Siemens eAircraft
Disrupting the way you will fly!
Electrification, automation and digitalization
Are the core of the Siemens strategy

Leveraging key technology enablers along our entire portfolio to create next level of customers benefits.

**Big Data & Analytics**

**Cloud**

**Mobile & Collaboration**

**Electrification**

**Digitalization**

**Automation**

**Design & Engineering**
Highest productivity & shortened time-to-market

**Maintenance & Service**
Predictive, prescriptive & efficient services

**Operations**
Next level of flexibility & resilience in operations

**Connectivity & Internet of Things**

Security, ease-of-use, manageable complexity
Digitalization has an impact on the entire value chain …

… and Siemens

<table>
<thead>
<tr>
<th>Digital Factory</th>
<th>Energy Management</th>
<th>Wind Power</th>
<th>Power and Gas, Power Generation Services</th>
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<th>Process Industries and Drives</th>
<th>Healthineers</th>
<th>Building Technologies</th>
<th>Mobility</th>
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Disrupting the way you will fly!

Challenges and Needs

The Electric Propulsion Unit (EPU)

Siemens Solutions, Collaborations & Achievements

Engineering EPUs using Digital Twins
Disrupting the way you will fly!

Challenges and Needs

The Electric Propulsion Unit (EPU)

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Engineering EPUs using Digital Twins
In the meantime in aviation industry…
… compete each other to boredom!

Boeing 367-80 “Dash 80” – FF 15 July 1954
Evolved into Boeing 707
The aviation industry is on the verge of a major shift towards electrified propulsion

1. **Reduction of fuel consumption:** main lever to reduce aircraft TCO (example 737-800)
   - Fuel: 51%
   - Purchase: 20%
   - Crew: 15%
   - Maintenance, modific., insur., fees: 14%
   - TCO: 100%

2. **Projected emission goals:** can only be reached with disruptive concepts
   - Possible through innovation of existing technologies
   - Requires biofuels and/or disruptive concepts (e.g. eAircraft)
   - EU agreement "Flight-path 2050": 75% CO₂ emission reduction (per PK) ²

3. **Customer perspective:** extension of potential operating hours through noise reduction

---

Industry: various hybrid electric propulsion roadmap defined for demonstration (TRL's) and product development until 2035, e.g.

- **2016 – 2020**
  - **Hybrid Electric Systems Project**
    - Hybrid Ground Demonstrator, 10 MW platform
    - <2 MW potential platform applications vertical take off and landing (VTOL), door-to-door

- **2028**
  - **Regional Aircraft**
    - 100 passengers, 6-8 MW

- **2035+**
  - **Short Range Aircraft**
    - 150-200 passengers, 20 MW

---

1) IATA technology roadmap, June 2013
2) Siemens AG 2018
Innovation happens Bottom-Up

German start-up Volocopter writes aviation history:
First ever public demonstration of an Autonomous Urban Air Taxi Dubai, 25th of September 2017

Day of the first test flight
Innovation happens Bottom-Up
Aircraft “Powerplant”
Thrust & Energy Needs

Engine Power Output for typical Wide-Body Aircraft Engine

- Electric generator: 200 kW
- High pressure bleed air: 1.2 MW
- Hydraulic pump: 240 kW
- Fuel & oil pumps: 100 kW

Potential scope of
More Electric Aircraft

Thrust power: c. 40 MW
Total non-thrust power: c. 1.7 MW
Disrupting the way you will fly!

Challenges and Needs

The Electric Propulsion Unit (EPU)

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Engineering EPUs using Digital Twins
Conventional propulsion relies on piston engines, turboprop or turbofan

Types of aircraft propulsion: conventional

Piston engine

- Combustion engine moves the piston which rotates the propeller at low rotations per minute

  **Advantage**
  - Simple setup
  - Scalable

  **Disadvantage**
  - Not efficient for heavy-weight planes

Turboprop

- Turbine used to rotate a propeller at high rotations per minute

  **Advantage**
  - Combines simple propeller setup with efficient turbine drive

  **Disadvantage**
  - Gear necessary
  - High maintenance necessary

Turbofan

- Turbine used to rotate fan for an air stream that generates thrust

  **Advantage**
  - Less fuel consumption than conventional combustion or jet turbine

  **Disadvantage**
  - High maintenance necessary
  - Complex setup

Connections:
- Electrical
- Mechanical
- Fluid
Three different types of electric propulsion allowing to substitute or support conventional technology

