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Transformative Vertical Flight Workshop – 08/03/2015

Electric propulsion components with high power densities for aviation

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The world is becoming electric – in aviation as well

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We develop serial hybrid electric propulsion systems for aircraft

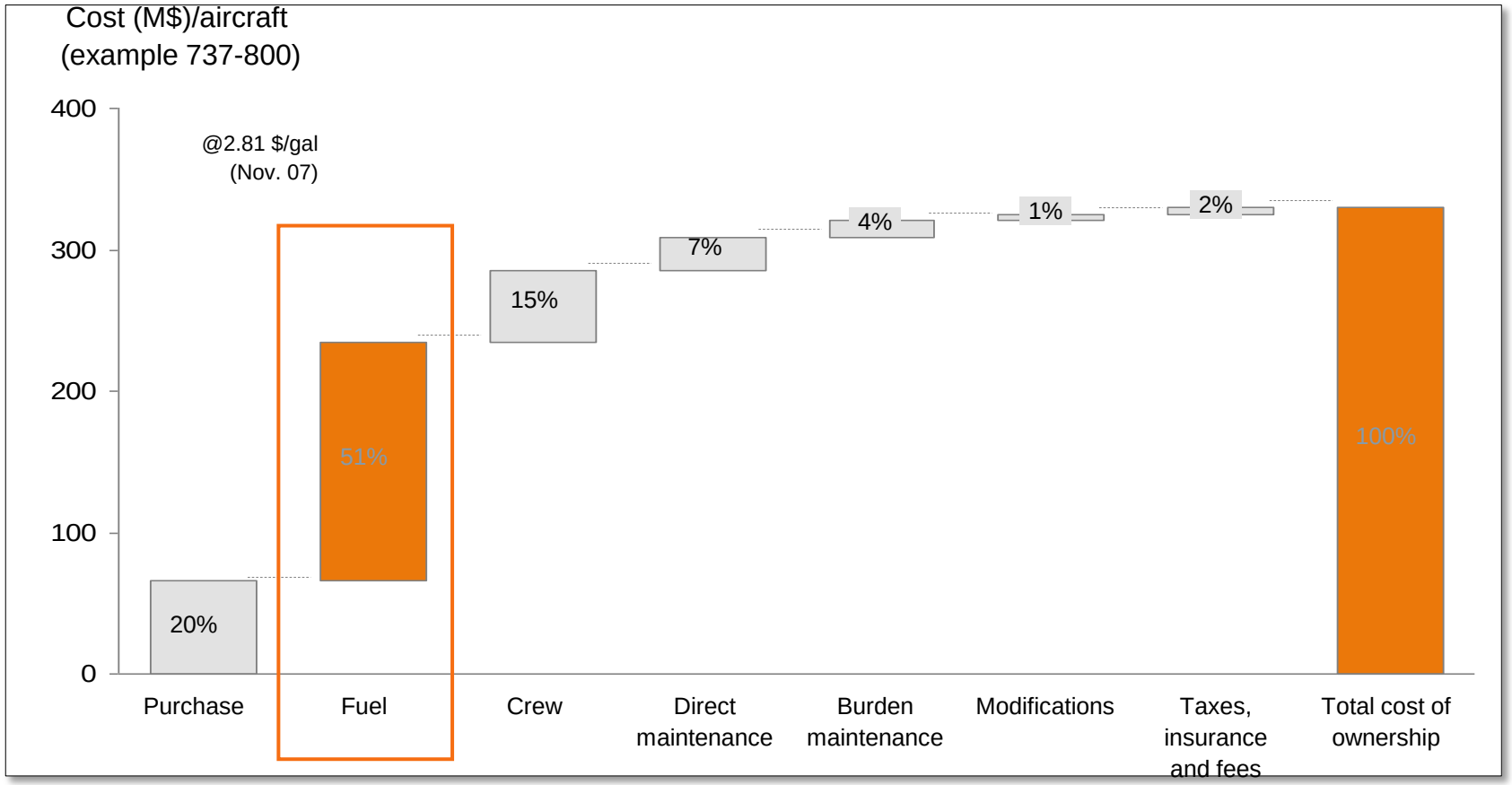
The technology is scalable and will soon be making its way into small aircraft and, in the future, into commercial aircraft with 60 to 100 passengers, making aviation 'greener'.

