APISAT 2019

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Electric Systems

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Impact of Propulsion Technology Levels on the Sizing and Energy Consumption for Serial Hybrid-Electric General Aviation Aircraft

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Goal:
- Identify most important technology parameters
- Quantify possible improvements

→ Technological thresholds

Means: Parameter variation studies for 2 aircraft starting from 3 technology levels

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Agenda

1. Initial Sizing for Hybrid-Electric Aircraft

2. Baseline Aircraft and Technology Levels

3. Parameter Studies E-Motor P/W & Battery Energy Density

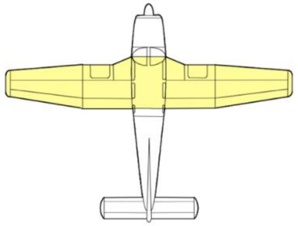
4. Conclusion

1. Initial Sizing for Hybrid-Electric Aircraft

- Initial Sizing = First calculation of mass, wing area, thrust/power

MTOM

Wing Area



Thrust / Power

- Conventional methods e.g. Raymer, Roskam, Gudmundsson

Fuel burning ICE
→ A/C loses weight
→ Breguet range formula

EM powered from batteries
→ A/C does not lose weight
→ Modified Breguet formula

Either one
⬇
Conv. methods

Both
⬇
Other method needed

1. Initial Sizing for Hybrid-Electric Aircraft

- Sizing method for hybrid-electric GA aircraft from FH Aachen UAS, described by (Finger 2018)

