Design decision and technology readiness assessment for aircraft electrical power systems

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Outline

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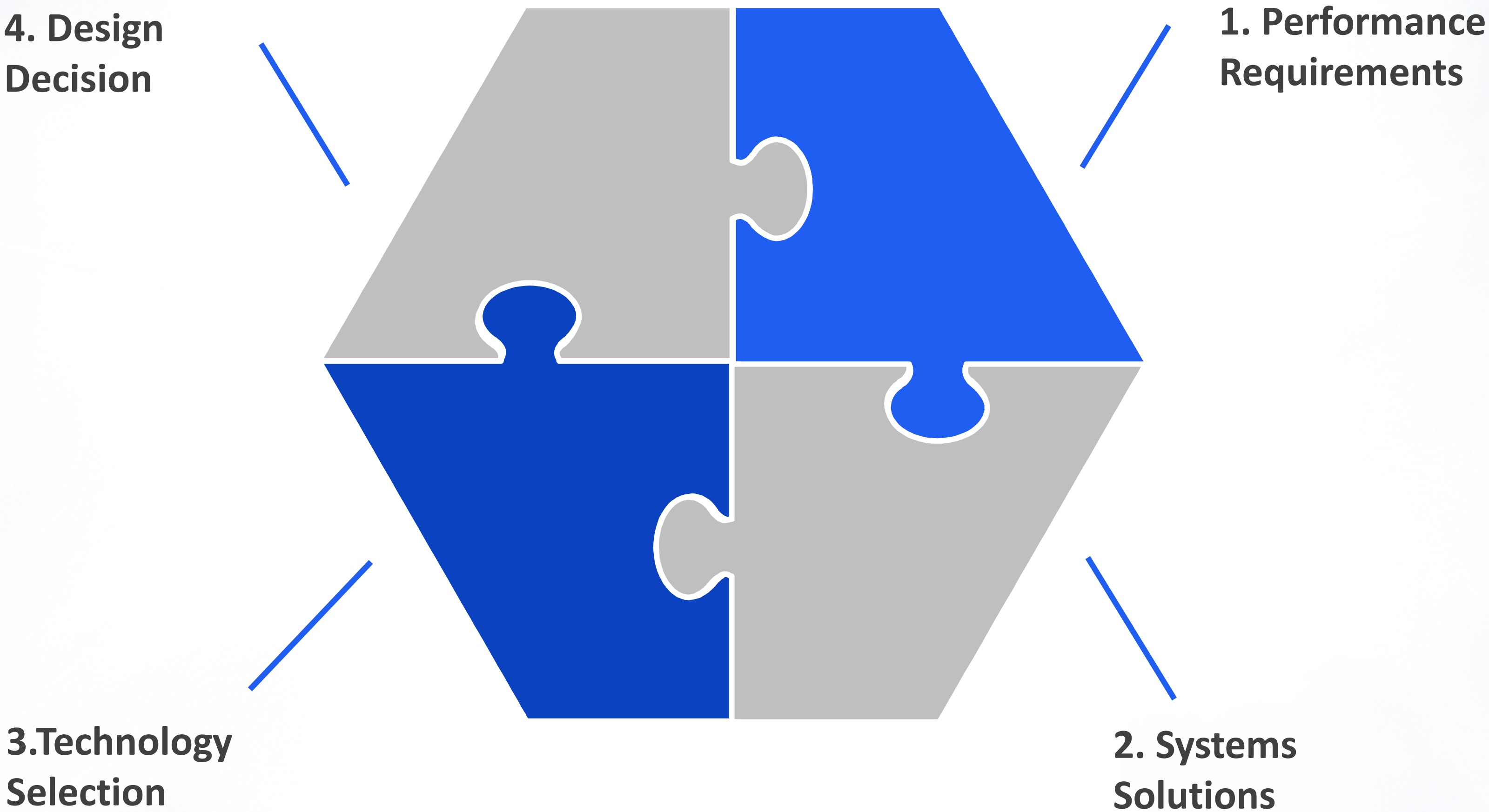
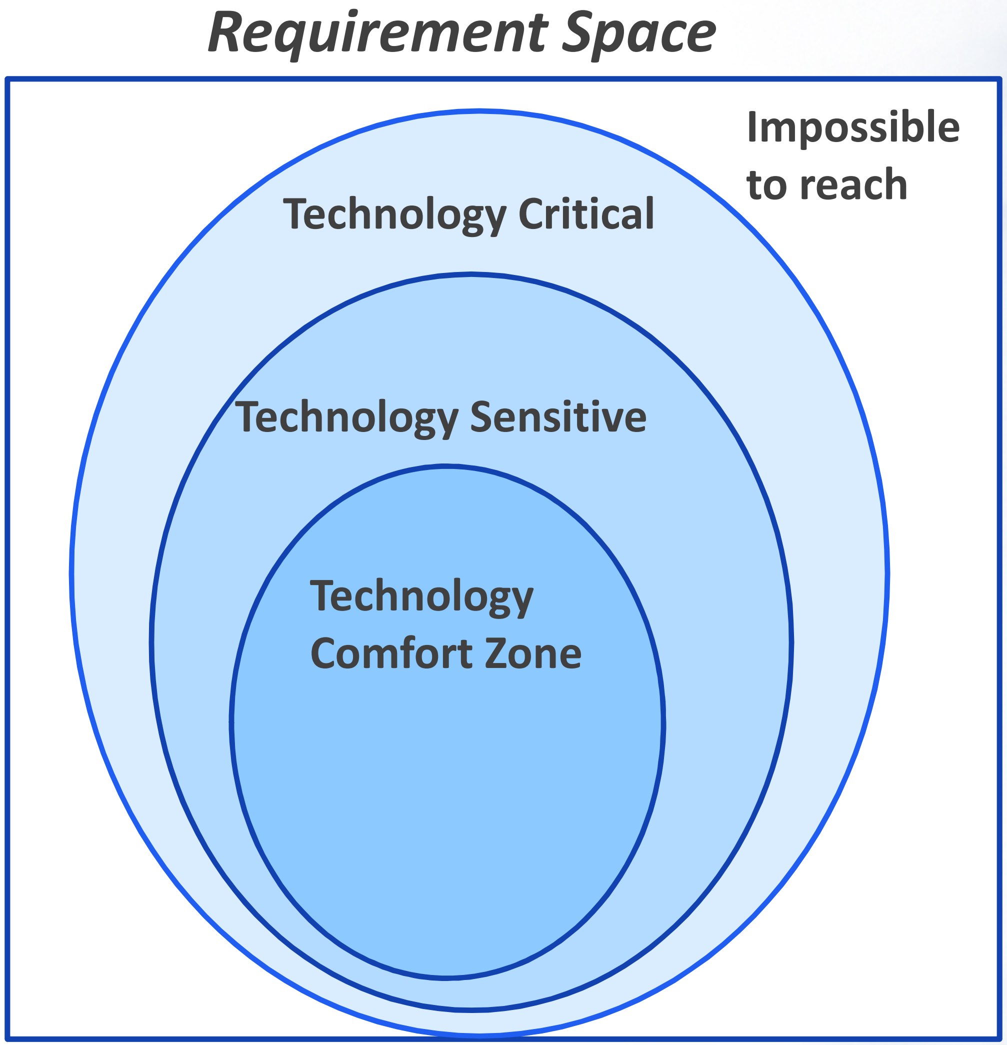
Architecting Technological Systems