Aviation optimization possibilities thanks to electric propulsion are

- Less or no fuel consumption and pollution by using hybrid or full electric drives
- Increase of aerodynamic efficiency of aircraft by distributed propulsion
- Silent propulsion for night starts and landings
- Lower operation costs (fuel, maintenance)
- Safety increase with redundant energy sources

Motivation of these days:
80 kW propulsion in flight

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

Challenges: Light construction, Safety, Certification & Integration

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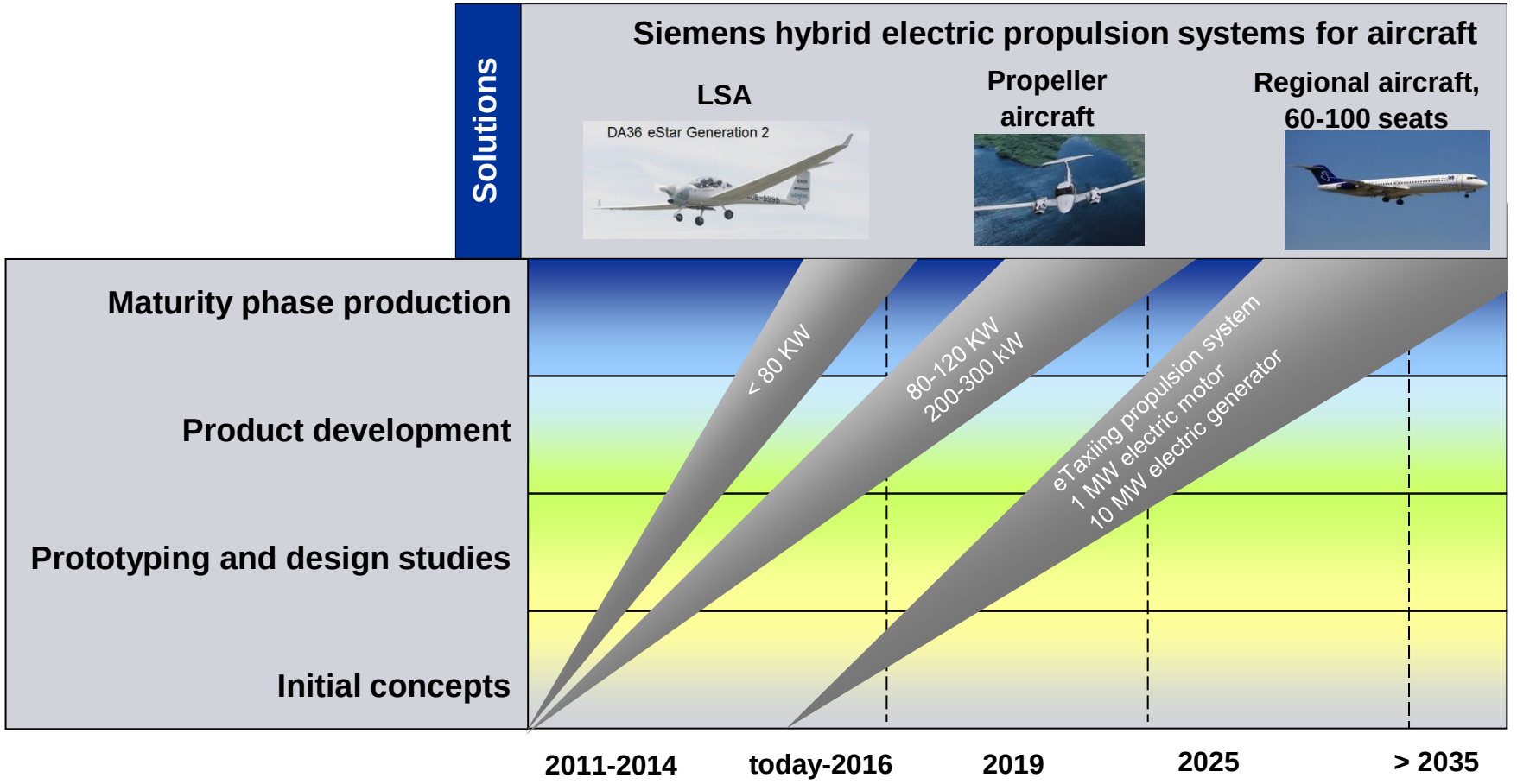
Propulsion	light, efficient, reliable & safe, silent
E-machine	> 95 % > 6 kW/kg
Inverter	> 20 kVA/kg
Controls	safe and redundant (HW, SW)
Cooling	Light, small and adapted to airframe
Combustion engine	light, low consumption and emissions
Energy storage	safe, integrated with airframe, light, optimized for energy or power density (depending on application)

