eAircraft: Hybrid-elektrische Antriebe für Luftfahrzeuge

Dr. Frank Anton, Siemens AG, Corporate Technology

14. Tag der Deutschen Luft- und Raumfahrtregionen, Potsdam, 10. September 2019
We develop **hybrid electric propulsion** systems for aircraft

Hybrid-electric propulsion is a **scalable technology**
eVTOL potentially large number → economy of scale

**Enabler to reduce total cost of ownership and environmental impact:**

- Hybrid electric propulsion → Useful range
- Separation of power generation and thrust generation → Decreased fuel flow & emission
- Distributed propulsion → Silent propulsion
- Vectorized thrust → Increased aerodynamic efficiency
- → eSTOL, eVTOL
The eAircraft portfolio has been designed to meet aerospace requirements and is now on the way to industrialization & certification.

The eAircraft portfolio has been shaped by close collaboration with partners such as Airbus.

In the lower power classes, the systems have already been tested in flight and are being installed in first commercial applications.

In the high power classes, a 2 MW lab demonstrator is currently awaiting test results and a design of a 10 MW generator based on superconducting technology exists as digital twin.
Our core portfolio – electric propulsion units (EPU) for applications with high power/weight requirements
With our partners we have continually extended the boundaries of eFlight. The year 2016 marks the beginning of real electric flight applications.

- **2011**: Maiden flights of the DA36 e-Star, world's first hybrid-electric aircraft, and improved eStar 2, with Airbus and Diamond Aircraft.
- **2013**: Maiden flight of the fully electric WattsUp trainer with Pipistrel.
- **2014**: Extra 330LE.
- **2016**: Magnus e-Fusion, sub-100kW class. ¼ Megawatt. Extra 330LE.
Wholistic toolchain for system development

NX 12.0
Part Modeling

NX 12.0
Assembly Modeling

NX 12.0
Topology Optimization

Star-CCM
Fluid Dynamics

NX Nastran
FEM Analysis
Concept to real-world object

Virtual concept

Virtual product

Real product
eFusion - more than 300 emission free flight hours. Diverse technologies on several test platforms in flight testing.
Progression of SP70D Motor

<table>
<thead>
<tr>
<th></th>
<th>SP45D</th>
<th>SP55D</th>
<th>SP70D</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td></td>
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<td></td>
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<tr>
<td>2018</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous Power</td>
<td>45</td>
<td>55</td>
<td>70</td>
</tr>
<tr>
<td>Peak Power</td>
<td>60</td>
<td>72</td>
<td>92</td>
</tr>
<tr>
<td>Rotational Speed</td>
<td>2500</td>
<td>3000</td>
<td>2600</td>
</tr>
<tr>
<td>Weight</td>
<td>28 kg</td>
<td>27 kg</td>
<td>26 kg</td>
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</table>
A Magnus eFusion with Siemens Electric Propulsion System crashed on May 31st, 2018 near Pécs, Hungary.

The pilot and a technical observer were killed in the incident.

The electric propulsion technology was operating faultlessly.

- The technical investigation has not revealed any evidence of malfunction of the structure or any system of the aircraft.
- According to data available, there is no sign of smoke or fire during the flight. The fire started after the aircraft crashed to ground.
- During the flight the displays related to the electric propulsion system showed normal operations.

Our deepest thoughts are with the casualties’ families.
Magnus eFusion Hybrid-Electric configuration
First Flight April 11th, 2018 - aerokurier award at Aero 2019
Maiden flight – hybrid-electric eFusion April 2018
eFusion - more than 300 emission free flight hours. Diverse technologies on several test platforms in flight testing.
Sun Flyer 2 Completes First Flight with Siemens Electric Propulsion System (12 FEB 2019)

- Planned use of SP70D in FAA certified aircraft
- Business case for 2 and 4 seat electric training aircrafts
Flight Design F2e completes first flight with Siemens Electric Propulsion System (29 MAY 2019)

- First Flight Design prototype for low noise emission trainers to be developed
- Modular concept for easy installation of new components like energy storage
Parallel hybrid system
H3PS - High Power High Scalability Aircraft Hybrid Powertrain

