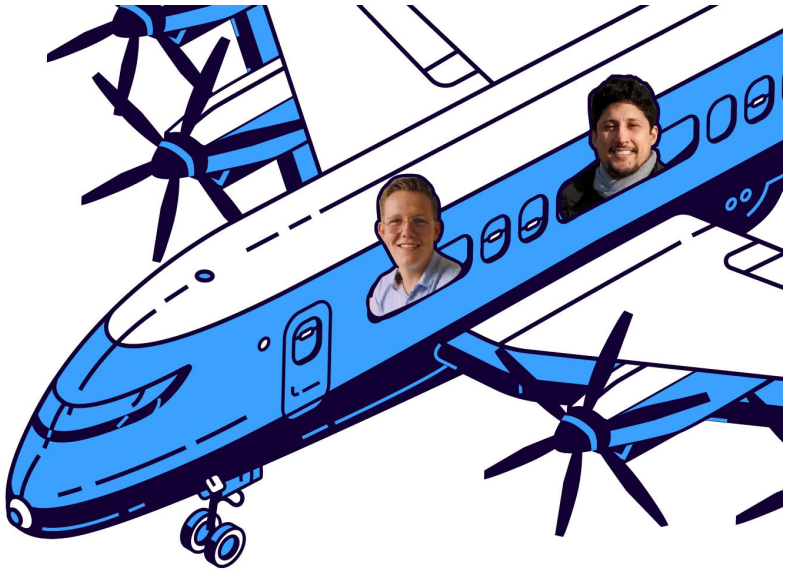
Power electronics and EMC on board All-Electric Aircraft, a marriage for success

Patrick Koch & Leonardo Malburg

University of Twente

Who are we?