- P_{Mech} : 0,66 MW continuous
- Power density: 0,87 kW/kg

- P_{mech} : 0,26 MW continuous,
- scalable
- Power density: 5 kW/kg

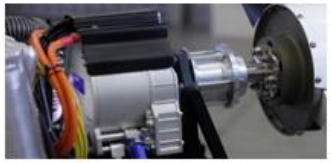
Roadmap of our development projects



Milestones

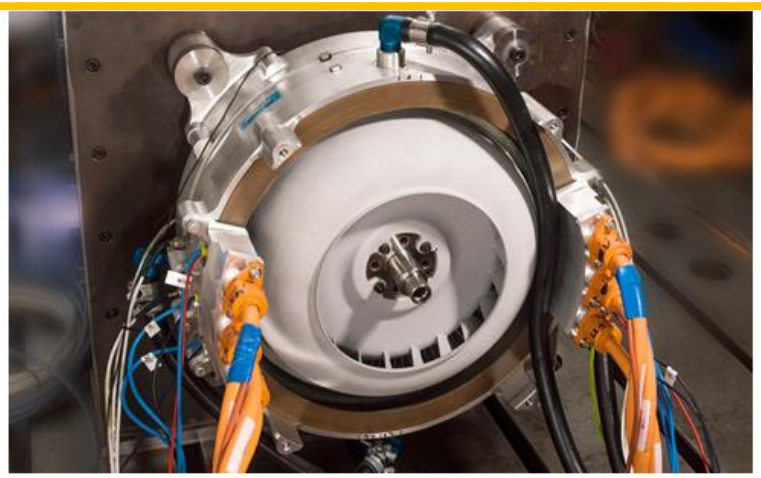
2011

2013



2014

2015



2013

Application: DA 36 E-Star 2
Motor Glider Propulsion System
Maiden Flight 01. June 2013

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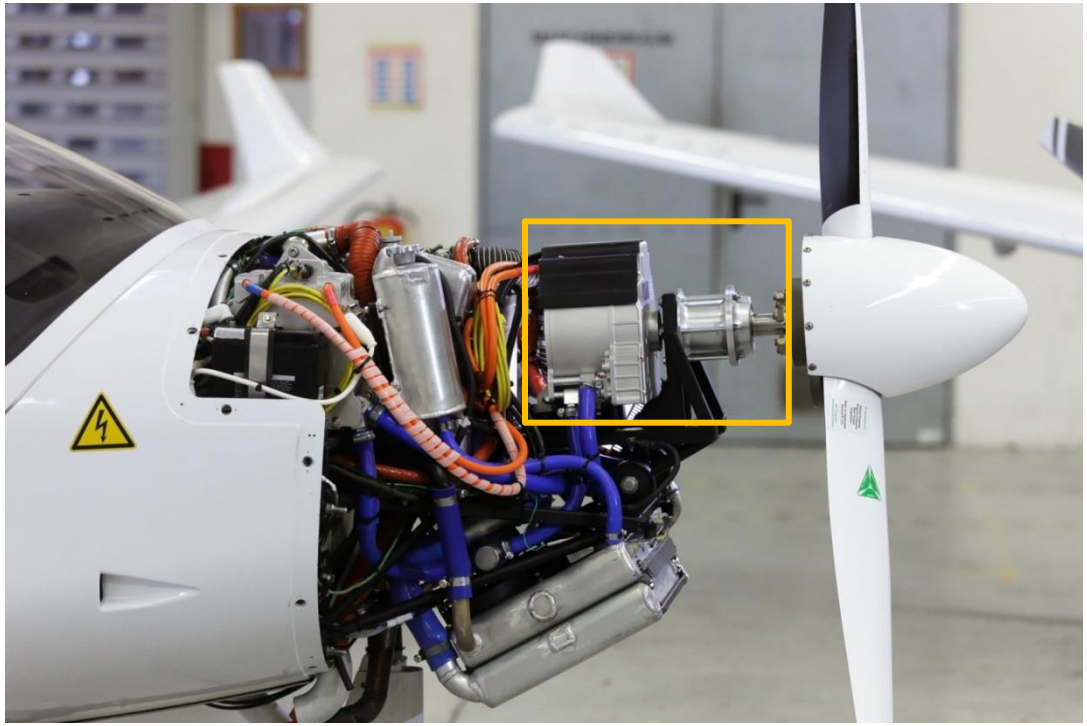


- Developed in cooperation with Compact Dynamics
- Serial hybrid electric aircraft with
  same payload and range as standard aircraft

Key data

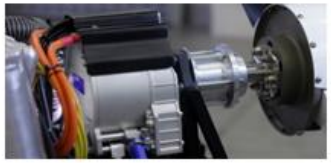
P_{180s} = 80 kW
$N_{max\ intern}$ = 11000 rpm
M_{180s} = 70 Nm
$N_{max\ shaft}$ = 2400 rpm
Liquid cooled

