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Electro-mobility and the Future of Transport Aircraft Development

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10th European Workshop on Aircraft Design Education
Naples, Italy, 27 May 2011

Topics to be Covered

>> Motivation for Electro-mobility in Aviation

>> Technology Outlook for Aviation

>> Morphological and Systems Solutions

>> Operational Aspects and Performance

>> Closing Remarks

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Motivation for Electro-mobility in Aviation

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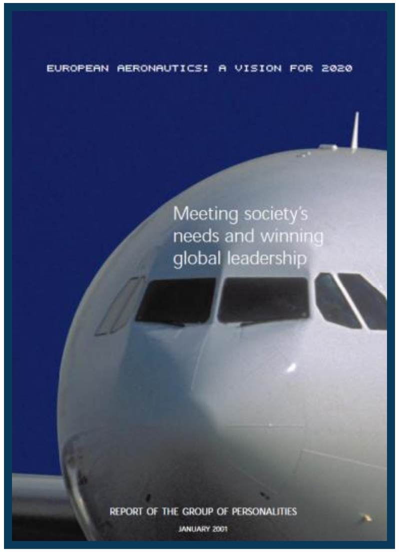
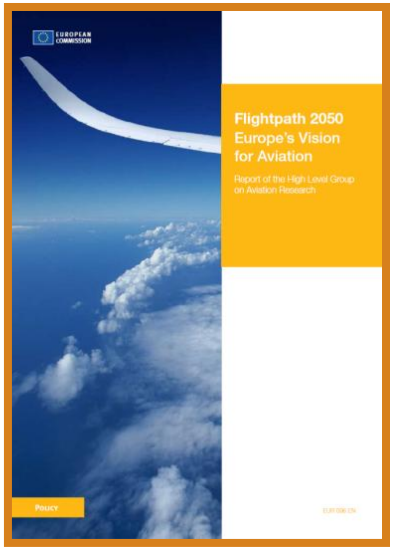
PC-Aero GmbH
2011

>> ACARE 2020

- > 50% cut in CO_2 per PAX-km
- > 80% cut in NO_x emissions
- > 50% perceived aircraft noise reduction
- > Five-fold reduction in accidents
- > ATS to handling 16M flights a year
- > 99% of all flights arrive 15 mins of plan





>> Flight Path 2050

- > 75% cut in CO_2 per PAX-km
- > 90% cut in NO_x emissions
- > Emission-free ground manoeuvring
- > 65% perceived aircraft noise reduction
- > No. of accidents reduced by 80%
- > 90% EU PAX door-to-door within 4 hrs
- > All flights arrive within 1 min of plan
- > Vehicles designed to be recyclable

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Technology Outlook for Aviation (1)