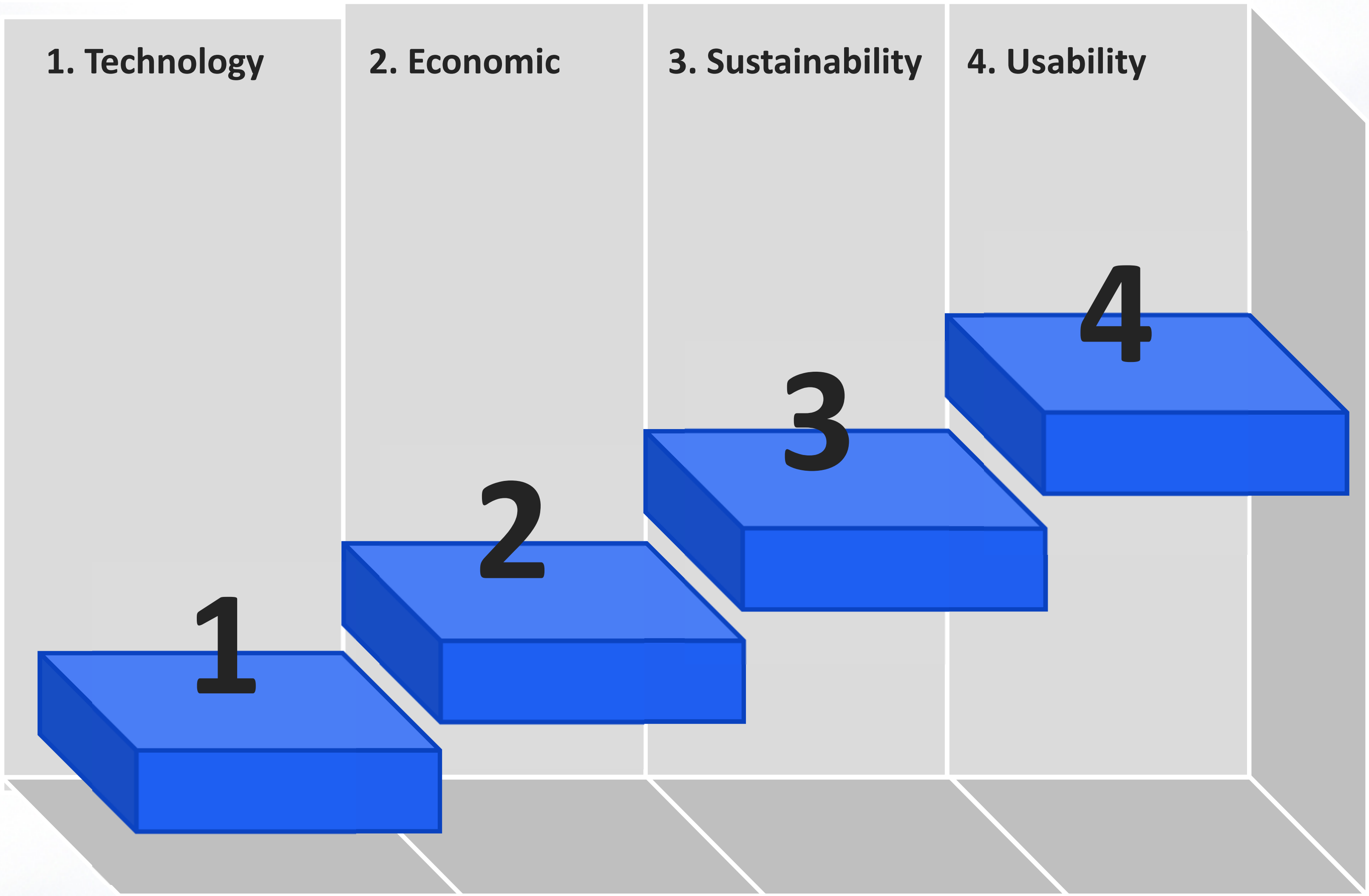


Technology and Requirement Space

- How can we identify reuirements where viable products can be produced?
- Considering both market and available technology



What are the paths that guide designers?



The Concept Of Technology Criticality

$$p = f_p(\mathbf{x}, \zeta)$$

$$c = f_c(\mathbf{x}, \zeta)$$

1. Improvement in the technology, ς . should have a strong effect on system performance, *p*
2. The change on a design parameter, x, would have a low sensitivity on performance combining with a significant sensitivity on cost, *c*, from x.

- The cost benefit factor κ_i of a design parameter is now defined as:

$$\kappa_i = \frac{k_{0,p,i}}{k_{0,c,i}} = \left(\frac{x_i}{p}\frac{\partial p}{\partial x_i}\right)\left(\frac{x_i}{c}\frac{\partial c}{\partial x_i}\right)^{-1} = \frac{c}{p}\left(\frac{\partial p}{\partial x_i}\right)\left(\frac{\partial c}{\partial x_i}\right)^{-1}$$

- I.e. Sensitivity of performance κ to design parameter, divided with sensitivity of cost to the same design parameter
- A working definition used for criticality of a technology is if the sum of all (n) :

$$\kappa = \sum_{i=1}^{n} \kappa_i < 1$$

- κ is here called the **Criticality Factor.**
- If κ is larger than 2, we are in the ***Technology Comfort Zone***

Range Equation for Battery Powered Aircraft

$$R = \left(\frac{\eta c_b}{g}\right)\left(\frac{L}{D}\right)\frac{W_b}{W_0}$$

c_b :Battery energy density (J/kg)