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

Milestones

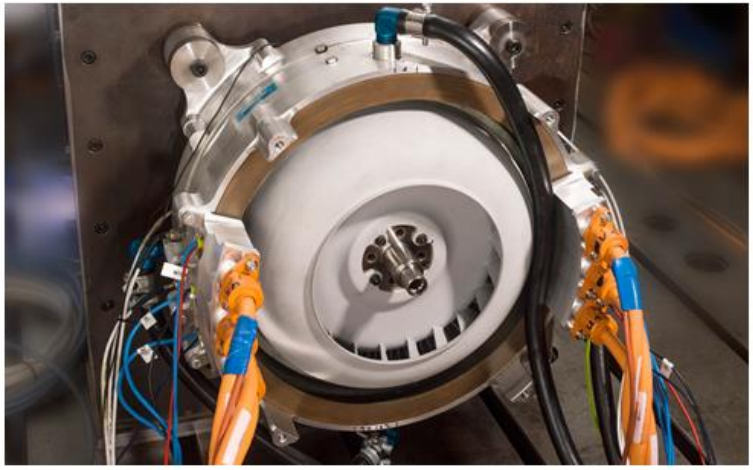
2011

2013



2014

2015



2013

¼ MW electric motor for aircraft propulsion put into operation in January 2015

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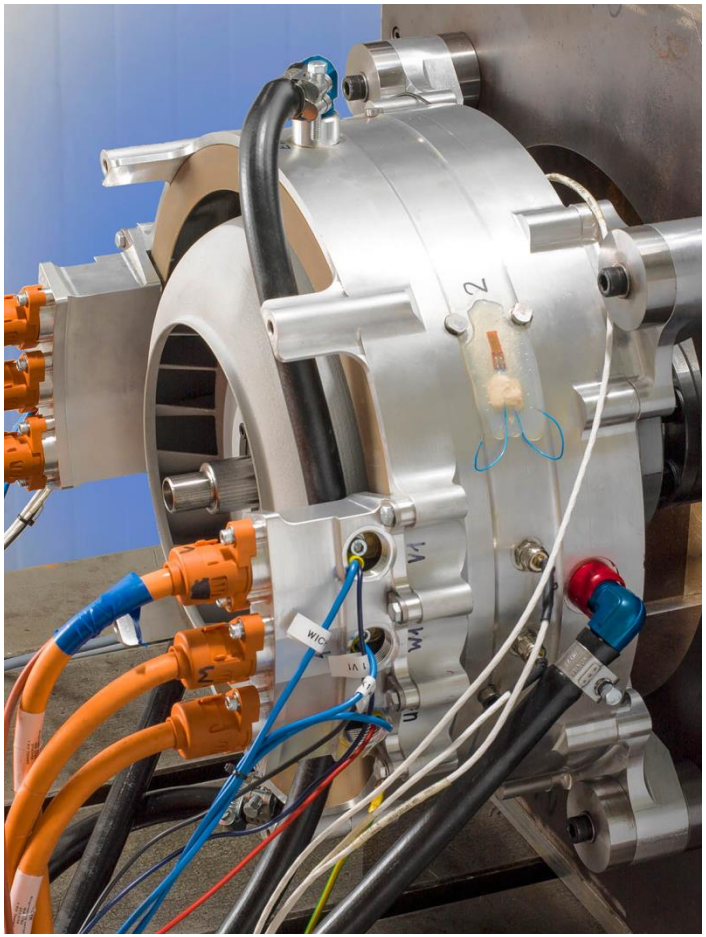

Electric Motor Performance

- Successfully tested at a continuous mechanical power of 261 kW at 2500 rpm
- Excellent thermal behavior
- Motor can drive propeller directly without gearbox
- Motor was developed for aircraft application
- Motor design is scalable towards 1 MW

This is the strongest motor,
ever built with
a power density of 5 kW/kg

¼ MW electric motor has been developed in application project in LUFO IV

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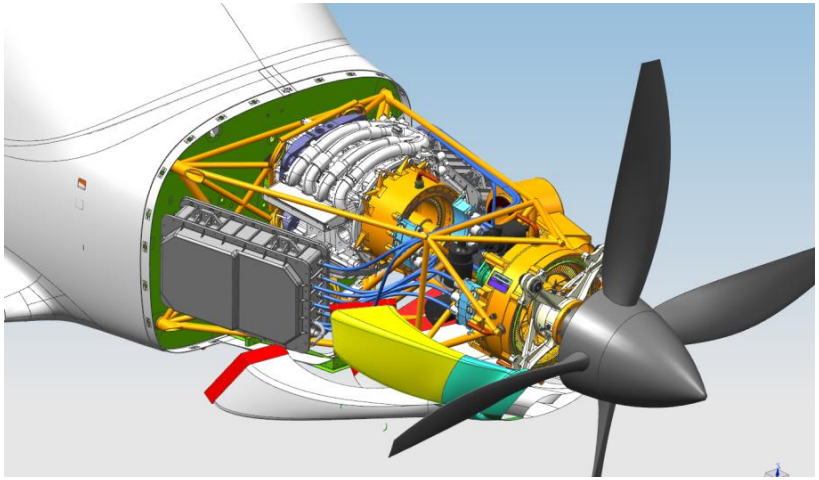
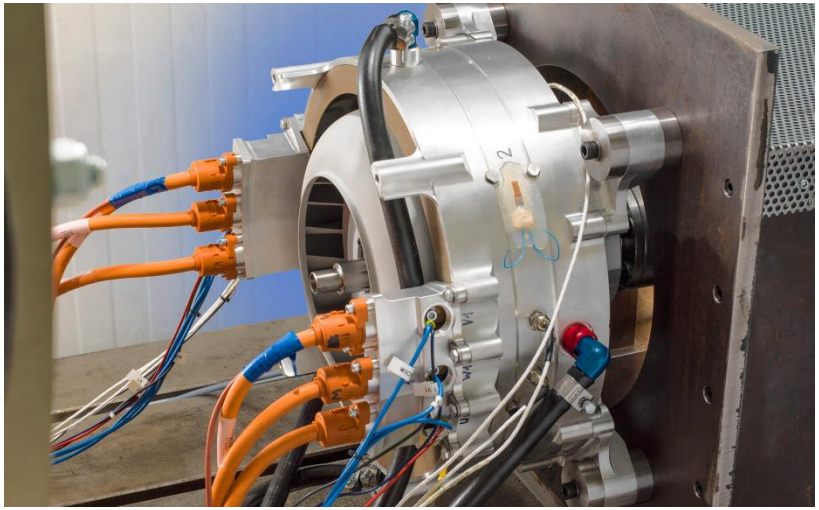