- To be implemented in CS-23 category aircraft
- Lightweight 30kW motor/generator can deliver an extra boost for take-off, ICE is used during cruise
SP260D-A is the next development step towards a Safe and redundant design with excellent performance-to-weight ratio

Developed for maximal Power Density
Redundant 3 Phase Windings

Implemented in Extra 330LE

Achievements:
- Electric Aircraft Speed Records
- Electric Aircraft Climbing Records
- First All-Electric Glider Towing

<table>
<thead>
<tr>
<th></th>
<th>SP260D-0</th>
<th>SP260D-A</th>
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<tbody>
<tr>
<td>MTOP</td>
<td>260 kW @ 2500 RPM</td>
<td></td>
</tr>
<tr>
<td>Torque</td>
<td>977 Nm</td>
<td></td>
</tr>
<tr>
<td>UDC</td>
<td>580 V</td>
<td></td>
</tr>
<tr>
<td>Oil cooled @ 90 °C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>95%</td>
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<tr>
<td>50 kg</td>
<td>Weight</td>
<td>44 kg</td>
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<tr>
<td>5.2 kW/kg</td>
<td>Power Density</td>
<td>5.9 kW/kg</td>
</tr>
<tr>
<td>50 kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.2 kW/kg</td>
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</table>

50 kg
5.2 kW/kg
Extra 330LE
FAI Official World Record Flights at Dinslaken Schwarze Heide Airfield

November 25th, 2016: FAI time to climb world record
eAircraft 500…1000 kg
3000 m in 4 min 22 sec
Pilot: Walter Extra

March 23rd, 2017: FAI speed world record
337.5 km/h (eAircraft <1000 kg)
Pilot: Walter Extra
342.8 km/h (eAircraft >1000 kg)
Pilot: Walter Kampsmann
World’s strongest electric aircraft Extra 330LE with SP260D propulsion system towed FFVV Swift glider and showed aerobatics at Paris Air Show 2017

Pilots:
Nicolas Honnons, Swift
Ulrich Schell, Extra 330LE
World’s strongest electric aircraft Extra 330LE with SP260D propulsion system towed FFVV Swift glider and showed aerobatics at Paris Air Show 2017

"Demonstrators are key to new technology,... the only way we can learn ... is by testing vehicles in flight."

said Mark Cousin, Airbus, at Paris Le Bourget 2017
Smartflyer - 4-seat hybrid-electric cruise aircraft by Swiss company Smartflyer
- Powered by one SP260D and a Siemens inverter, combined with Rotax engine as range extender
- First flight envisaged 2020/2021

The Swiss development company smartflyer AG shows what the hybrid-electric future of General Aviation looks like. The Siemens SP260D does not drive the propeller at the front of the aircraft, but on the fin. A configuration that is only possible due to the high power density of electric motors.

The increase in efficiency of the aircraft results from the free flow of the wake flow (push) of the large propeller. The high torque of the Siemens SP260D electric motor permits a low speed of 1800 RPM for the take-off phase, thereby reducing noise.

The smartflyer is a touring aircraft with a range of 750 km, which cannot be achieved with today's battery technology purely electrically. A range extender produces the necessary energy during the flight. The Rotax 914 aircraft engine drives a generator which charges the batteries in horizontal flight.

The serial hybrid drive is complex, but offers more safety than conventional drives. The SP260D with its two independent winding circuits and inverters integrates two motors on one propeller. The energy for the horizontal flight can be supplied directly from one of the four battery boxes or from the Range Extender.

Further reading:
- 9-seat all-electric commuter aircraft by Israeli company Eviation
- Powered by 3 Siemens SP260D motors with associated inverters
- First flight planned for summer 2019

Inspired by the new design possibilities that emerged by replacing turbine engines with all electric motors, Eviation and its team have reimagined what sleek, stylish and cost effective air mobility can be.

The fully operational all-electric regional commuter Alice will be capable of flying with nine passengers at 220 knots to a range of 650 miles on a single charge. The plane features innovations in thermal management and autonomous landing, as well as distributed electric propulsion, industry-leading battery technology and cutting-edge composite body frames.

The Alice will be displayed at the upcoming Paris Air Show and will conduct its first flight later this year.