- PhD candidates
-
- LUCHTVAART in transitie TEPS

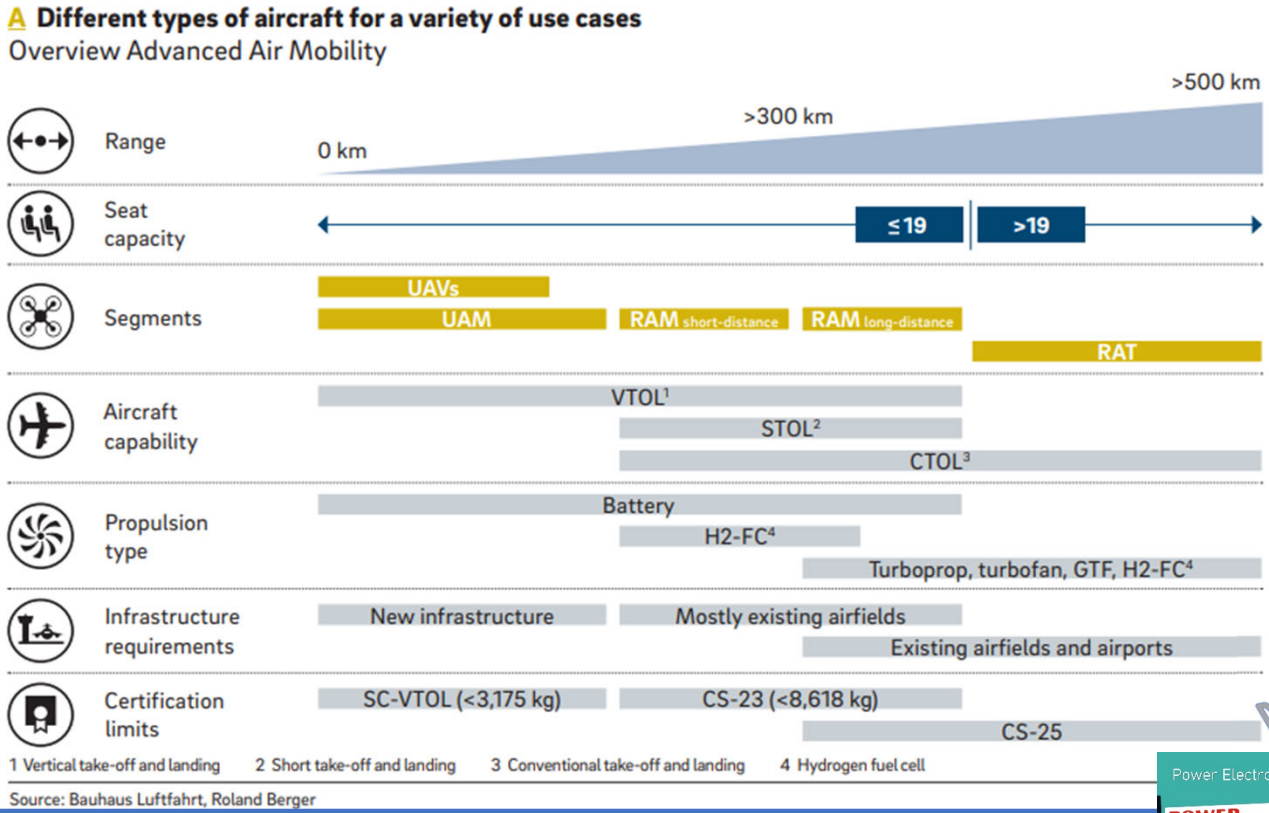


Patrick Koch
Leonardo Malburg

UNIVERSITY OF TWENTE.

The future of air travel

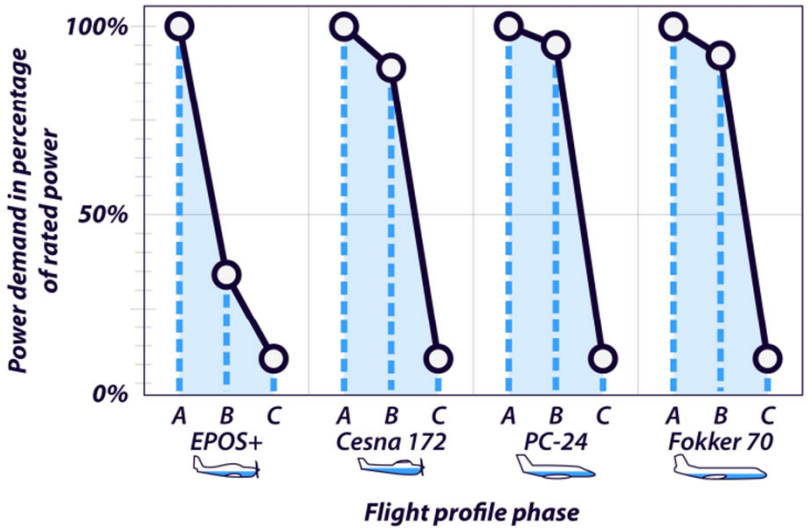
- 2035
- SAF
- Hydrogen
- Hybrid
- Full electric



Source: https://www.rolandberger.com/publications/publication_pdf/roland_berger_regional_air_mobility.pdf

The Electromagnetic environment

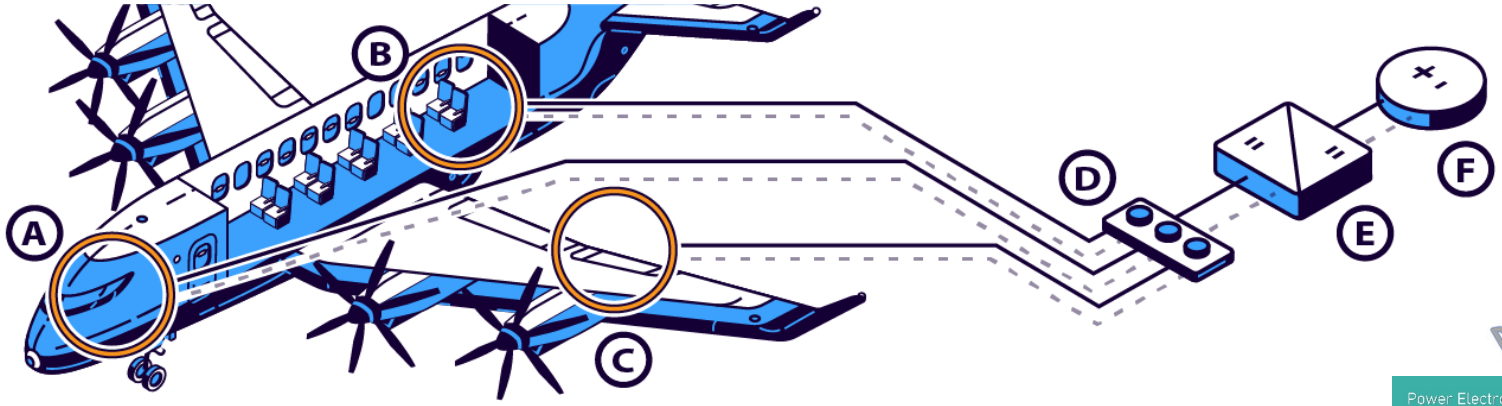
- A) Climb
- B) Cruise
- C) Descent



UNIVERSITY OF TWENTE.