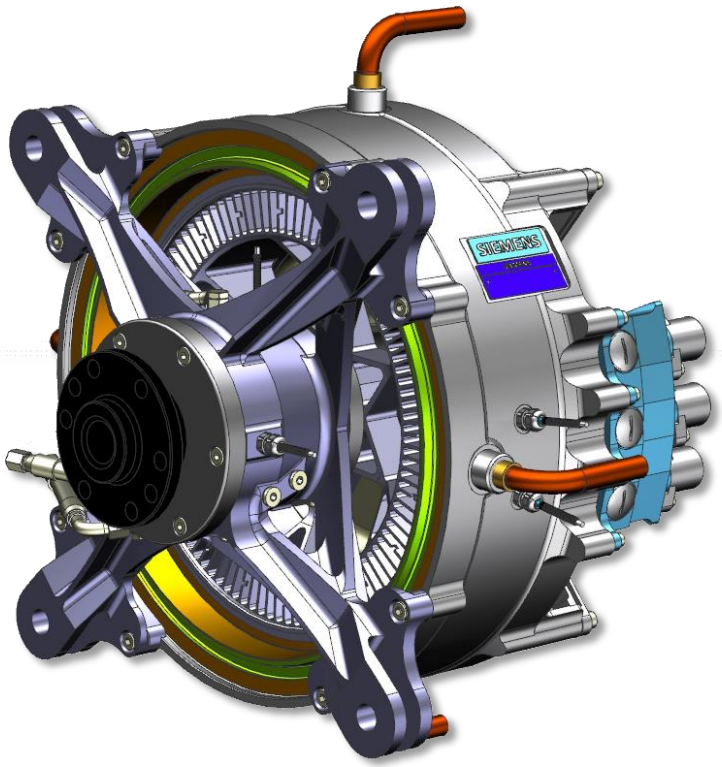
Design data	Tested on bench
P_{cont} = 230 kW	P_{cont} = 261 kW
N_{nom} = 2250 rpm	N_{max} = 2500 rpm
M_{cont} = 977 Nm	M_{cont} = 1000 Nm
U_{ZK} = 580 V	η_{260kW} = 95 %
I = 2*218 A	
η_{230kW} > 95 %	

- 2 redundant winding systems
- Direct cooling with T_{inlet} = 90 ºC
- Integrated propeller bearing

- Motor with prop. bearing = 50 kg
- Power density > 5 kW/kg
- Dimensions:
  D = 418 mm, L = 300 mm
  (w/o prop. bearing)

Gefördert durch:
Bundesministerium für Wirtschaft und Technologie
aufgrund eines Beschlusses des Deutschen Bundestages

