HYPSTAIR – System Architecture, Certifiability and Safety Aspects

Symposium E²-Fliegen 2016, Stuttgart

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The Pipistrel Panthera
It‘s beautiful already – let‘s make it a pioneer of green aviation

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Source: http://www.panthera-aircraft.com/gallery

A high power-to-weight e-motor alone is not doing the trick

Conventional G/A piston engines …

- … can integrate a **hydraulic governor**
- … provide **pressurized oil** to the governor
- … are air-cooled or have an integrated, mechanically linked **cooling pump**
- … work with **high** (~ 120°C*) **coolant temperatures** keeping cooling drag and cooling subsystem weight down
- … have an integrated **propeller mount**

* Source: Rotax 914 Series Operators Manual

The HYPSTAIR System Design Approach: Aircraft-Level Optimization

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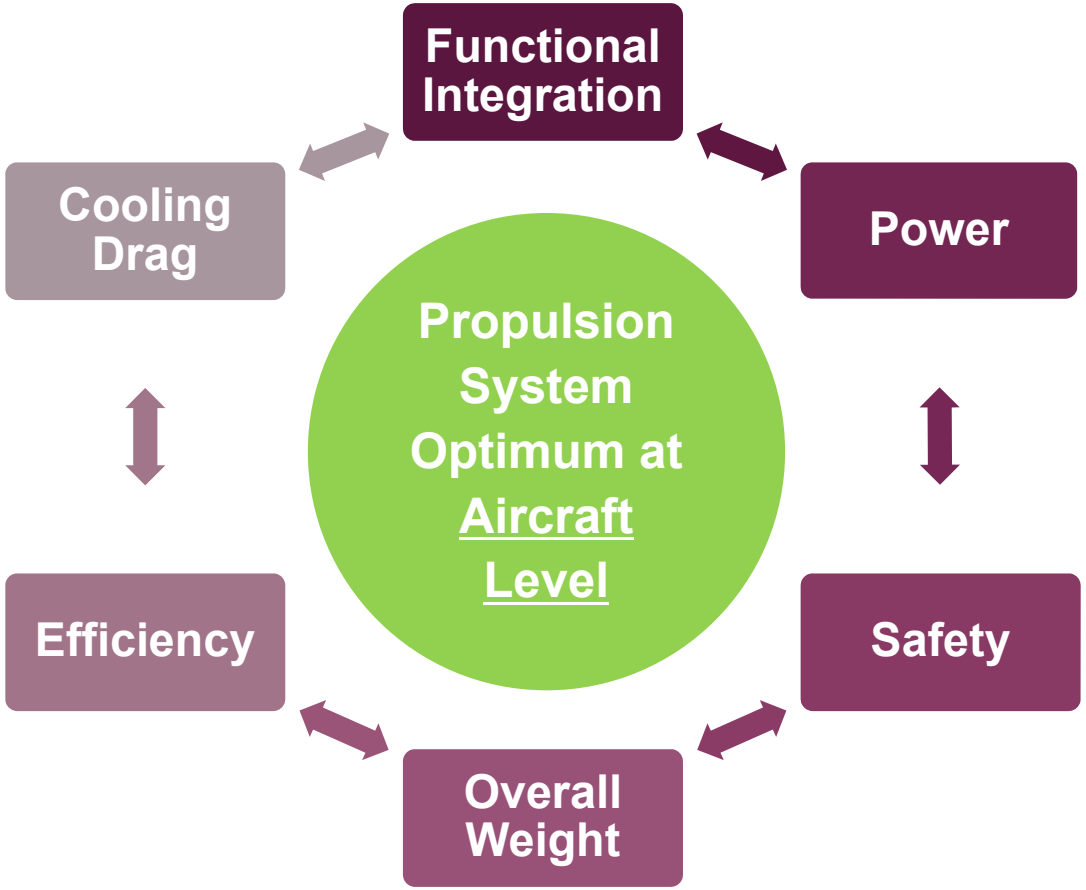

The HYPSTAIR System Architecture
2 separate power paths for near-twin-like levels of redundancy

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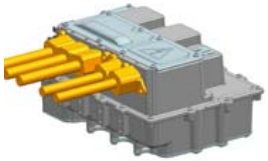
Rotax 914