(Battery specific energy J/kg or J/N=Nm/N=m

200 Wh/kg state-of-the-art li-poly corresponds to 73000 m)

η :Propeller efficiency (range of 0.83-0.9)

L/D :Lift over drag (range 7-22)

W_f / W_0 :Fuel fraction, typically 0.2-0.5

Example

$$R = \left(\frac{\eta c_b}{g}\right)\left(\frac{L}{D}\right)\frac{W_b}{W_0}$$

c_b :Battery energy density (J/kg)

(Battery specific energy J/kg or J/N=Nm/N=m

li-poly 73000 m)

η :0.9

L/D :20

W_f / W_0 :1

$R = 0.9 \times 73000 \times 20 \times 1 = 1310 \times 10^3$ m=1310 km

Technology Criticality in Battery Powered Aircraft

Technology sensitivity

$$k_{0,\zeta} = \frac{c_{b,}}{R}\frac{\partial R}{\partial c_b} = \frac{c_b}{R}\frac{\partial}{\partial c_b}\left(\eta \frac{c_b}{g}\left(\frac{L}{D}\right)\frac{W_b}{W_b + W_{pay} + W_e}\right) = 1$$

Range

$$R = \eta \frac{c_b}{g}\left(\frac{L}{D}\right)\frac{W_b}{W_b + W_{pay} + W_e}$$

Cost (assumed to be related to weight)

$$c_W = W_{pay} + W_s + W_b$$

Introduce as design parameter

$$\Psi = \frac{W_b}{W_{pay} + W_s}$$

$$R = \eta \frac{c_b}{g}\left(\frac{L}{D}\right)\frac{\Psi}{1+\Psi}$$

Performance Sensitivity

$$k_{0,p} = \frac{\Psi}{R}\frac{\partial R}{\partial \Psi} = \frac{\Psi}{R}\frac{\partial}{\partial \Psi}\left(\eta \frac{c_b}{g}\left(\frac{L}{D}\right)\frac{\Psi}{1+\Psi}\right) = \frac{1}{1+\Psi}$$

Cost sensitivity

$$k_{0,c} = \frac{\Psi}{c_W}\frac{\partial c_W}{\partial \Psi} = \frac{\Psi}{1+\Psi}$$