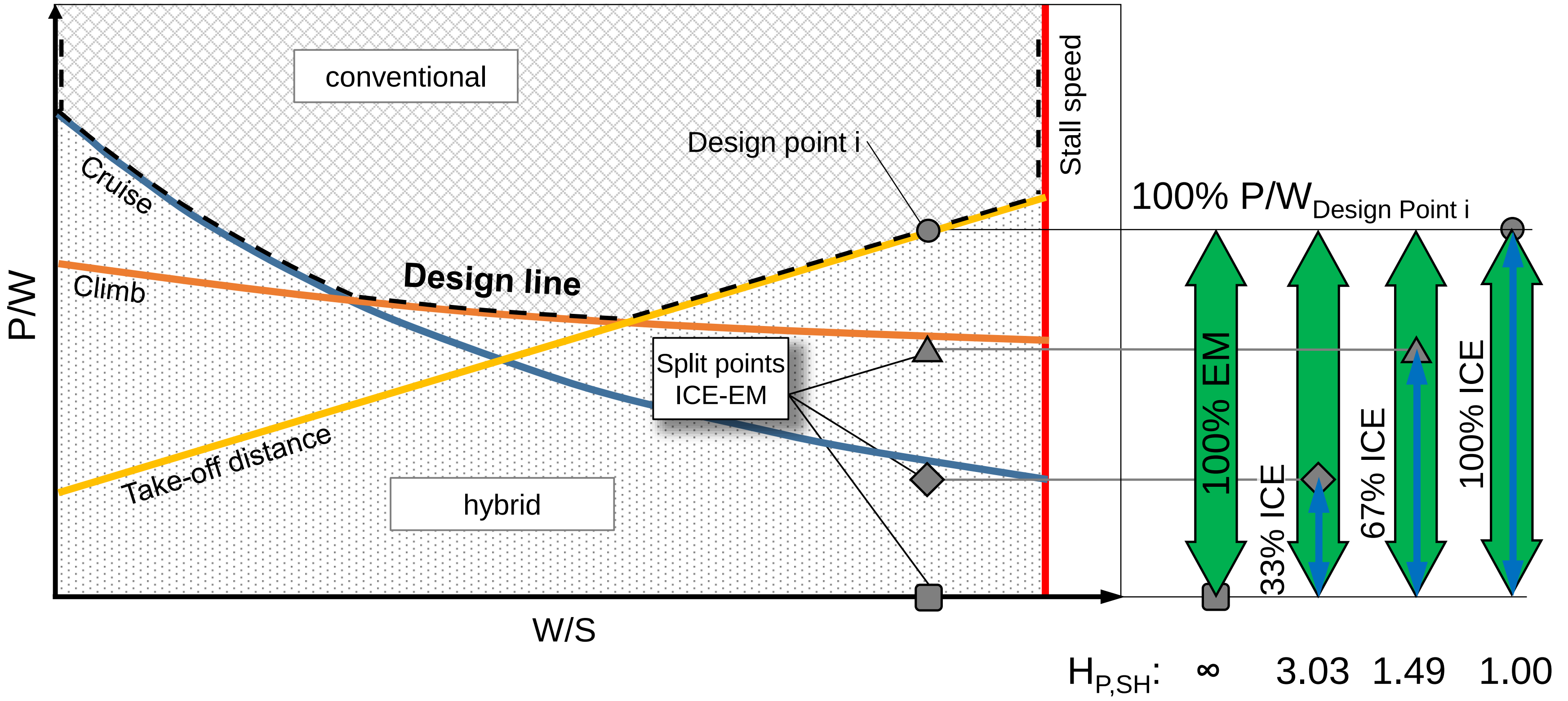
- 2 key points of this method

  1. Energy based approach for iteration of weights & new empty-mass-fractions

  2. Definition of Degrees of Hybridization using the Matching Diagram

1. Initial Sizing for Hybrid-Electric Aircraft

Definition of Degrees of Hybridization for SERIAL hybrid using the Matching Diagram



Degree of Hybridization of Power

$$H_{P,SH} = \frac{P_{E-Motor}}{P_{ICE}}$$

Degree of Hybridization of Energy

$$H_{E,mean} = \frac{E_{non-consumable}}{E_{total}}$$

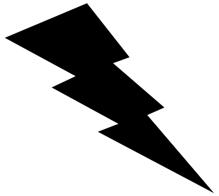
1. Initial Sizing for Hybrid-Electric Aircraft

- 2 assessment criteria and design objectives are used

Maximum Take-Off Mass (MTOM)

and

Primary Energy Consumption (PEC)



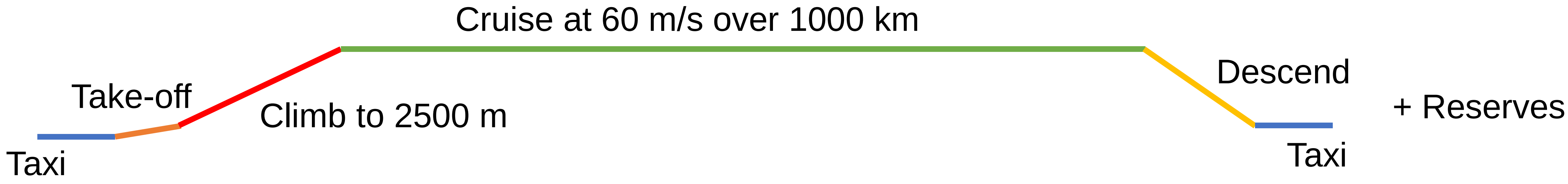
- Most common
- Correlates to cost

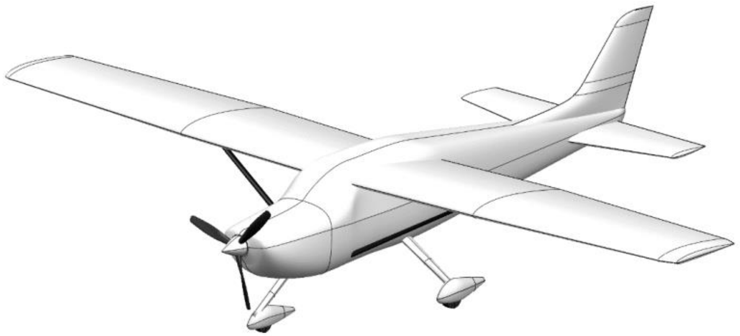
- Total expended energy to provide fuel / electricity
- Factors from Germany 2016

- Fossil fuel = 1.1 (refinement process from raw oil)
- Electricity = 2.8 (electricity mix, coal, gas, …)