Steps to achieve a light weight E-Motor design I



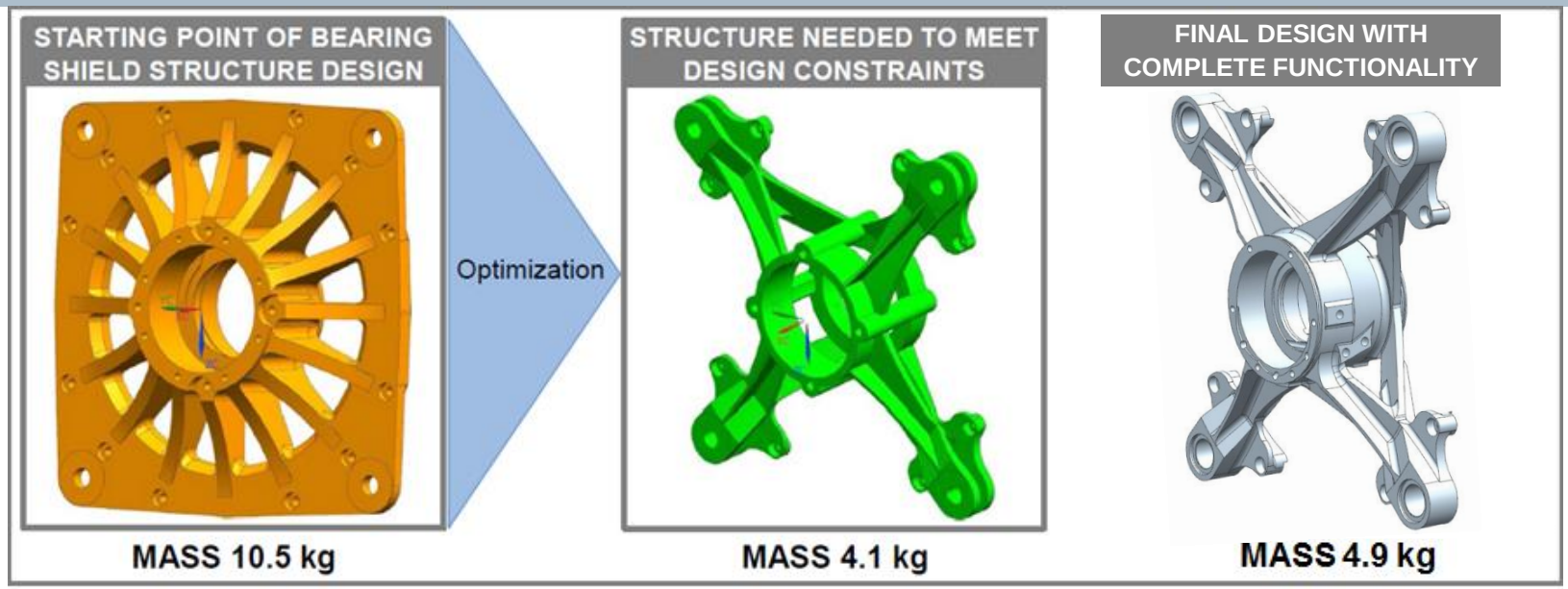
1. Electromagnetic design with high performance magnetic materials to the edge of physical boarders

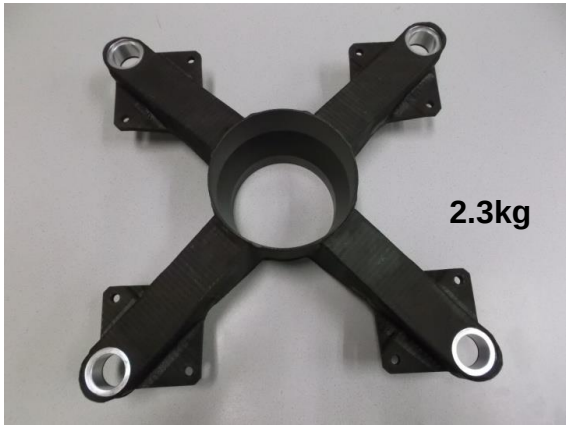
- High electric frequency
  to achieve highest torque density
- Flat wire windings
- Smart magnetic circle using Halbach array

2. Highly performing cooling

- Major losses are copper losses, therefore direct cooling
  →continuous current density significantly higher than usual
- High coolant temperature level (90-100 ºC) is possible, which minimizes cooler size and weight

Steps to achieve a light weight E-Motor design II





3. Structural weight optimization of passive parts

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

Serial hybrid electric propulsion systems for aircraft under development

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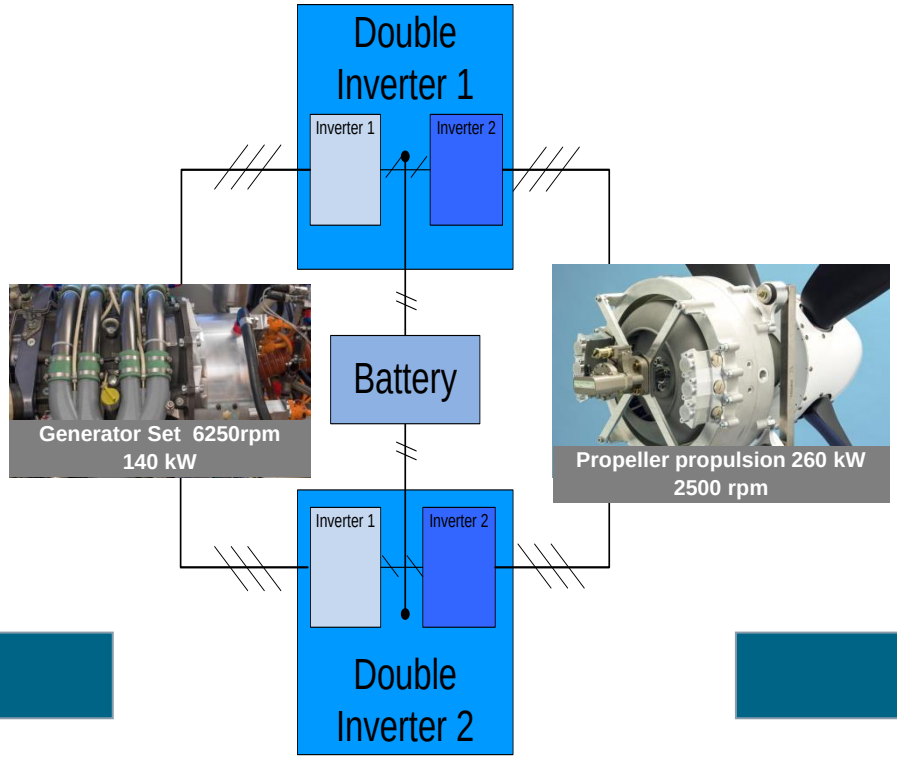
Generator sets in development