$$\boxed{\kappa = \frac{k_{0,p}}{k_{0,c}} = \Psi^{-1}}$$

The criticality of battery technology for electric aircraft

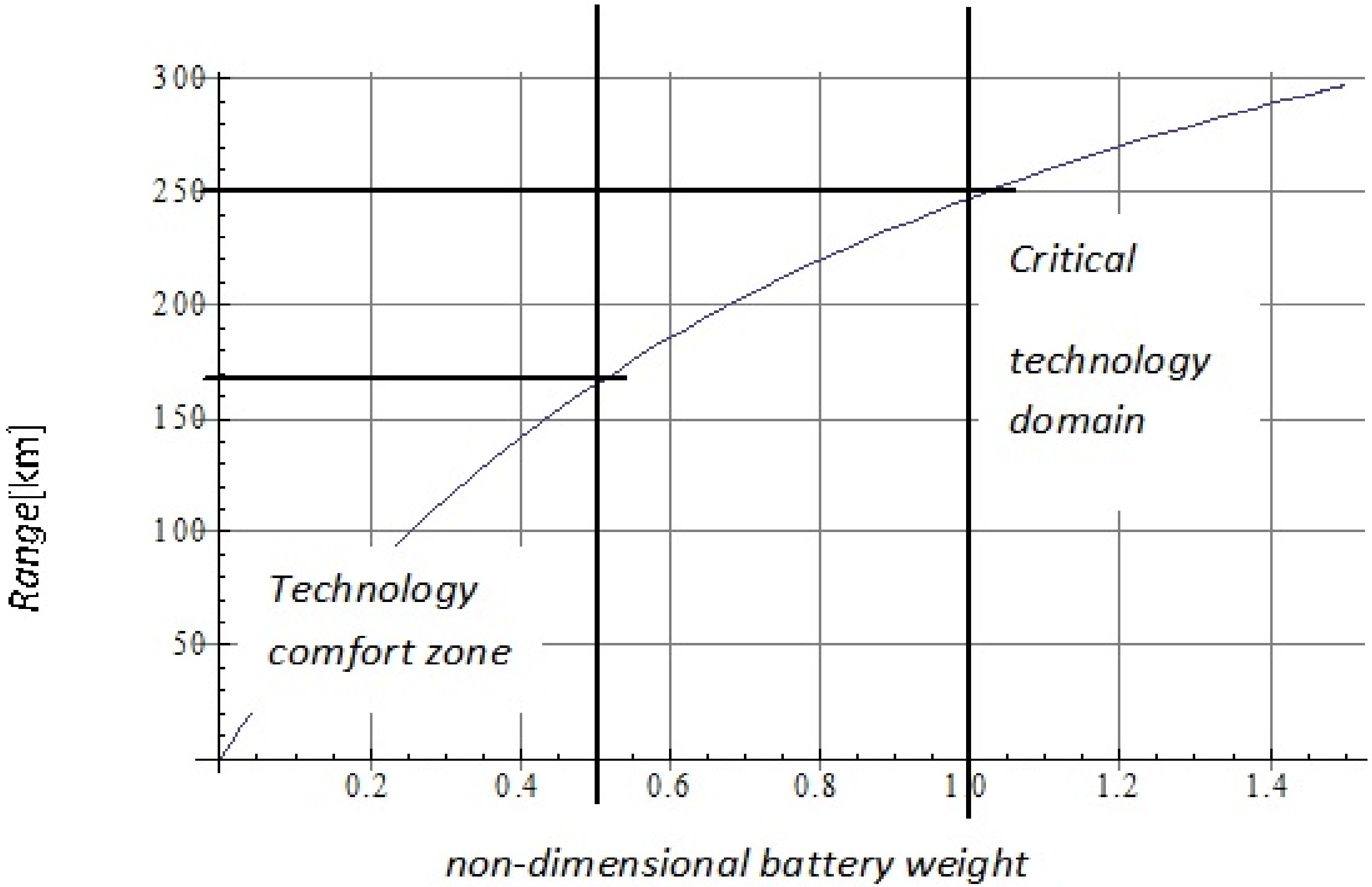
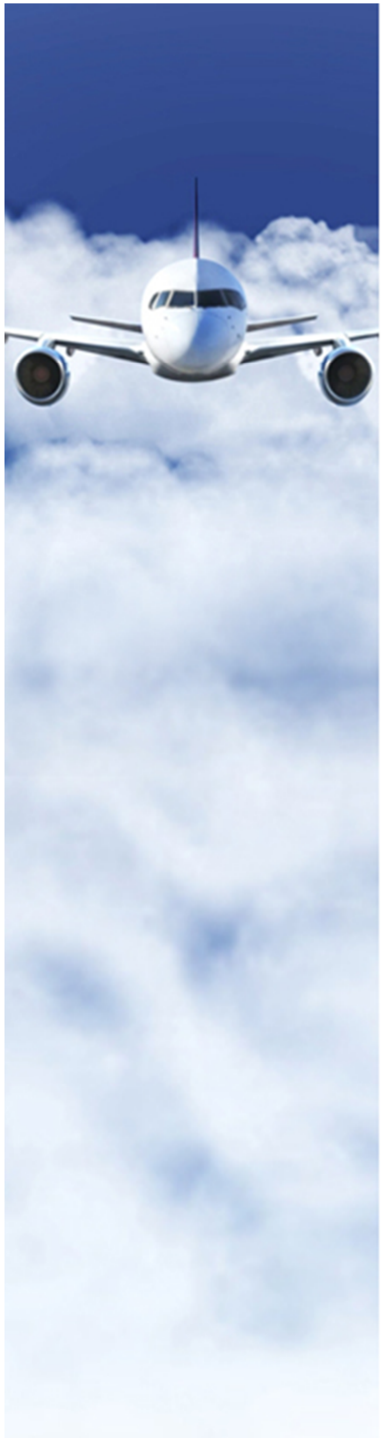


Figure 1. Range as a function of non-dimensional battery weight.



Conclusion

1. According to the Technology Comfort Zone, a larger range is not impossible to achieve, but the cost benefit becomes poor.
2. It would require that special emphasis has to be put on weight reduction and aerodynamic design, using more extreme electric technologies, and a very high portion of the aircraft weight would be taken up by the battery.
3. Staying within the Technology Comfort Zone means that readily available, mature, relatively inexpensive technologies off the shelf, can be used.
4. Although the range is independent of size, the endurance is not. A small aircraft will generally fly slower, and the endurance will thus increase simply because of the speed is lower.

Tak! Thanks! Obrigada!

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