The need for electrification

- Primary (Propulsion)
  - 10’s kW to 10 MW’s
- Secondary (Non propulsion)
  - 100’s W to 10’s kW’s



UNIVERSITY OF TWENTE.

The energy needed

Power needed

The energy needed

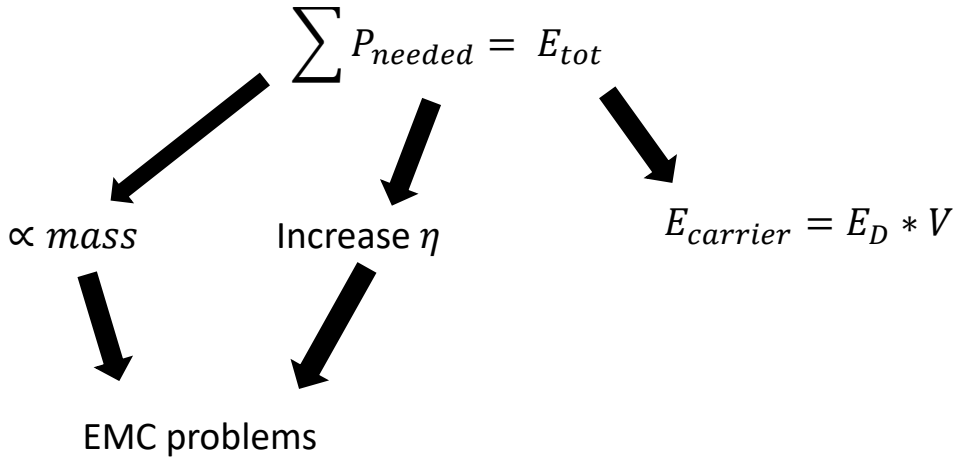
$$\sum P_{needed}$$

The energy needed

$$\sum P_{needed} = E_{tot}$$

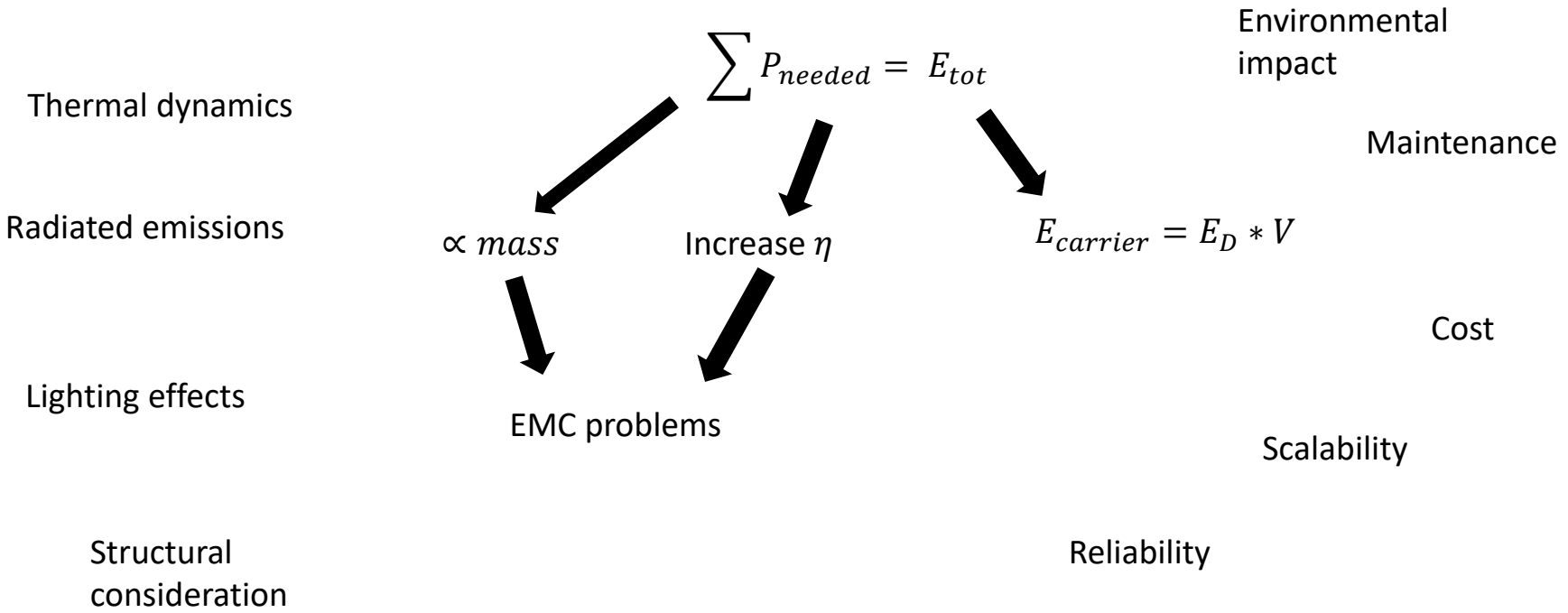
UNIVERSITY OF TWENTE.