Types of aircraft propulsion: electric

**Pure electric**

- **Battery**
- **Converter**
- **Electric motor**

Energy from battery is used in electric motor to turn electric into mechanical energy for propeller rotation

**Advantage**
- Full potential for distributed arrangements

**Disadvantage**
- Battery endurance still low

**Serial hybrid**

- **Combustion engine**
- **Generator**
- **Converter**
- **Electric motor**
- **Battery**
- **Fuel tank**

Combustion engine used to generate electrical energy to charge a battery or run the electric motor

**Advantage**
- Separate power generation from thrust generation

**Disadvantage**
- Additional weight of generator
- Higher complexity than conventional

**Parallel hybrid**

- **Battery**
- **Converter**
- **Electric motor**
- **Combustion engine**
- **Fuel tank**

Electric motor provides rotation and supports the combustion engine for peak performance

**Advantage**
- Conventional engine able to run at optimal power point with peak power by electric motor

**Disadvantage**
- Higher complexity than conventional

Connections:
- **Red**: Electrical
- **Blue**: Fluid
- **Gray**: Mechanical
Our core portfolio – electric propulsion units (EPU) for applications with high power/weight requirements
Siemens eAircraft
Our motivation for electrifying aircraft propulsion

• Drive systems are going electric – on land, at sea, and in the air

• Electric drive systems are one of the main business domains of Siemens

• The application to aerospace is attractive, technologically challenging, and requires safety and certification

• We are committed to the development and production of hybrid electric aircraft propulsion systems as a future area of business

• Technology spill over for other Siemens businesses

\[
\begin{align*}
P_{\text{Mot}} &\approx 1/2 \text{ MW} \\
P_{\text{Mot}}/m_{\text{Mot}} &\approx 0.87 \text{ kW/kg} \\
P_{\text{Mot}} &\approx 1/4 \text{ MW} \\
P_{\text{Mot}}/m_{\text{Mot}} &\approx 5.2 \text{ kW/kg}
\end{align*}
\]
We expect e-propulsion to be the standard solution by 2050

Milestone outlook for e-propulsion market

- **Today**
  - Experimental flight with small certified aircraft demonstrated

- **2017**
  - **Market entry** for ultra-light and military due to less strict certification rules

- **2021**
  - **Market ramp-up for certified systems** e.g. two- and four-seaters

- **2025**
  - **Fully electric** flying for medium range (energy storage capacity sufficient)

- **2030**
  - **Airlines offering scheduled flights** based on hybrid-driven aircraft

- **2050**
  - **E-propulsion is the standard solution for all aircraft segments**

**Increasing dominance of electric propulsion**
Disrupting the way you will fly!

Challenges and Needs

The Electric Propulsion Unit (EPU)

Siemens Solutions, Collaborations & Achievements

Engineering EPUs using Digital Twins
SP70D & SP55D
NextGen Si inverter

Direct Drive permanent-magnet electric motors
Hollow shaft

Design derived from SP45D which has >300 flight hours on eFusion Motor and Inverter Water-Glycol cooled
Magnus eFusion
Maiden Flight on April 11, 2016 at Matkópuszta airfield

eFusion - Magnus Aircraft Corp. (Hungary)
Two-seat side-by-side low-wing monoplane with aerobatic capability for upset recovery training.

Safe and Robust battery propulsion system designed, developed and verified by Siemens
Target cost-sensitive segments of Very Light, Light Sport and Ultra Light Aircraft.
Magnus eFusion
Full electric aircraft propulsion system installed firewall-forward

Magnus eFusion – maiden flight Summer 2016

Aircraft Data

| Empty weight including batteries and parachute | 410 kg |
| MTOW | 600 kg |
| Wingspan | 8.4 m |
| Length | 6.6 m |
| Height | 2.4 m |

Propulsion System Data

| Power | 45 kW MCP 
60 kW MTOP 
85 kW max. |
| N_{max} | 2500 rpm |
| DC-link voltage (nominal) | 350 VDC 
(300 …450 V) |
| Torque M_{Boost} | 324 Nm |
| Battery | 10.1 kWh |
| Max. airspeed | 97 KIAS |
Magnus eFusion
High Power Density Inverter SD104