Official press release:

CityAirbus uses Siemens SP200D EPU Direct Drive: Based on SP260 technology - 50% increase in Torque to Mass Ratio

![Image of CityAirbus technology]

In 9 months and 19 days through digital twin

<table>
<thead>
<tr>
<th></th>
<th>SP260D 2015</th>
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<th>SP200D 2017</th>
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<tbody>
<tr>
<td>Continuous Power</td>
<td>260 kW</td>
<td></td>
<td>204 kW</td>
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<tr>
<td>Rotational Speed</td>
<td>2500 RPM non-geared</td>
<td></td>
<td>1300 RPM non-geared</td>
<td></td>
</tr>
<tr>
<td>Continuous Torque</td>
<td>1000 Nm</td>
<td></td>
<td>1500 Nm</td>
<td></td>
</tr>
<tr>
<td>Mass</td>
<td>50 kg</td>
<td></td>
<td>49 kg</td>
<td></td>
</tr>
<tr>
<td>Torque to Mass Ratio</td>
<td>20 Nm/kg</td>
<td>Increase by 50%</td>
<td>30.6 Nm/kg</td>
<td></td>
</tr>
<tr>
<td>Inverter Type</td>
<td>Si</td>
<td></td>
<td>SiC</td>
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Airbus is communicating the CityAirbus project

Presentation of City Airbus demonstrator in Ingolstadt, 11.03.2019
Study of DLR, MTU, RUAG and Siemens: Dornier Do228hep demonstrator could be flying testbed for hybrid-electric propulsion in commuter class

- Substitution of one turboprop unit by an electric propulsion unit and an optimized propeller
- Integration of a gas turbine and an electric generator for hybrid-electric operation
- Integration of batteries for energy storage
Industry activity in hybrid-electric aviation rapidly increasing
Number of (hybrid-)electric projects announced (cumulative)

- Explosion of announced projects in 2017
- Significant funding of startup companies, e.g.
  - Lilium (90’ EUR, 2017)
  - Volocopter (31’ EUR, 2017)
  - Joby Aviation (100’ EUR, 2018)
- Growing investment activity of incumbents, e.g. Boeing (Aurora Flight Sciences and Zunum) or Geely (Terrafugia)
Diamond Aircraft and Siemens: Successful Maiden Flight of world’s first Serial Hybrid-Electric Twin Engine Plane

Distributed propulsion:
• Two electrically driven free-stream propellers
• One electrical generator driven by a jet fuel piston engine
• Battery
Diamond Aircraft and Siemens: Successful Maiden Flight of world’s first Serial Hybrid-Electric Twin Engine Plane

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Distributed Electric Propulsion:
The IBEFA consortium is investigating the feasibility of
a Multi-Propeller Hybrid-Electric Low-Noise General Aviation Plane.
Chance: Nachhaltige, innovative E-Mobility
Windenergie → Power-to-Green Fuel → Hybrid-Elektrisches leises Flugzeug

Green fuel production
Chance: Nachhaltige, innovative E-Mobility
Windenergie → Power-to-Green Fuel → Hybrid-Elektrisches leises Flugzeug

Green fuel production
Zero Emission
### SP2000D

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>$P_{\text{max, cont}}$</td>
<td>2,000 kW</td>
</tr>
<tr>
<td>$N$</td>
<td>6,500 rpm</td>
</tr>
<tr>
<td>$M_{\text{cont}}$</td>
<td>3,000 Nm</td>
</tr>
<tr>
<td>$U_{\text{DC}}$</td>
<td>3,000 V</td>
</tr>
<tr>
<td>$m_{\text{total}}$</td>
<td>261 kg</td>
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<tr>
<td>Cooling</td>
<td>Direct liquid cooling</td>
</tr>
<tr>
<td>Length</td>
<td>589 mm</td>
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<tr>
<td>Diameter</td>
<td>520 mm</td>
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</table>

All values are design values and currently under test.
Siemens sells electric aircraft-propulsion business to Rolls-Royce

Agreement signed on June 18th, 2019: Rolls-Royce to acquire eAircraft

Sale to accelerate development of sustainable air transport

Rolls-Royce intends to become the leading supplier of electric and hybrid-electric propulsion systems for aircraft

Siemens will continue to support the transition to electric aviation with its digital solutions portfolio

Closing expected in late 2019
Thank you for your attention

Dr. Frank Anton  
Senior Vice President eAircraft Transfer

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