The energy needed



UNIVERSITY OF TWENTE.

The energy needed

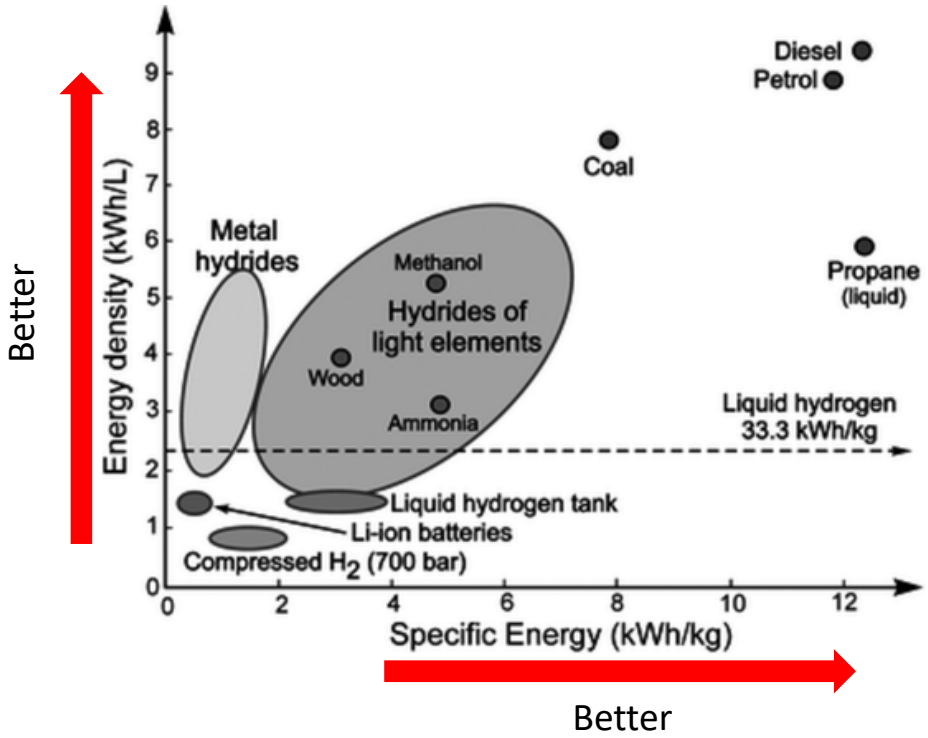


UNIVERSITY OF TWENTE.