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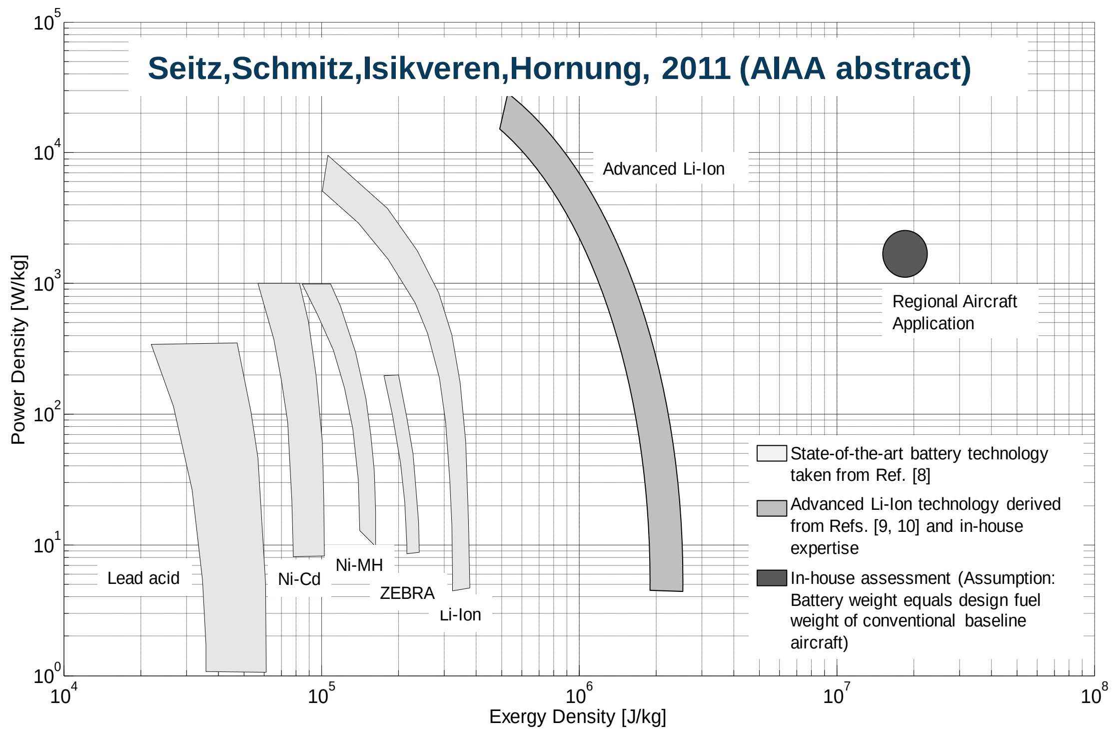
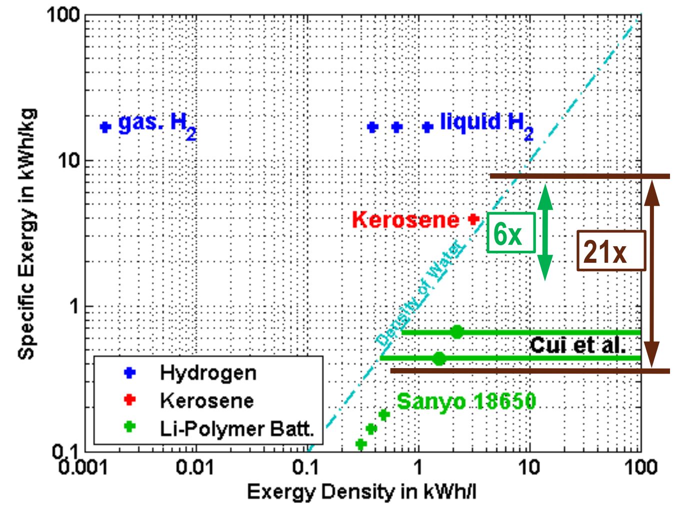
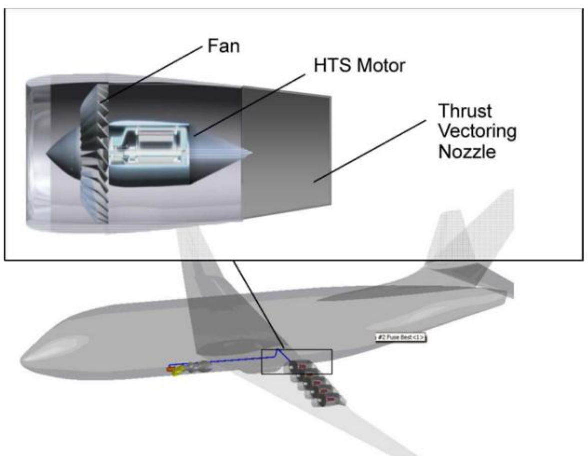


Kuhn,Sukhodub,Steiner,Sizmann, 2009



>> Feasibility based upon 2 metrics:

- > Exergy Density → measure of the duration of available power (storage capacity)
- > Power Density → measures the quantity of peak power delivered on demand



Masson,Nam,Choi,et al., 2009

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Technology Outlook for Aviation (2)

Component Technology	Current Technology Off-the-Shelf	Foreseeable Technology Industry & Academia Collaborative Research	Advanced Technology Academic Research
Batteries	Li-ion most promising 200 Wh/kg and <1 kW/kg or 60-80 Wh/kg and 3 kW/kg (utilised in every flying electric aeroplane today)	Combinations of metal oxide cathodes (Li[MnNiCo]O_x)and C anodes (still <350 Wh/kg); power capabilities dependent on electrode structure	Si anode combined with S cathode exhibit high energy capacity (>900Wh/kg); nano-structured electrodes will increase power capabilities
Fuel Cells	Proton exchange membrane fuel cells (PEFC); moderate power (~1.2 kW/kg on stack level); Specific power of system dependent on balance of plant (H_2-O_2 or H_2-Air system); (used in the Fuel Cell Dimona Demonstrator of Boeing Phantom Works, in the DLR-Antares H2 and in the ENFICA-Project)	PEFC most promising due to highest specific power amongst fuel cell types; specific power of 1.5 kW/kg on the stack level possible in the near future;	High-temperature PEFC still under discussion but still not mature; HT-PEFC introduce new challenges to overall system due to higher temperature; Solid oxide Fuel Cell (SOFC) under research but still too low specific power: weight is an crucial issue
Power Generators and Motors	High torque or high speed motors/generators at 1-3 kW/kg; often groups design and build their application specific motor; few off-the-shelf motors for aviation	Hybrid or high-temperature superconducting devices increasing specific power to ~5kW/kg	High-temperature superconducting (HTS) motors and generators; high power density (demonstrated ~9 kW/kg, incl. cooling)