SD104 Inverter
Silicium Carbide
Micro-Channel cooling plate
Dimensions: 47 mm x 94 mm x 141 mm
Weight: 900 g
Propulsive Power: 57 kW
Magnus eFusion Hybrid-Electric configuration
First Flight April 11th, 2018
SP260D & SP260D-A
Record breaking Power Density

Direct Drive Permanent Magnet

MTOP 260 kW @ 2500 RPM
Torque 977 Nm
UDC 580 V
Oil cooled @ 90 °C
Efficiency 95%

Weight

SP260D
50 kg
5.2 kW/kg

SP260D-A
44kg
5.9 kW/kg

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
Extra 330LE
Flying Testbed for ¼-MW class electric propulsion systems

**Aircraft Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>MTOW</td>
<td>1000 kg</td>
</tr>
<tr>
<td>Wingspan</td>
<td>8.0 m</td>
</tr>
<tr>
<td>Height</td>
<td>2.6 m</td>
</tr>
<tr>
<td>Length</td>
<td>7.5 m</td>
</tr>
<tr>
<td>Wing area</td>
<td>10.7 m²</td>
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**Propulsion System Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>( P_{cont.} )</td>
<td>260 kW</td>
</tr>
<tr>
<td>( N_{max} )</td>
<td>2250 rpm</td>
</tr>
<tr>
<td>( M_{cont.} )</td>
<td>1000 Nm</td>
</tr>
<tr>
<td>( U_{2k} )</td>
<td>580 VDC</td>
</tr>
<tr>
<td>( \eta_{Motor} )</td>
<td>max. 95%</td>
</tr>
<tr>
<td>( m_{motor including propeller bearing} )</td>
<td>50 kg</td>
</tr>
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* As rated in the Extra 330LE
Extra 330LE
Maiden Flight on July 4, 2016 at Dinslaken airfield

https://m.youtube.com/watch?v=fiu8TFnXYFY
Achievements, Record Flights and Opportunities
Fly-Over Noise Reduction

https://www.youtube.com/watch?v=WylLWeDtpy0&index=7&t=0s&list=PLw7ILwXw4H53YUddJ99vzOVFgn-o4f17U
Achievements and Opportunities
Electric Glider Towing

https://www.youtube.com/watch?v=R4T7LZaMxl&index=2&t=0s&list=PLw7lLwXw4H53YUddJ99vzOVFgn-o4f17U
World’s Strongest Electric aircraft delivers the Most Silent flight demo
Paris Air Show 2017

Extra 330LE with SP260D Towing of FFVV Swift glider, followed by Aerobatic Show

Pilots:
Nicolas Honnons, Swift
Ulrich Schell, Extra 330LE
eAircraft Airbus-Siemens Collaboration – joint development agreement signed April 2016

“Siemens is determined to establish hybrid-electric propulsion systems for aircraft as a future business.”

“Both companies take a significant joint development decision

• Demonstrate the technical **feasibility of various hybrid-electric propulsion systems by 2020**

• Assemble **joint development team** of some 200 employees

“We believe that by 2030 **passenger aircraft** below 100 seats could be propelled by **hybrid propulsion systems...**”

Airbus Group CEO Tom Enders

• **Prototype propulsion systems ranging from a few 100 kW up to 10 MW and more**

• for short, local trips with aircraft below 100 seats, helicopters or UAVs up to classic short and medium-range journeys.

• **Target: breakthrough innovation in aerospace e-mobility**
Airbus & colleagues
... feel the pressure

What the new entrants are working on

Source: http://airbus-xo.com/innovation-age-third-aerospace-revolution/
Siemens – Airbus
Roadmap towards Hybrid-Electric Flight

Source: http://airbus-xo.com/innovation-age-third-aerospace-revolution/
SP200D
Record breaking Torque Density

Direct Drive Permanent Magnet

\[
P_{\text{max,cont}} = P_{\text{max,5min}} = 204 \text{ kW}
\]

\[
N_{\text{cont}} = N_{\text{max}} = 1300 \text{ RPM}
\]

\[
M_{\text{cont}} = M_{\text{max}} = 1500 \text{ Nm}
\]

UDC 450 - 850 V

Oil cooled *Syltherm 800*

Weight 49 kg

Record Torque Density 30 Nm/kg

Designed for high-torque low-speed requirements.