The biggest hurdle

- Weight
- Volume

- How do we minimize that



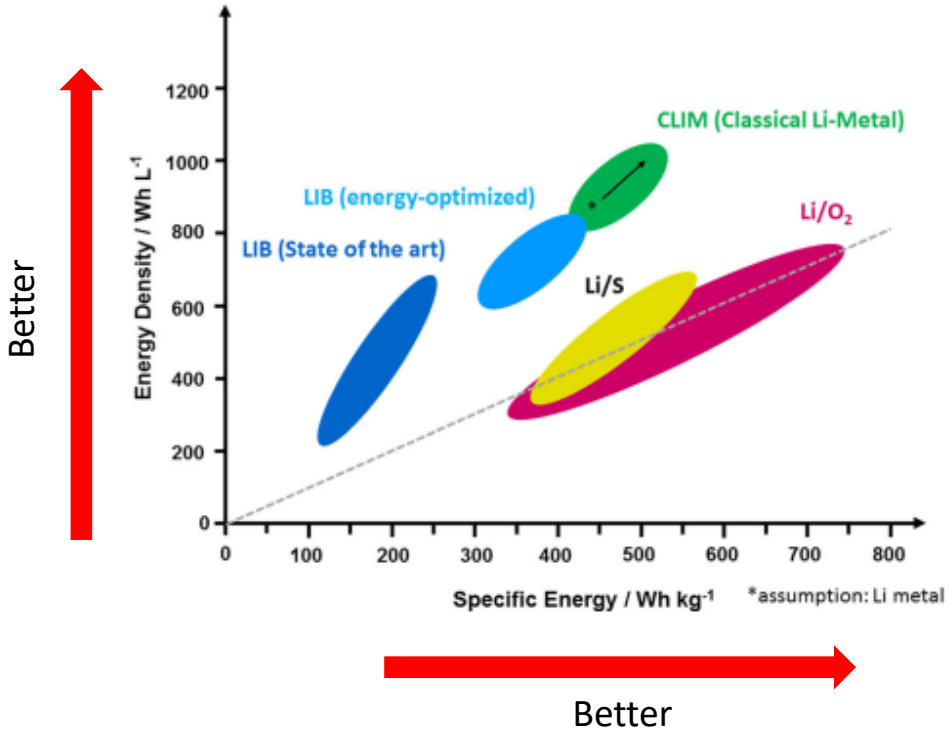
Source: 10.1007/978-3-662-03610-7

UNIVERSITY OF TWENTE.