Inverter

ICE

Geno 1

Geno 2

Inverter 1

Contr. Unit 1

Inverter 2

Contr. Unit 2

Battery

Inverter 3

Contr. Unit 3

Inverter 4

Contr. Unit 4

E-Mot 1

E-Mot 2

Propeller

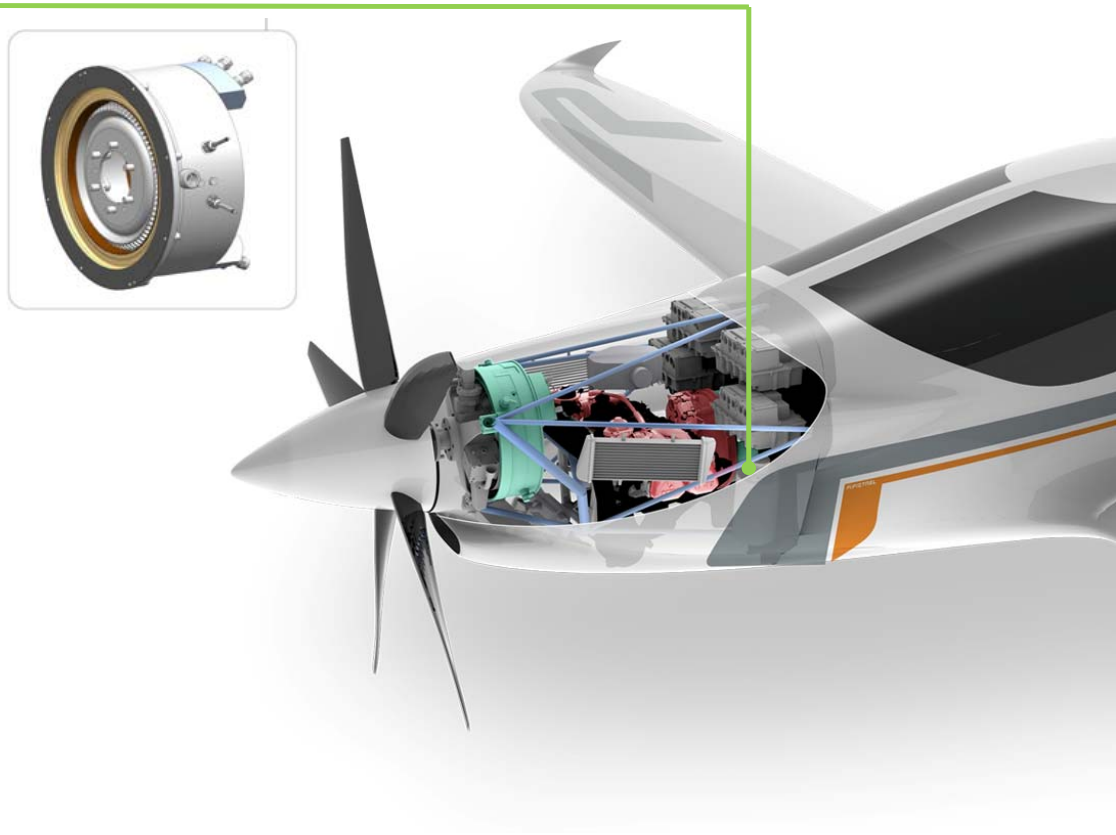
Dual winding
system generator

Dual winding
system e-motor

The HYPSTAIR Components

Siemens Generator – 100kW MCP

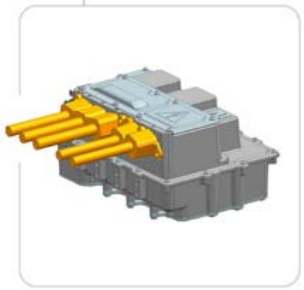
- **LIGHTWEIGHT** Power density 5,3 kW/kg
- **SAFE** Redundant winding system
- **ROBUST** 90 - 105°C coolant inlet temperature
- **EFFICIENT** η > 95% at cruise power
- **HIGH LEVEL OF INTEGRATION**
  - Acts as ICE starter
  - Acts as ICE flywheel