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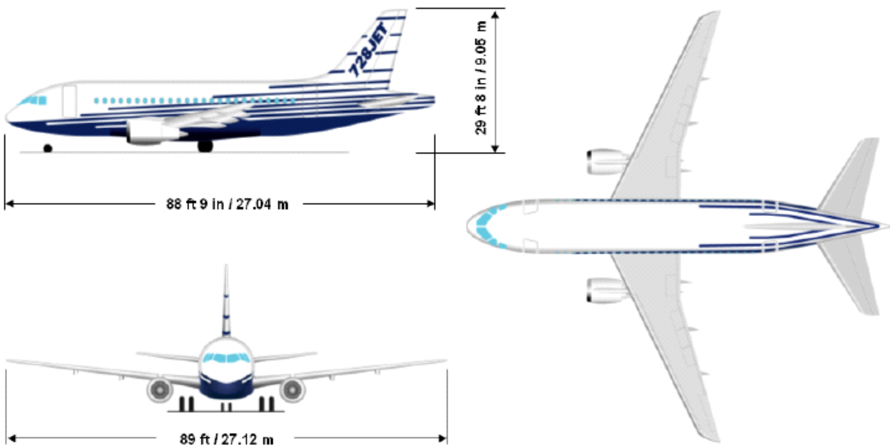
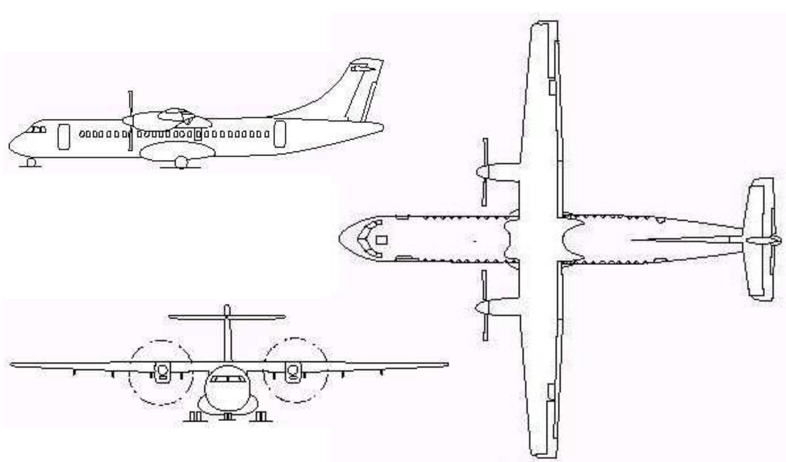
Morphological and Systems Solutions (1)

Baseline Platforms – Design Exercise Looking at Major Derivatives



>> *728-200 Particulars*

- > 75 PAX std acc (equal comfort)
- > Design range for Std PAX 1750 nm
- > VMO/MMO 295 KCAS/335 KCAS/M0.82
- > Std cruise spd M0.78 or 450 KTAS
- > ICA, ISA, MTOW b.r., FL350
- > AR = 9.81, Λ_{qchd} = 23.7°, W/S = 104 psf



>> *ATR 72-210 Particulars*

- > 66 PAX std acc (equal comfort)
- > Design range for Std PAX 890 nm
- > VMO/MMO 250 KIAS/M0.55
- > Std cruise speed M0.41 or 248 KTAS
- > ICA, ISA, MTOW b.r., FL250
- > AR = 11.6, Λ_{qchd} = 1.5°, W/S = 71.7 psf

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Morphological and Systems Solutions (2)