The biggest hurdle

- Weight
- Volume

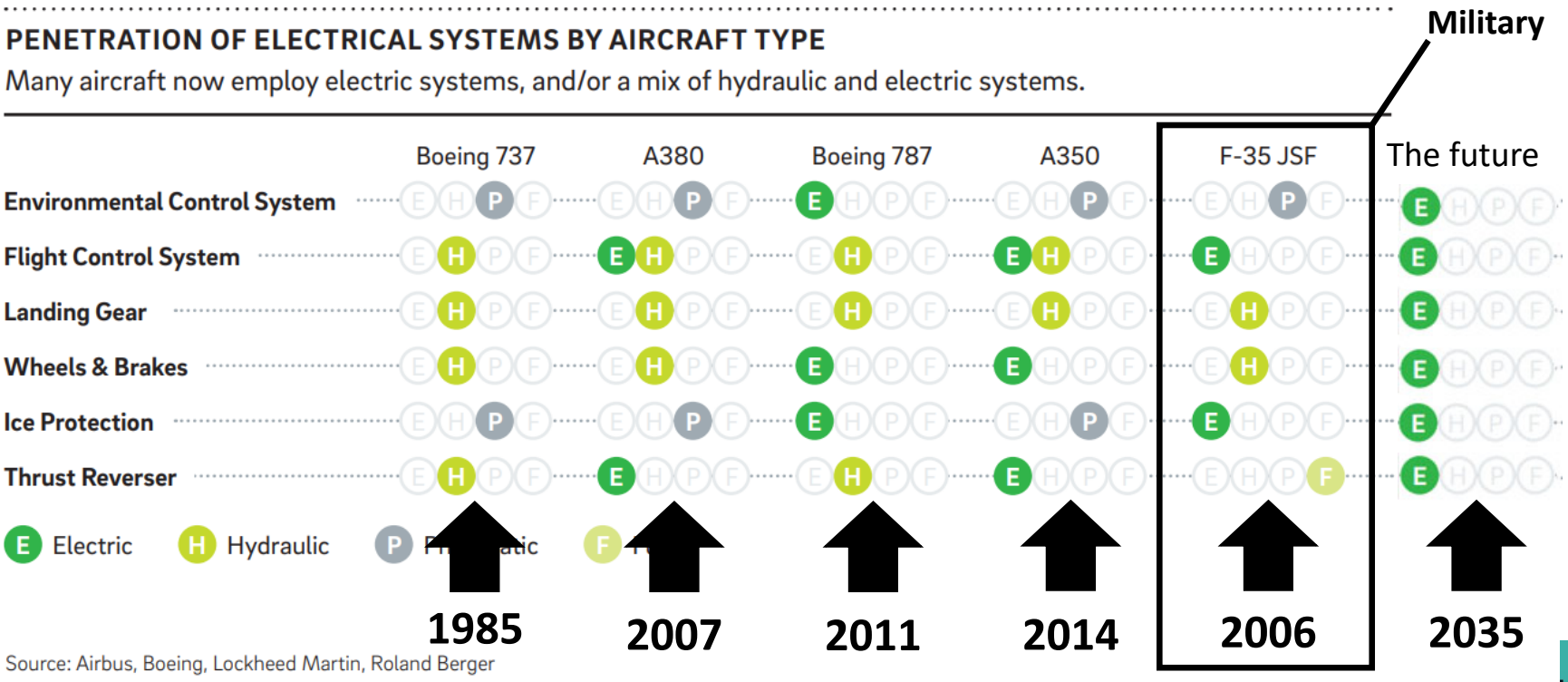
- How do we minimize that



Source: 10.1007/s00339-022-03610-7

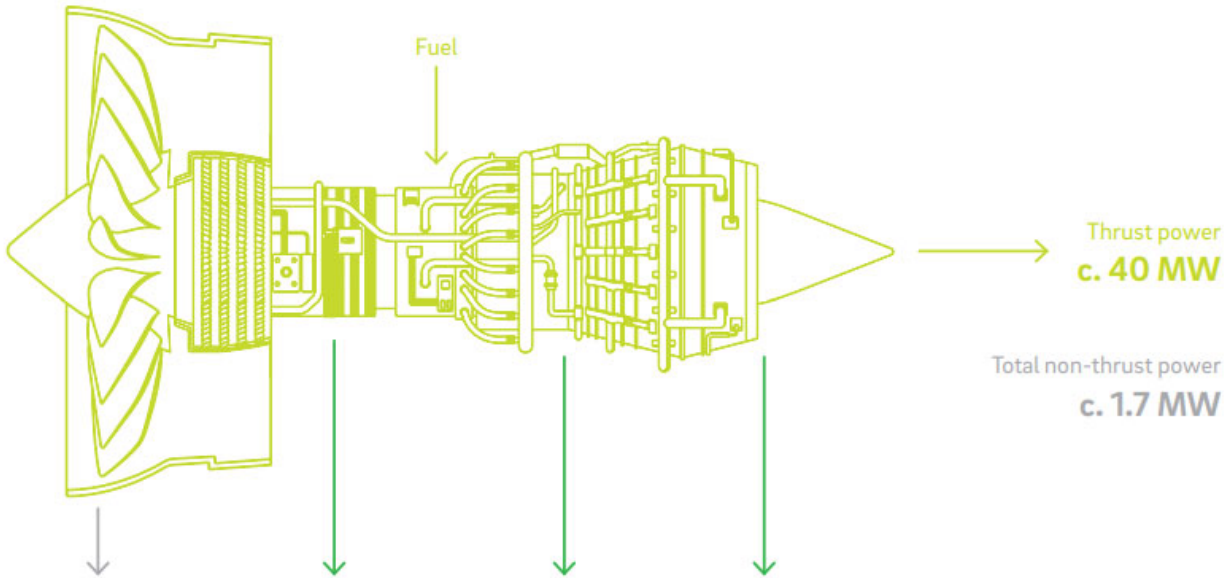
UNIVERSITY OF TWENTE.

But isn’t it already electric?



UNIVERSITY OF TWENTE.

How do they do it now?

