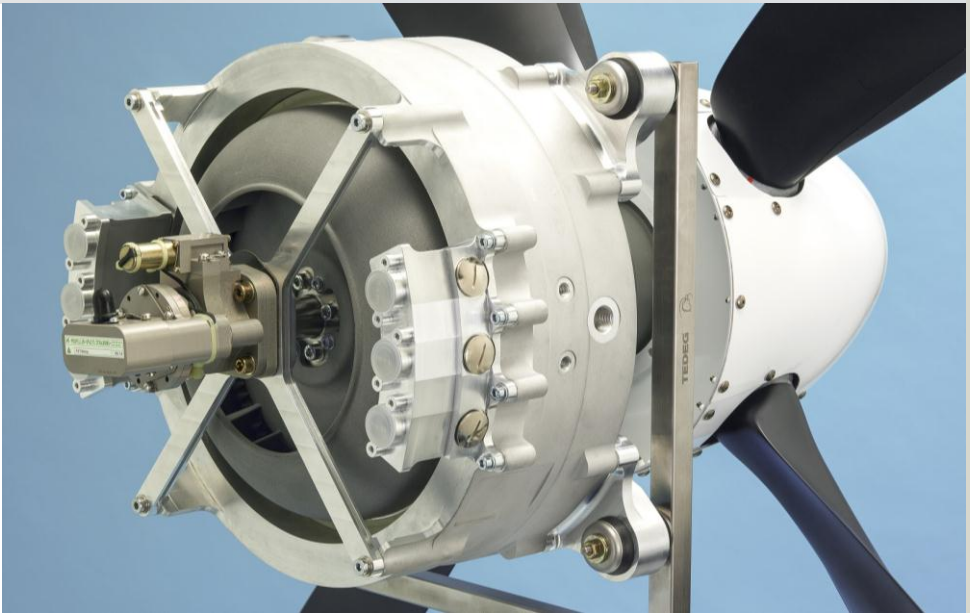
Serial Hybrid E-Drives for Aeroplanes



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