EIS 2025 – Hybrid Kerosene-Battery Solution

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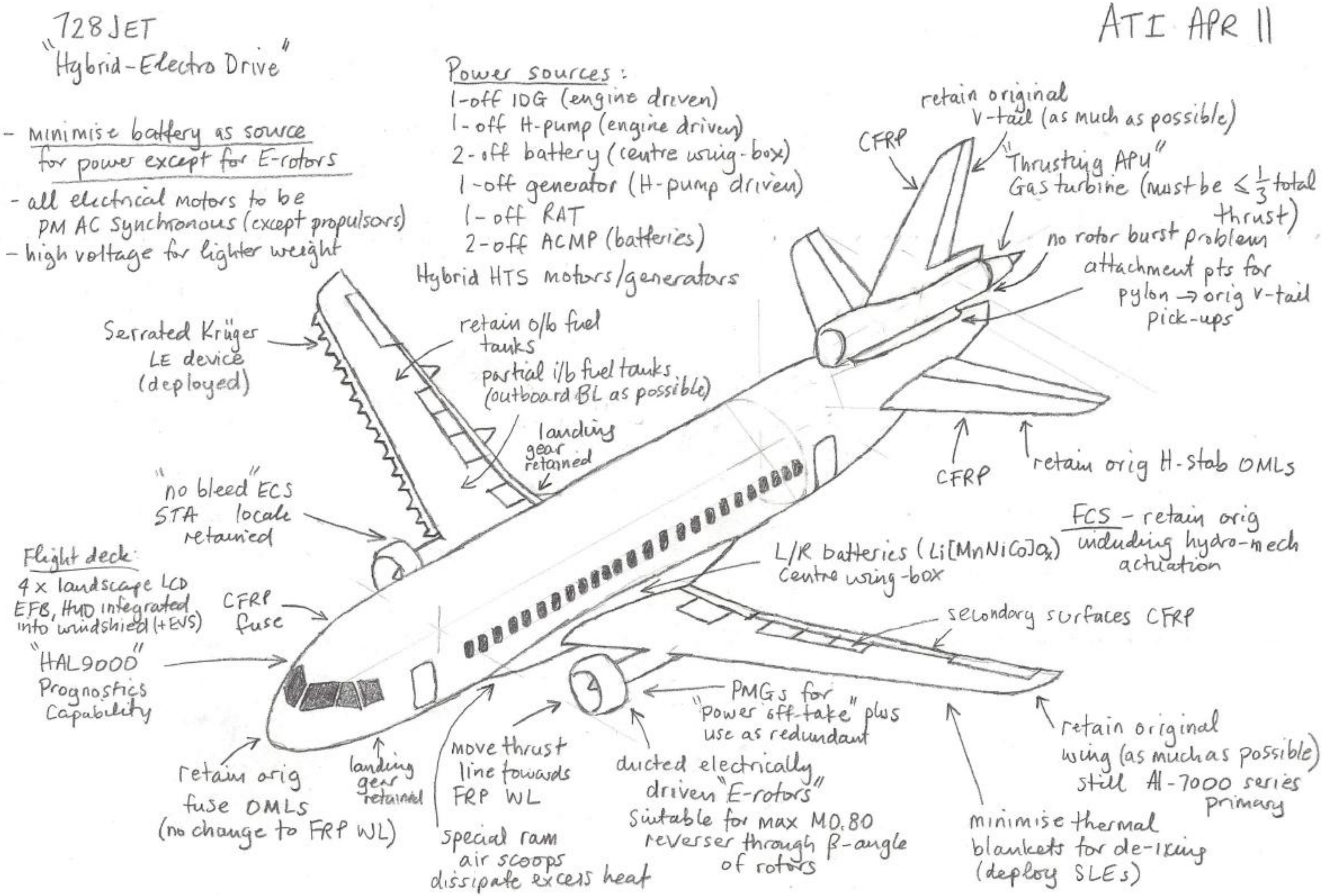

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Morphological and Systems Solutions (3)

EIS Beyond 2030 – Fuel Cell vs Batteries

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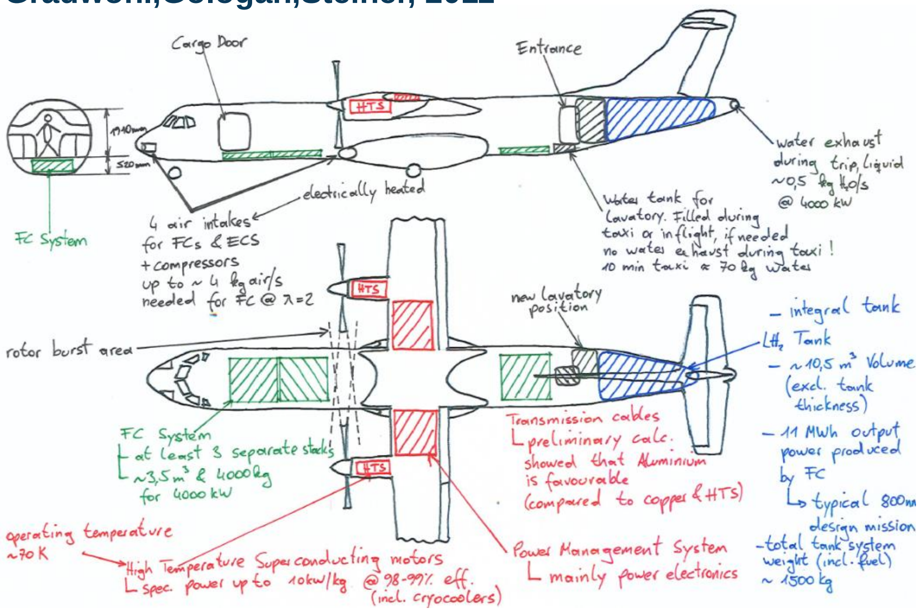
Gradwohl,Gologan,Steiner, 2011