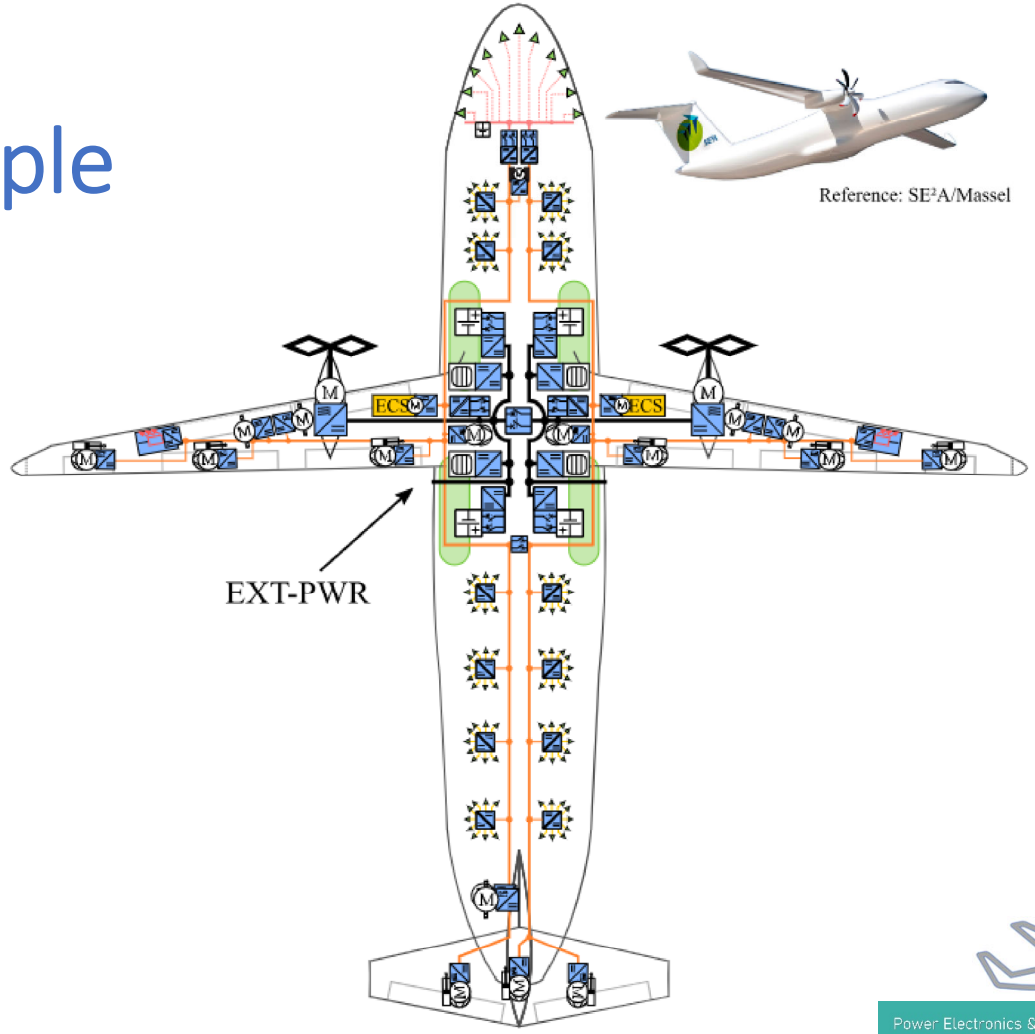


Source: University of Nottingham "Electrical Machines for Aerospace Applications", Roland Berger

UNIVERSITY OF TWENTE.

A distribution example

- HVDC/kHVDC
  - 570 Vdc – 1400 Vdc
- LVDC
  - 28Vdc – 400 Vdc
- DC/AC
  - Motor controllers
- Isolated DC/DC
  - Secondary loads