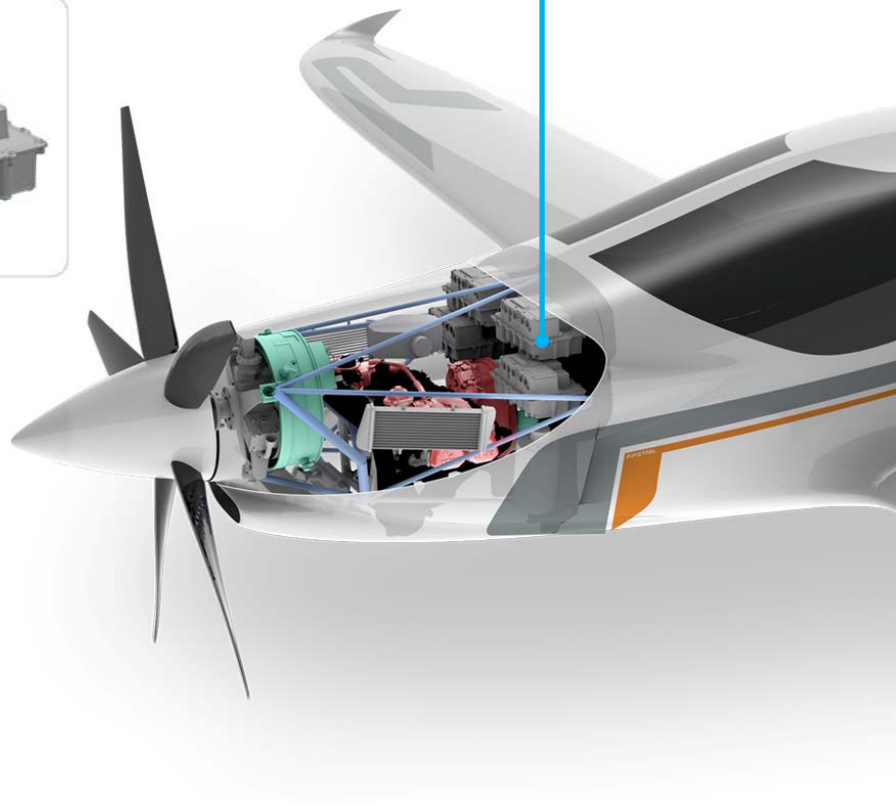


The HYPSTAIR Components

Siemens NextGen Converter – 100 kVA

- **LIGHTWEIGHT** power density of 10,5 kW/kg
- **EFFICIENT** η = 98%
- **ROBUST** 85 ºC coolant temperature
- **SMART** Integrated Central Control Unit for
  - Inverter Control Functions
  - Central Control Functions

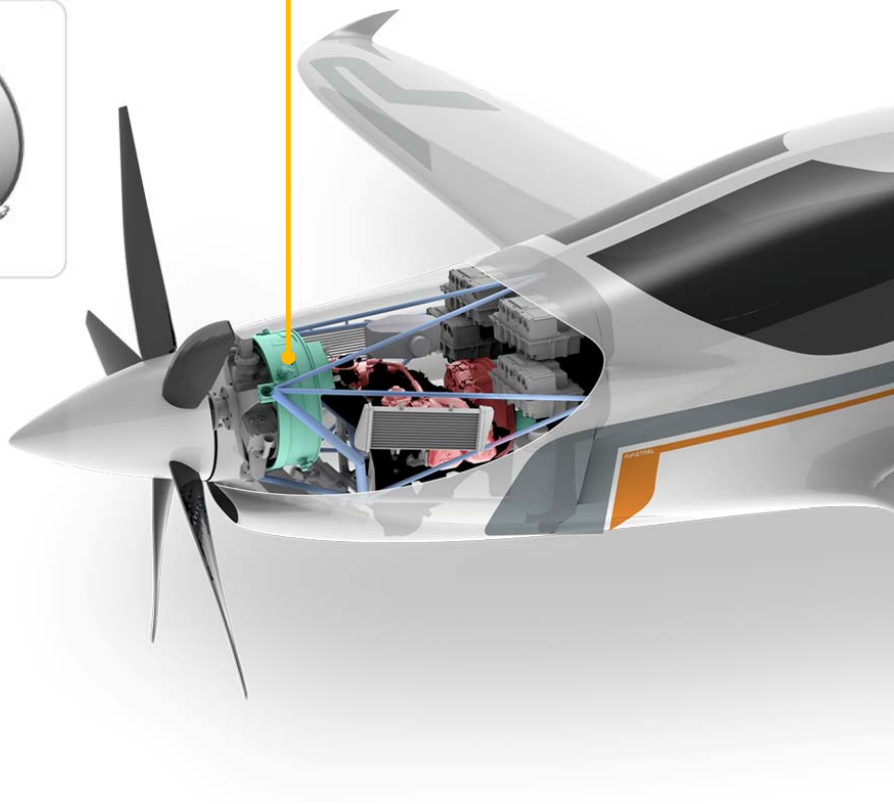




The HYPSTAIR Components

Siemens e-Motor – 150kW MCP, 200kW MTOP

- **LIGHTWEIGHT** 3,7 kW/kg @ MCP
  5,0 kW/kg @ MTOP
- **SAFE** Redundant winding system
- **ROBUST** 90 - 105°C coolant inlet temperature
- **EFFICIENT** η = 96% at cruise power
- **HIGH LEVEL OF INTEGRATION**
  - Built-in propeller bearing
  - Integrated governor & oil pump
  - Integrated cooling pump