- 100 kW compatible with Rotax 912 and Rotax 914
- 135 kW compatible with AE300
- 170 kW
- 10 MW (HTSC)

Serial hybrid electric propulsion system with two redundant power paths



Propulsion systems in development

- 60 - 120 kW for different voltage levels
- 200 kW- 260 kW
- 600 kW
- 1 MW

170 kW Generator
Lab Approval

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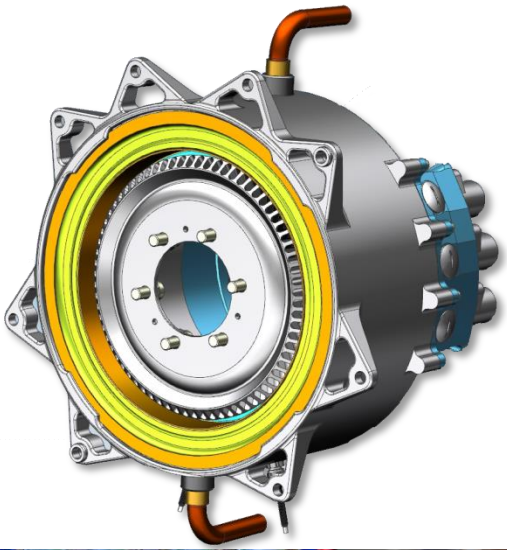

Design data

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

- Redundant winding system
- Each one can be overboosted for 3 minutes
- Usage as motor or generator possible
- Direct cooling
- 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 (electric machine only)