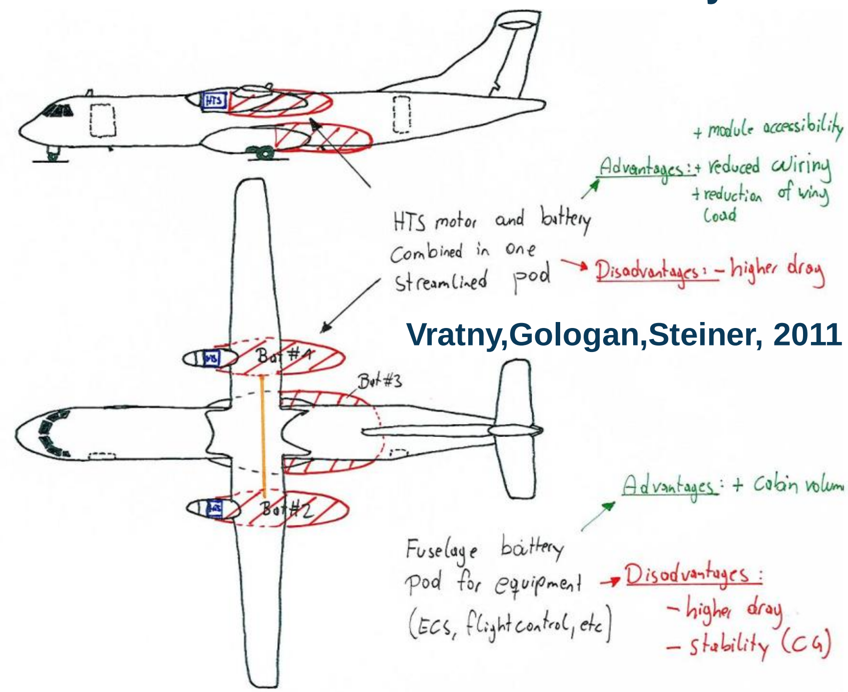


>> *Aspects w.r.t. Fuel Cells*

- > Cryogenic LH_2 storage most practical
- > Existing OMLs could be retained
- > +50% of stack weight for accessories
- > Additional ram air scoops required
- > Water exhaust during en route ops

>> *Aspects w.r.t. Batteries*

- > Power and propulsion in single pod
- > Extended sponsons house more batt.
- > Less problems w.r.t. heat dissipation
- > Considerable weight and drag
- > Modular and ease of accessibility



Vratny,Gologan,Steiner, 2011

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Morphological and Systems Solutions (4)
Proposed General & Detailed Architecture for Fuel Cell Solution