2. Baseline Aircraft and Technology Levels

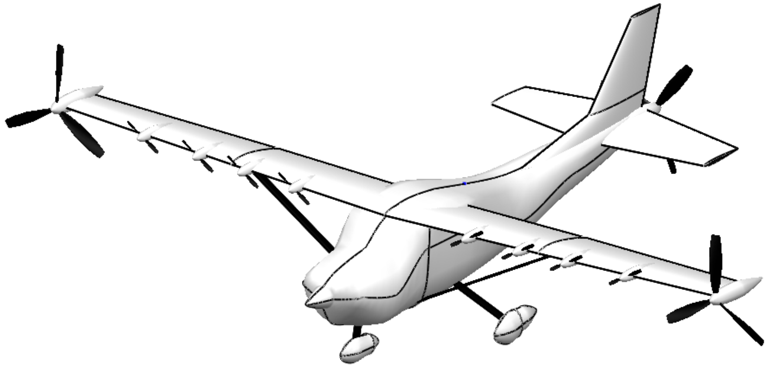
- 2 serial hybrid-electric baseline aircraft with same mission





Aircraft #1

	Aircraft #1 Non-DEP	Aircraft #2 DEP
Payload [kg]	340	340
c_{D0} [counts]	290	250
$c_{L,max}$ [-]	2	4
$c_{L,TO}$ [-]	1.2	2



Aircraft #2

2. Baseline Aircraft and Technology Levels

- 3 technology levels

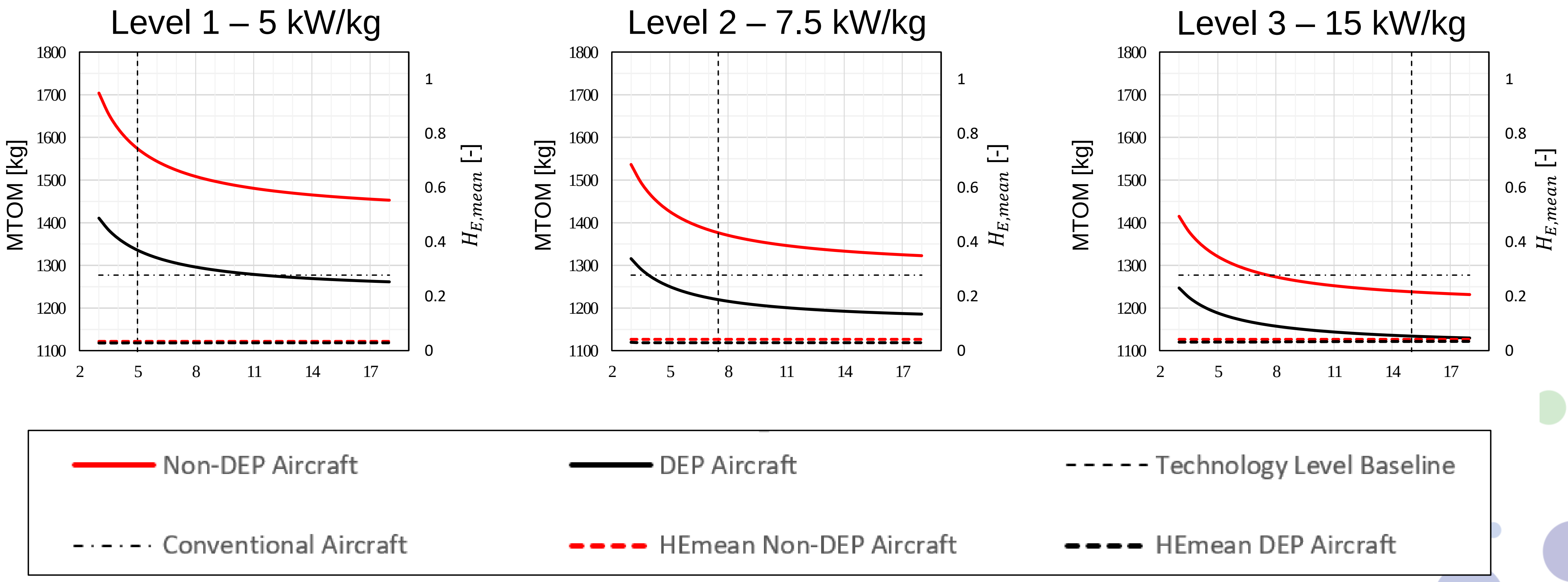
	Level 1 – today	Level 2 – 2035	Level 3 – 2050
Battery Specific Energy [Wh/kg]	250	400	1000
Battery Specific Power [kW/kg]	2.5	4	10
E-Motor Specific Power [kW/kg]	5	7.5	15
E-Systems Efficiency [-]	0.91	0.94	0.96