Redundancy in many components increases safety and minimizes risk of total loss of power 1/2

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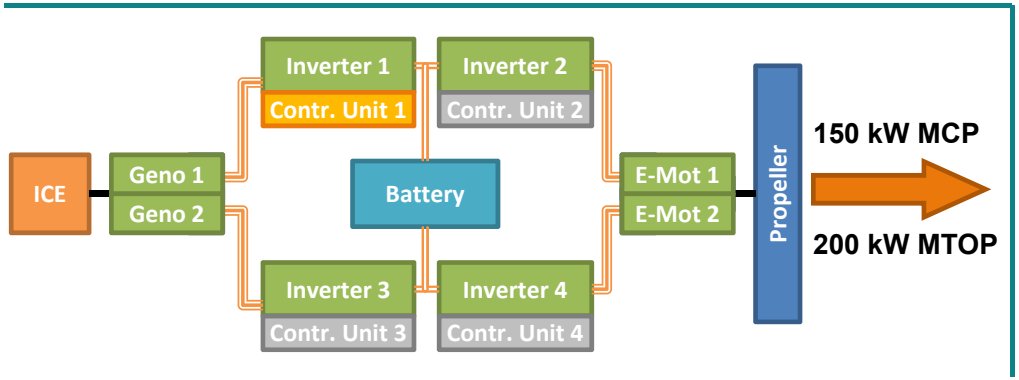
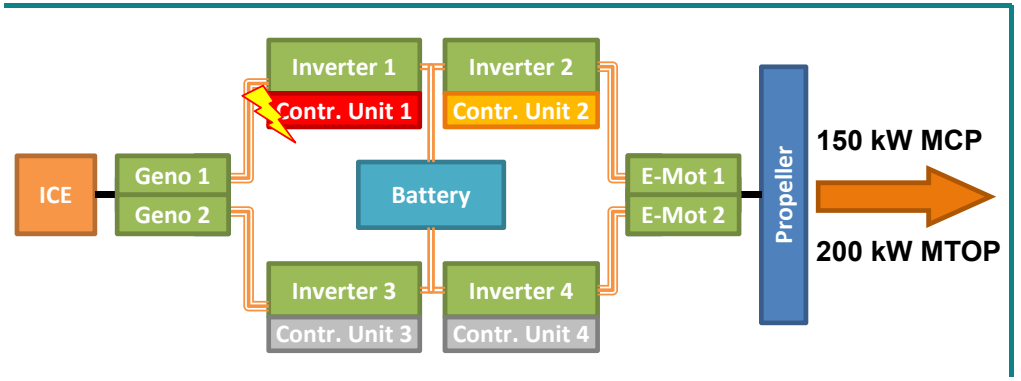
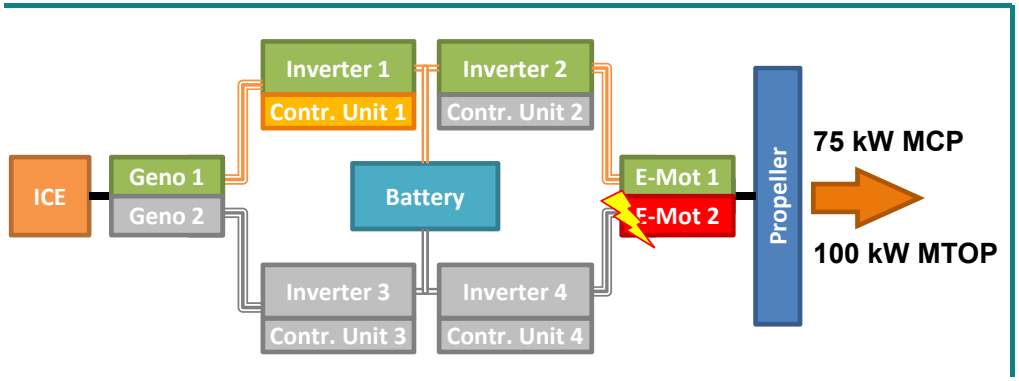
Fully operational, undegraded HEPS