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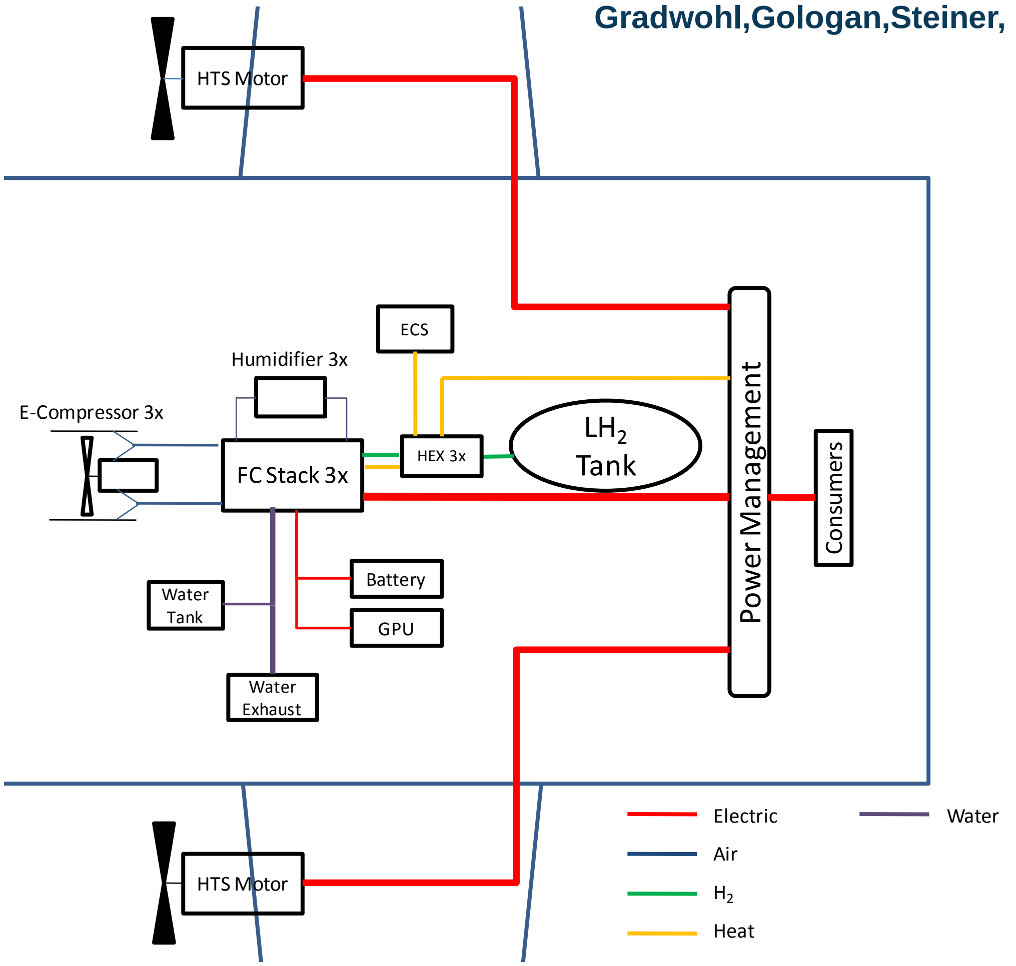
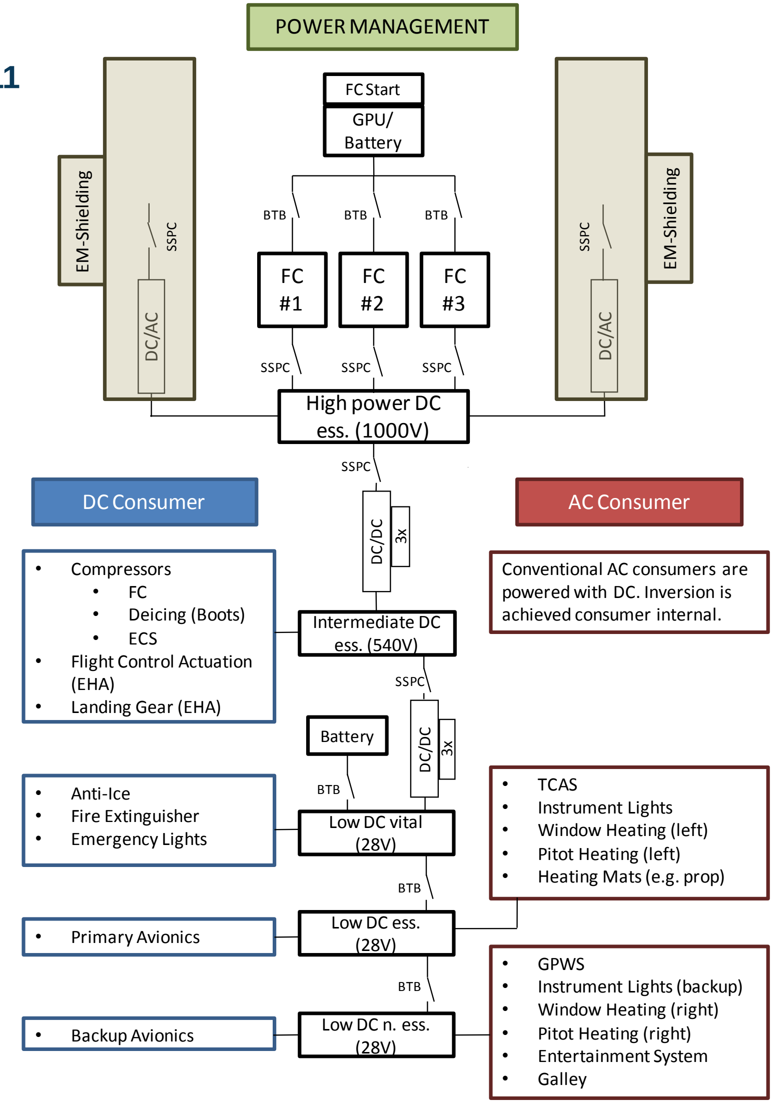
Gradwohl,Gologan,Steiner, 2011





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Morphological and Systems Solutions (5)