↳ = E-Motor Efficiency x Battery Efficiency x Controller Efficiency

- Further parameters that were changed with the technology levels:
  ICE Specific Power, Primary Energy Factors

3. Selected Parameter Studies

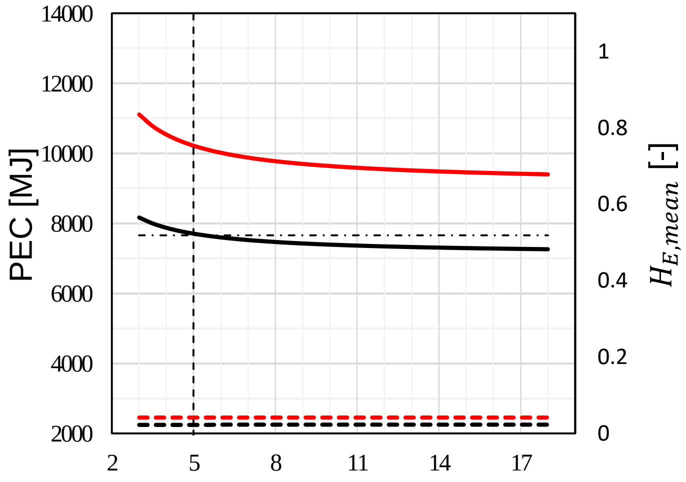
- E-Motor Specific Power varied from 3 - 18 kW/kg (lowest MTOM)



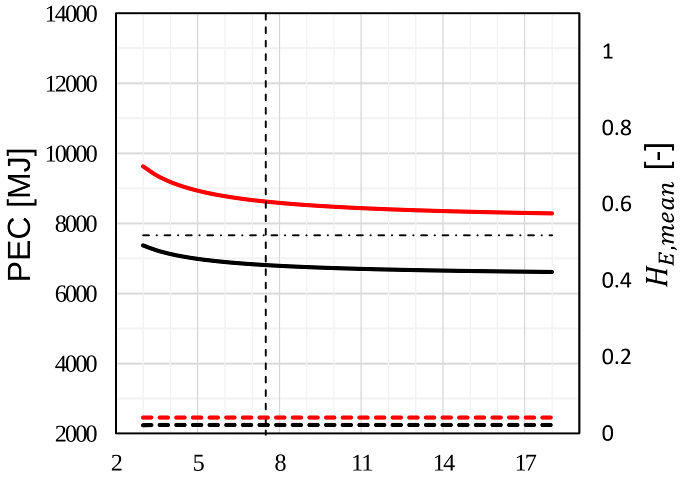
3. Selected Parameter Studies

- E-Motor Specific Power varied from 3 - 18 kW/kg (lowest PEC)