Allows for slow rotating propellers, hence low noise.

Currently under Test
SP200D
Powering the CityAirbus

4x 2 SP200D
4x 2 Contra-rotating,
Fixed pitch, Low RPM,
Ducted Propellers

2x EPDC
Electric Power
Distribution Center

8x Inverters
CityAirbus: Multi-passenger Self-piloted electric VTOL

2023 - fully certified CityAirbus part of Urban transport

CityAirbus “Iron Bird”
Integration testing

Target Piloted First Flight eo. 2018
Airbus, Rolls-Royce, and Siemens team up for electric future Partnership launches E-Fan X hybrid-electric flight demonstrator

High Power Class
Flying testbed E-Fan X

Serial Hybrid architecture

Joint Press Release by Siemens, Airbus and Rolls-Royce

Airbus, Rolls-Royce, and Siemens team up for electric future
London, 2017-Nov-28

Disrupting the way you will fly!

Challenges and Needs

The Electric Propulsion Unit (EPU)

Siemens Solutions, Collaborations & Achievements

Engineering EPUs using Digital Twins
EPUs with Record Power Density are Complex & Highly Integrated Products

Greener & Cost Effective Aircraft Operations

Efficient & Reliable Motor Performance

Aircraft | Mission | Environment

Electro-Magnetic | Electrical

Structural | Software

Thermal | Systems

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Page 42
Digitalization’s value fully realized
Digital threads connect the twins
Simcenter Portfolio
Engineer innovation for aircraft performance

Simcenter™
Engineer innovation.
Simulate. Explore. Test.
Simcenter Portfolio
Engineer innovation for aircraft performance

Aerodynamics Performance
External & Internal Aerodynamics, ECS & Cabin Comfort, Thermal

Structural Performance
Loads, Structural Pre-Sizing, Detailed Sizing, Margins of Safety

Thermal Management
Aircraft Level Thermal and Energy Management

Systems Performance
Landing Gear, Flight Control, ECS, Fuel, Electrical, Hydraulics

Integration, Verification & Certification
Virtual & Physical Testing, Component & Integration Testing
The Siemens SP200D - record breaking torque/weight ratio
Fly it before you build it, with Siemens PLM integrated solutions
CityAirbus uses Siemens SP200D EPU Direct Drive: Based on SP260 technology - 50% increase in Torque to Mass Ratio

In 9 months and 19 days through digital twin

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

- Set the conditions
- Run the simulation
- Iterate, iterate and iterate again
- Get your optimized design

Discover Better Designs, Faster!
Simulation-driven generative design

Computational fluid dynamics

Design space exploration
Automated flying and new mobility concepts
Next level of systems of systems simulation

Controlled airspace

“Un-controlled” airspace

Hitting-the-road - roadspace

Driver in control

Car in control

Verification and validation autonomous operations
Continued investment in the Digital Enterprise

UGS acquisition establishes software foundation for product development

Acquisition of LMS expands strategy for verification and validation of systems

Siemens establishes leadership in product and process simulation to enable digitalization

Production engineering and execution

Product development

+/-$10 Billion since 2007
In the meantime in aviation industry…
… compete each other to boredom!

Boeing 367-80 “Dash 80” – FF 15 July 1954
Evolved into Boeing 707
Innovation is happening today - New Concepts are in reach! The near future will be Cleaner, Less Noisy, … Fun!
Follow on Youtube!
Siemens eAircraft

Source: Youtube, Search for Siemens eAircraft Channel
https://www.youtube.com/playlist?list=PLw7ILwXw4H53YUddJ99vzOVFgn-o4f17U
Simcenter helps optimize design and deliver innovations faster, with greater confidence

Source: https://www.youtube.com/watch?v=T_X_9VQ03b0
Follow on Twitter!
Siemens eAircraft

Measurement of atmospheric turbulence with Tafun motorglider equipped with Siemens LMS Scadas XS at the #Pattisflieg #test
Explore how Simcenter helps optimize design and deliver innovations faster, with greater confidence

Read more on our Website

Connect to our Community

Watch us on YouTube

Stay tuned on LinkedIn
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