Proposed General Architecture for All-Battery Solution

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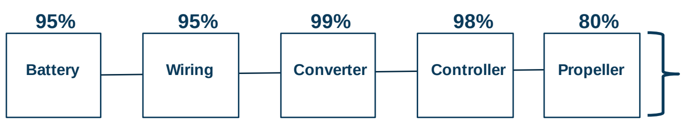
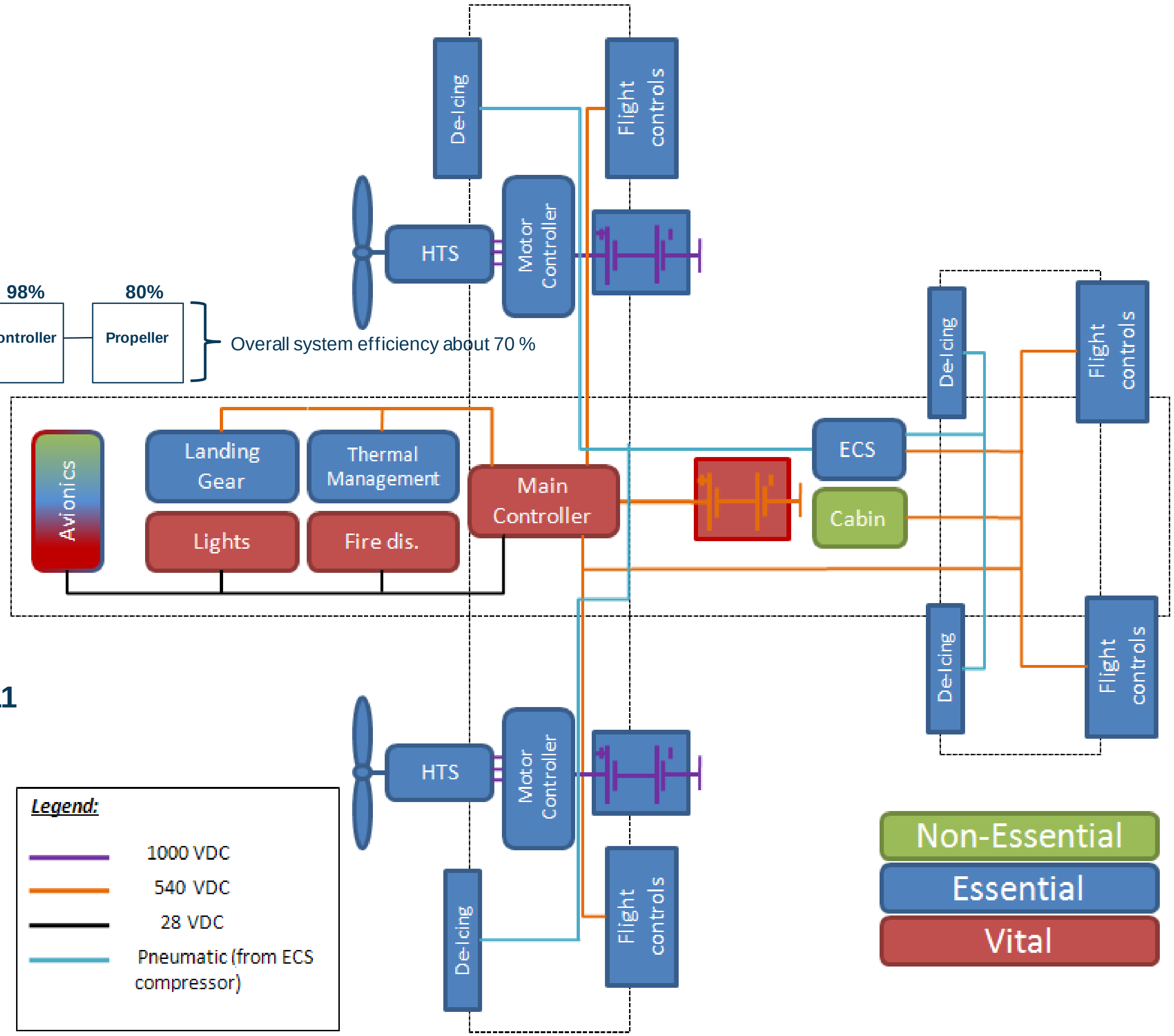
Assumed system efficiencies:





Vratny,Gologan,Steiner, 2011

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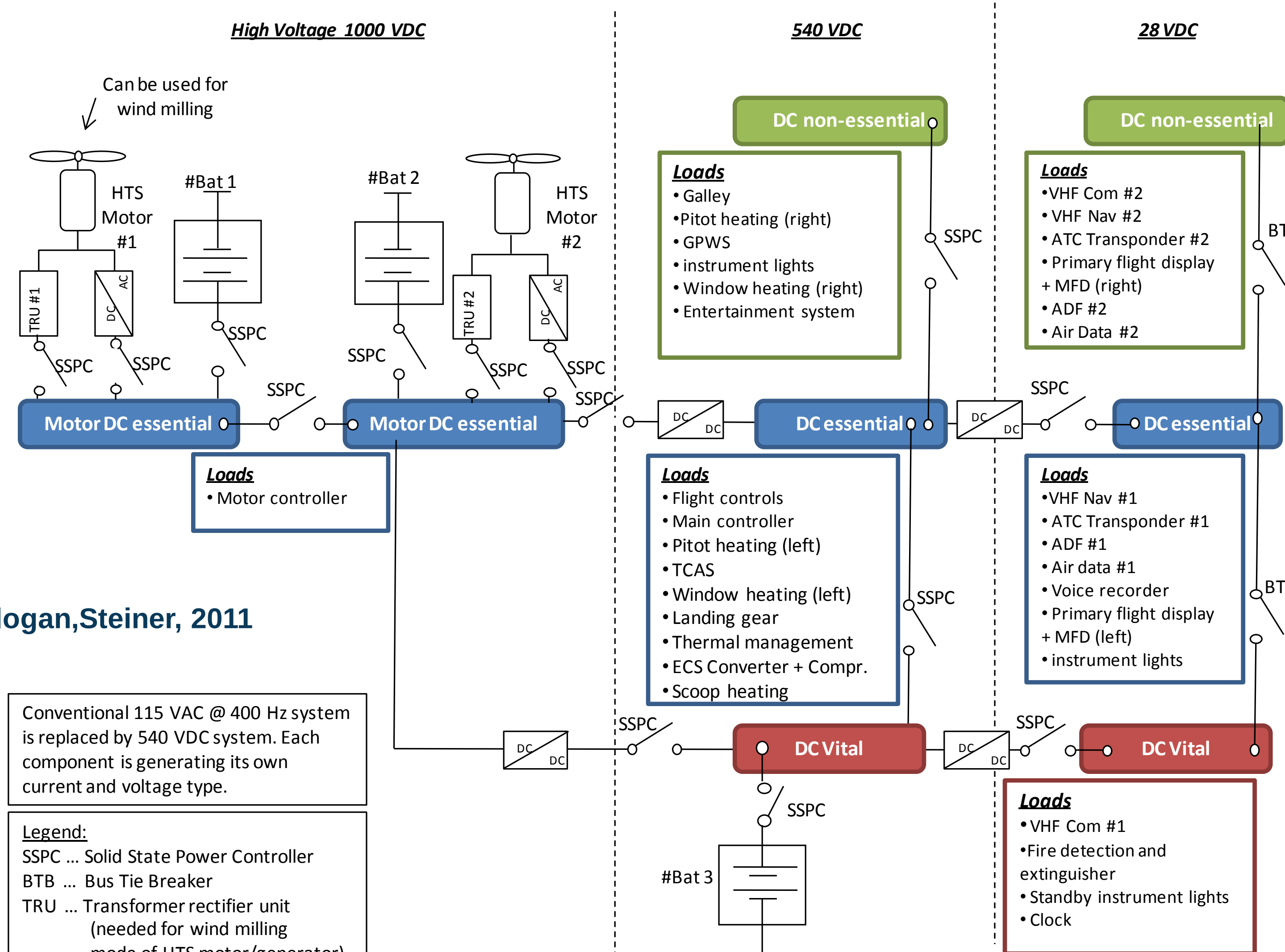
Morphological and Systems Solutions (6)

Proposed Detailed Architecture for All-Battery Solution



Vratny,Gologan,Steiner, 2011

Conventional 115 VAC @ 400 Hz system is replaced by 540 VDC system. Each component is generating its own current and voltage type.

Legend:
SSPC ... Solid State Power Controller
BTB ... Bus Tie Breaker
TRU ... Transformer rectifier unit (needed for wind milling mode of HTS motor/generator)

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Operational Aspects and Performance

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>> Loadability and Turn-around

- Little or no flexibility for manipulating loading loops
- Specialised procedures for ground handling due to power elec. and LH_2
- Recharge times during turn-around
- Less autonomy during turn-around

>> Normal Mode Performance

- Restricted or no step-cruise
- Less sensitive payload-range trade
- Buffet limitations become critical
- Lower noise attributes
- Low-spd and high-spd operation in actual ambient conditions

>> Servicing and Maintenance

- Specialised procedures when handling power electronic systems and LH_2
- Greatly improved MTBF, MTBUR
- Ease of access with modular integ.
- Impact of actual operating ambient conditions plus radiation on equip life

>> Abnormal Mode Performance

- OEI during en route conditions – no weight change, terrain clearance restricted plus KTAS fixed
- Impact after HIRF with continued ops
- Problems with restart, flame-out avoided

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Closing Remarks

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- >> ***Power electronics in terms of power density (max power) looks promising***
- >> ***Power electronics in terms of exergy density (storage capacity) is too low, even if a 15-year plus time-line is considered***
- >> ***Encouraging development w.r.t. e-rotors, e.g. HTS motors***
- >> ***Battery-alone solution suffers from excessive weight and drag penalties***
- >> ***Fuel Cell-alone better solution w.r.t. weight and drag, however, practical means of cryogenic storage is a problem***
- >> ***BHL committed to seeking electro-mobility solutions for aviation***
  - > **Currently targeting the regional market segment, EIS circa 2025, major derivatives**
  - > **Best integration strategy for EIS 2025 is Hybrid Electro-Drive (HED) → combination of e-rotors and gas-turbine using 2 + 1 layout**
  - > **Soon will engage in initial technical assessment activity where a clean-sheet, all-electric (motive power + systems customers) regional transport will be designed, EIS 2030+**

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