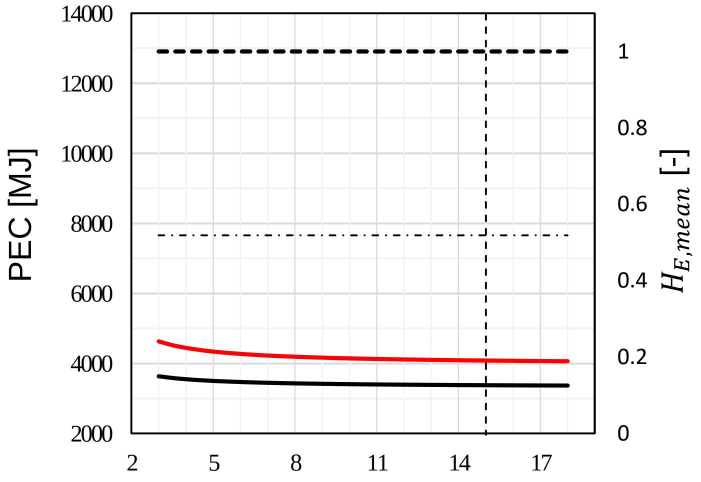
Level 1 – 5 kW/kg



Level 2 – 7.5 kW/kg



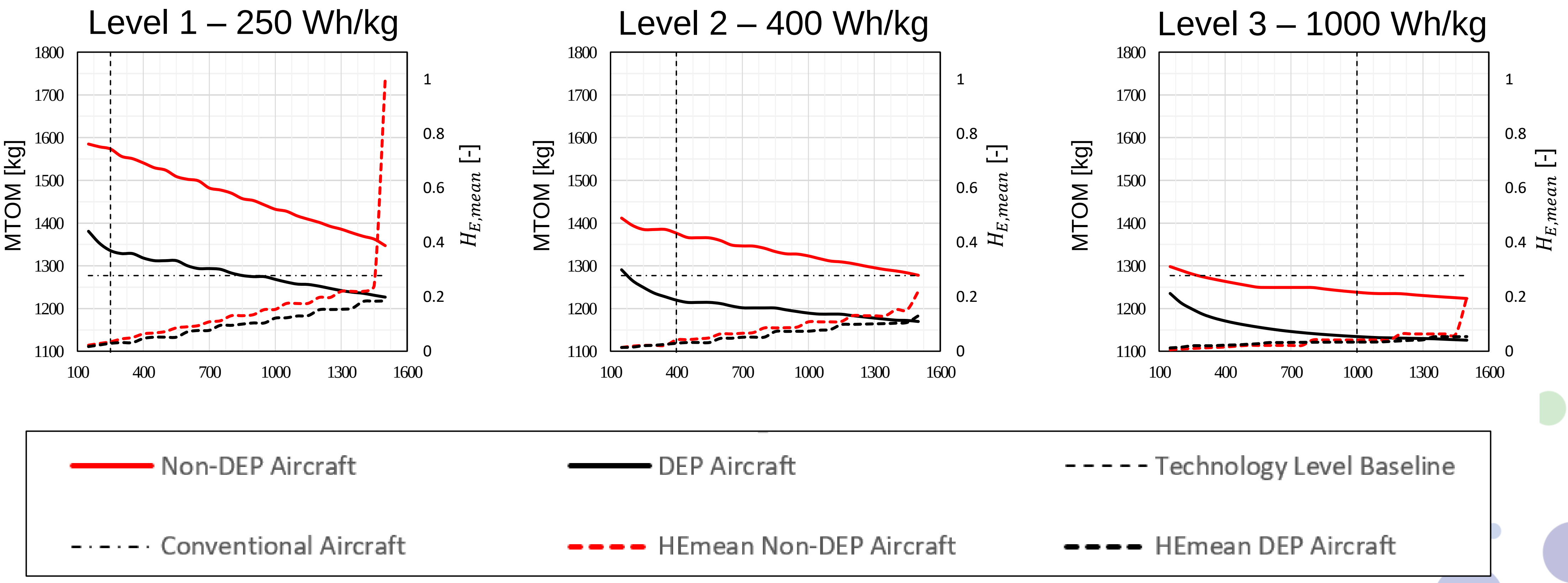
Level 3 – 15 kW/kg



Results: • MTOM and PEC generally decline with increasing P/W
• Gradient also declines
→ Technological threshold at around 5 – 8 kW/kg