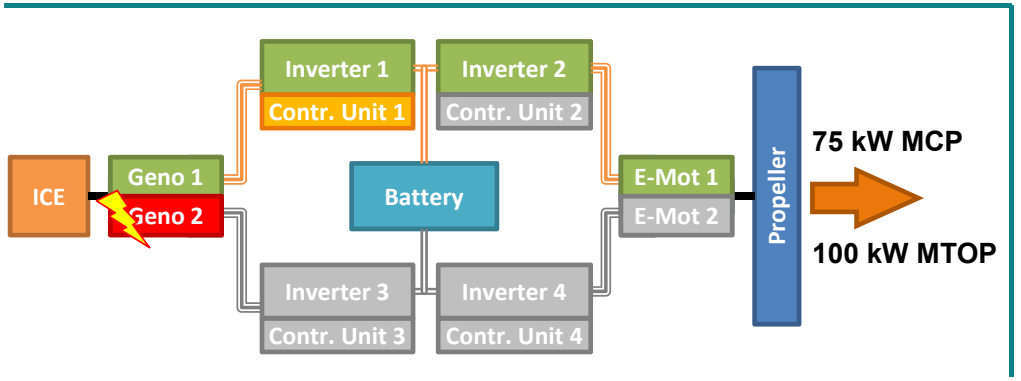
Control Unit #1 malfunction



E-Motor winding malfunction



Generator winding malfunction



Redundancy in many components increases safety and minimizes risk of total loss of power 2/2

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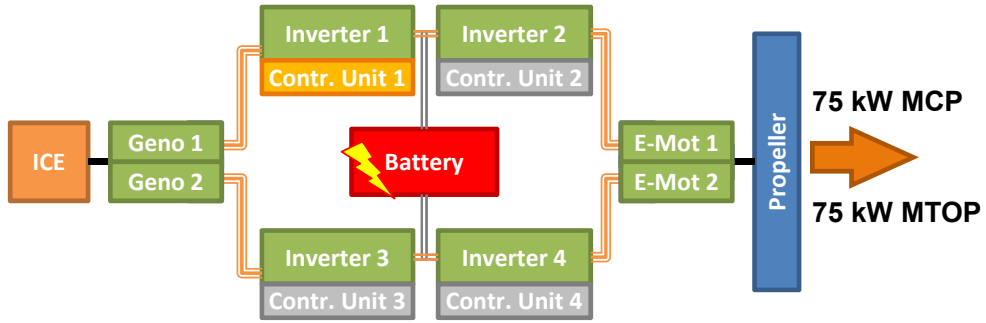
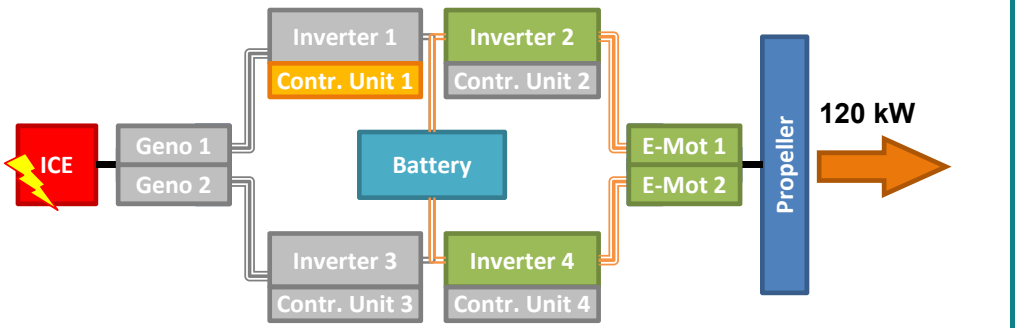
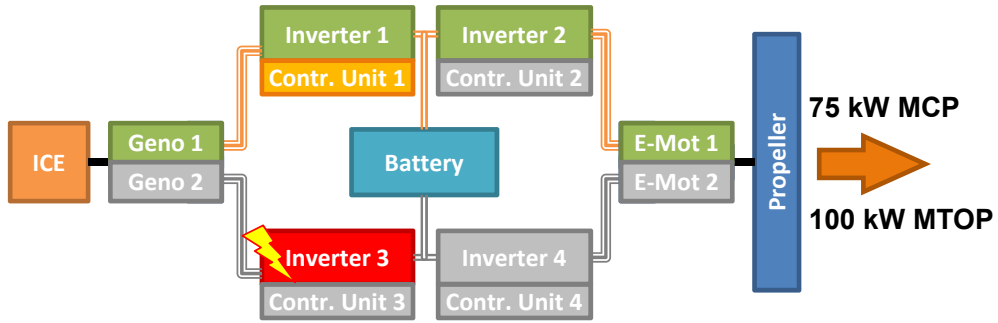
Battery malfunction



Combustion Engine malfunction



Inverter malfunction



d I. Stand des Flugmotorenwerkes der Siemens & Halske A.-G.