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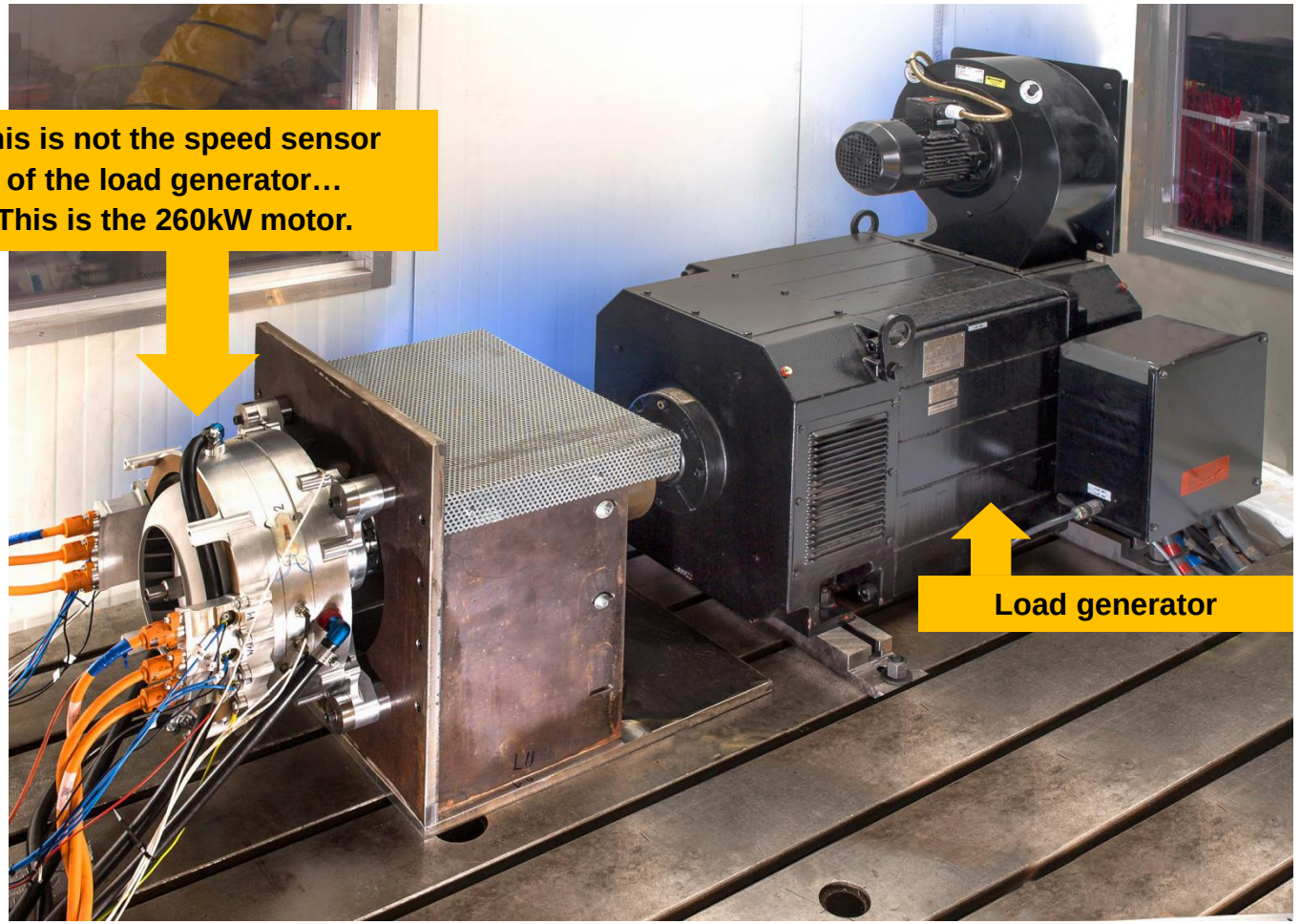
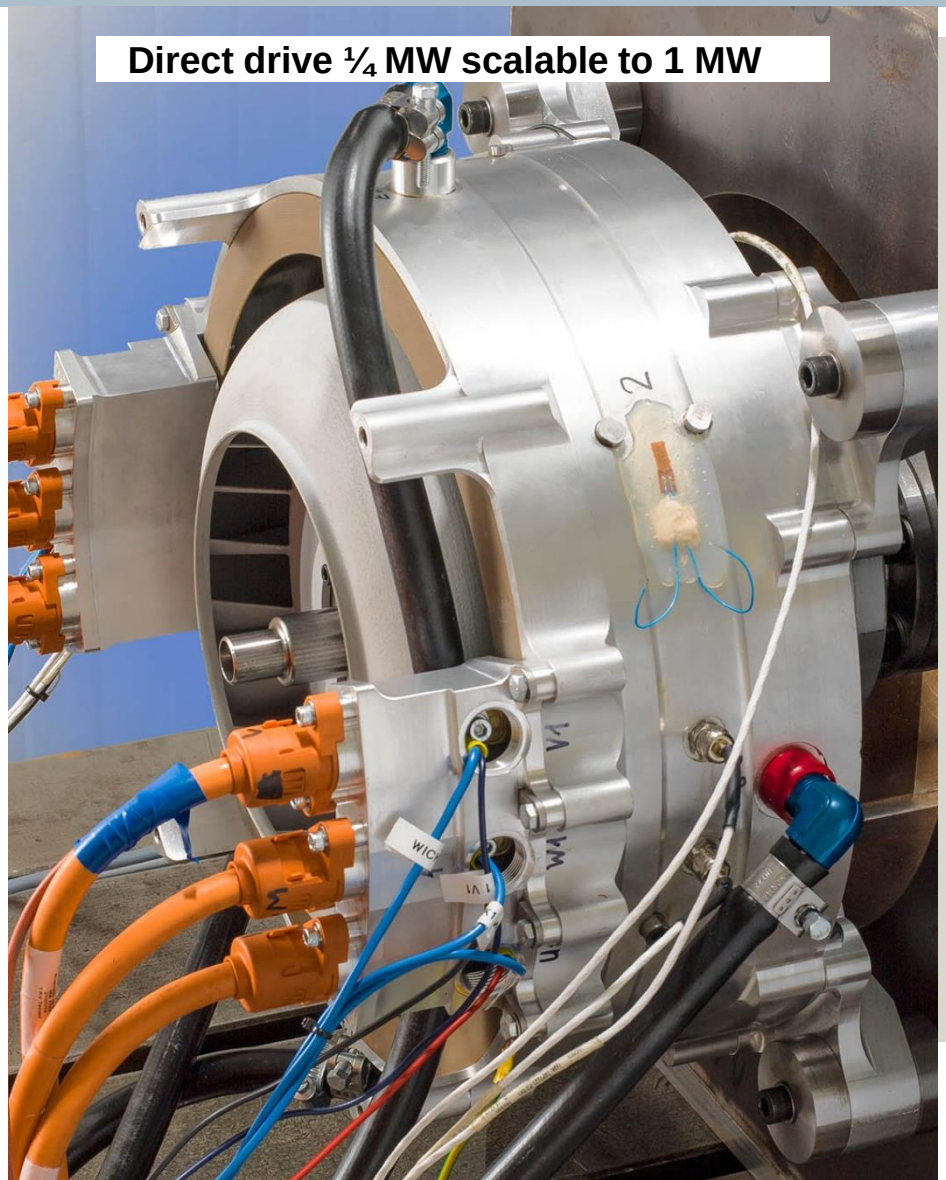
To close with a joke…



Electric Propulsion for Aircraft



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