3. Selected Parameter Studies

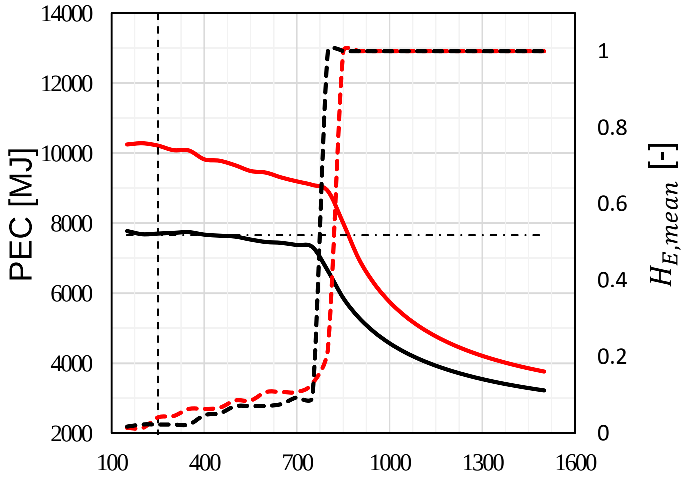
- Battery Specific Energy varied from 150 - 1500 Wh/kg (lowest MTOM)



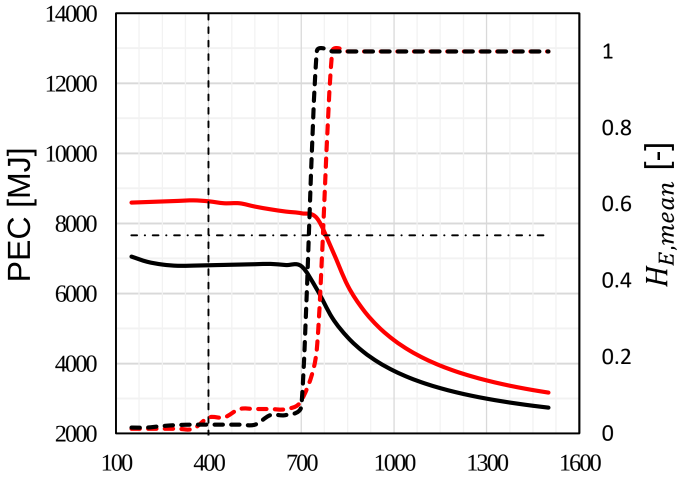
3. Selected Parameter Studies

- Battery Specific Energy varied from 150 - 1500 Wh/kg (lowest PEC)

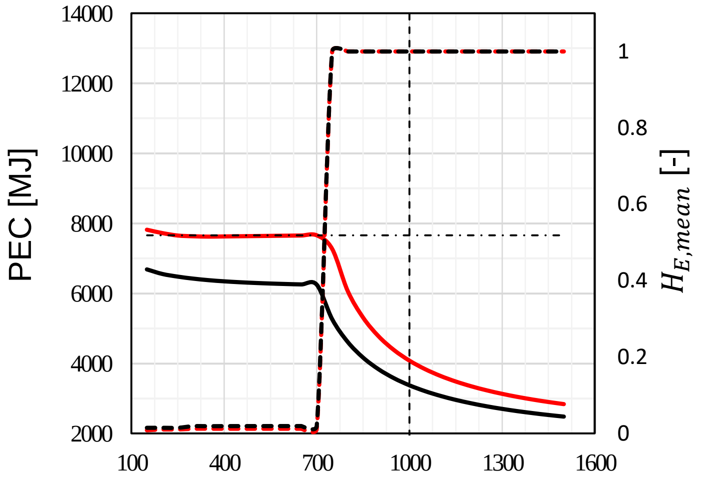
Level 1 – 250 Wh/kg



Level 2 – 400 Wh/kg



Level 3 – 1000 Wh/kg



Results: • MTOM nearly linear decline, PEC linear/flat then drops
- Drop is switch from hybrid to fully electric aircraft

→ Long-term fully electric aircraft superior to hybrid for lowest PEC

4. Conclusion

- Similar trends for both baseline aircraft and design objectives (MTOM and PEC) except for Battery Specific Energy
- E-Motor technological threshold around 5-8 kW/kg
- Fully electric aircraft best solution for lowest PEC when 700 Wh/kg batteries are available

References

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Thank you for your attention.

Questions?

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