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Technical & Regulatory Challenges for Novel HEPU / EPU Designs

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Technical Challenges of Novel EPU/HEPU Designs

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Principle design aspects:

- ✓ Development of sustainable airborne application concepts for electrical machines & power electronics
- ✓ Availability of high power dense energy sources > 500 Wh/kg
- ✓ Application optimized ICE concepts
- ✓ Reduction of overall system complexity
- ✓ Higher EPU/HEPU integration level to airframe designs
- ✓ Structural weight optimization of passive parts e.g. usage of alternative materials

Reliable safety concepts to:

- ✓ Avoid thermal runaway conditions of high voltage batteries
- ✓ Operate „safe & redundant“ control system architectures (HW / SW)
- ✓ Reliable and usefully HMI concepts
- ✓ Realize electrical security using high voltage in aircraft > 1.000 V (AC/DC)
- ✓ Enable the usage of power electronics at high altitudes considering cosmic radiation effects, etc. …

Efficient cooling system concepts for:

- ✓ Operational temperature and air density range
- ✓ High voltage batteries get max power output / time
- ✓ Electrical machines & power electronics to realize high power density

Sources for Electric Flight Certification Basis

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➢ **EASA sources for electric powered a/c:**

- CS-22 motor gliders (SC-22.2014-01)
- EASA CS-LSA Issue 1 (referring to ASTM F2840)
- DO-311(A) Minimum Operational Performance Standards for Rechargeable Lithium Battery Systems
- SAE J2464 Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System Safety and Battery Abuse Testing
- EASA CRI F-58 - Lithium Battery Installations
- LBA SC Brennstoffzellen 3. Ausgabe April 2012
- ASTM F2840 - 14
- ASTM F44.40 WG Integration (wip)
- ASTM F39.05 WG EPU&HEPU (wip)
- Industrial Standards & Specs - DIN 29576, MIL-HDBK-274…
- FAA Electric Propulsion – A Regulatory Feasibility Study
- Austro Control – Guideline for Installation & Certification
- CS-E / CS-23 (incl. A-NPA 2015-06, planned publ. Q2/2016)
- AC23.1309 System Safety Analysis and Assessment for Part 23 Airplanes
- AC23.1311 Installation of Electronic Display in Part 23 Airplanes
- AC23.1521 –Type Certification of Automobile Gasoline in Part 23 Airplanes with Reciprocating Engines
- AC23-2 Flammability Tests
- ARP-4754 / ED-79 System Development Process
- ARP-4761 Safety Assessment
- DO-160G/ ED-14 Environmental conditions and test procedures
- DO-254/ED-80 Electronic HW Development Process
- DO-264
- DO-200A / DO-201A Airborne Databases
- DO-178C / ED-12 Software considerations in Airborne Systems and Equipment Certification

Regulatory Challenges of EPU/HEPU Designs

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- **Design & Airframe integration aspects: → only basic regulations / proposals are available …**
  - ✓ ASTM F2840-14
  - ✓ CS-22H
  - ✓ SC‘s / CRI‘s
  - ✓ A-NPA’s
  - ✓ Guidance material …
- … but don‘t cover yet the full range of required regulatory frame for sustainable HEPU / EPU product development & certification base (future airworthiness design standards)

- **Adaptation/inclusion of existing regulatory frame (CS-x) to new technology need to be simplified and easy traceable (e.g. same CS-x numbering vs. trace matrix for more transparency & less complexity, especially important for aviation novices)**

- **Standard (ELOS) interpretation of conventional airworthiness requirements are only partly usable/reasonable, because of new technology aspects (→ new AMC‘s / guidance material required)**

- **Current initiatives like ASTM with initially transparent process for re-writing FAR-23 making slow progress, because of low willingness to invest significant effort, but political interest very high**

Thank you for your attention !

HYPSTAIR

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