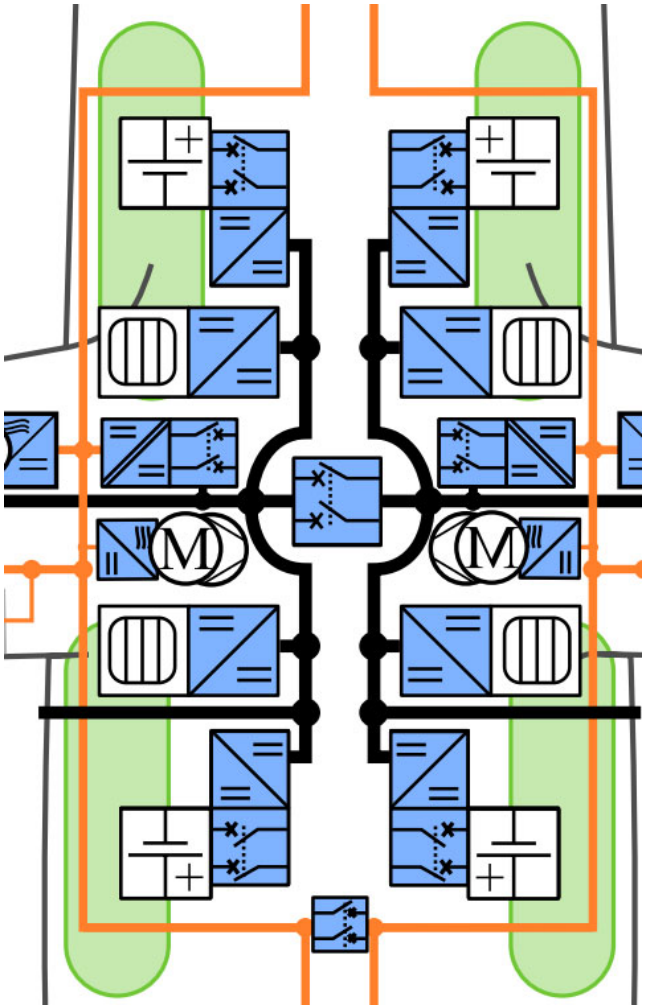


H. Schefer, L. Fauth, T. H. Kopp, R. Mallwitz, J. Friebe and M. Kurrat, "Discussion on Electric Power Supply Systems for All Electric Aircraft," in IEEE Access, vol. 8, pp. 84188-84216, 2020, doi: 10.1109/ACCESS.2020.2991804.

UNIVERSITY OF TWENTE.

A distribution example

- HVDC/kHVDC
  - 570 Vdc – 1400 Vdc
- LVDC
  - 28Vdc – 400 Vdc
- DC/AC
  - Motor controllers
- Isolated DC/DC
  - Secondary loads

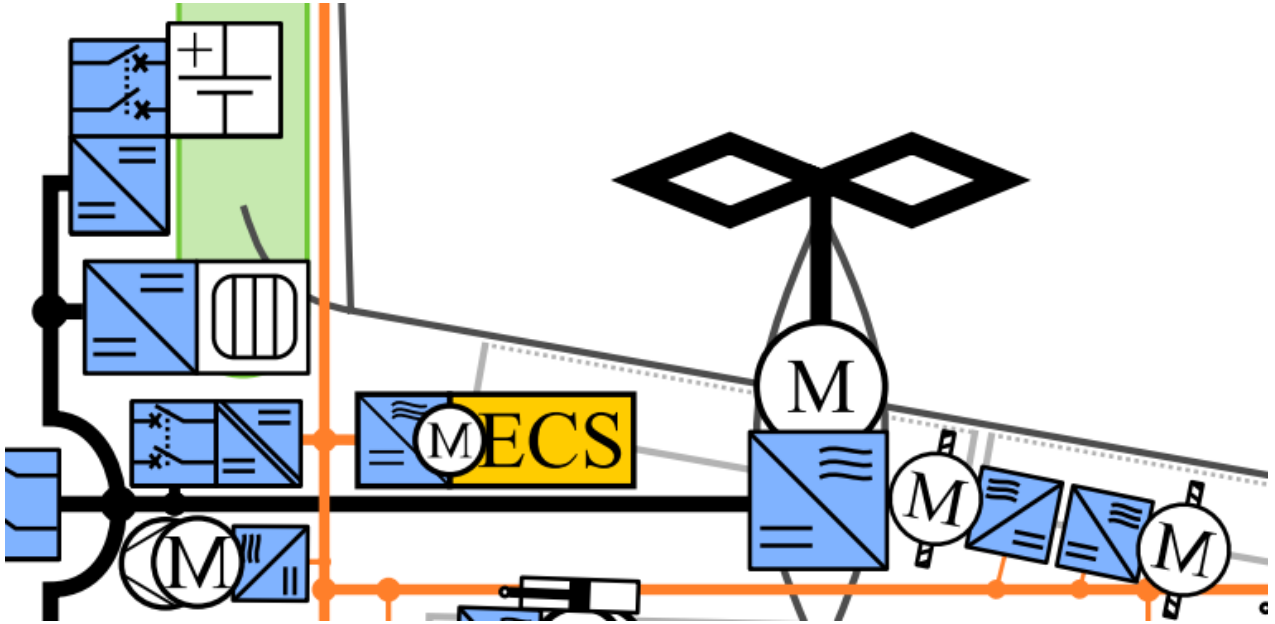


H. Schefer, L. Fauth, T. H. Kopp, R. Mallwitz, J. Friebe and M. Kurrat, "Discussion on Electric Power Supply Systems for All Electric Aircraft," in IEEE Access, vol. 8, pp. 84188-84216, 2020, doi: 10.1109/ACCESS.2020.2991804.

UNIVERSITY OF TWENTE.

A distribution example

- HVDC/kHVDC
  - 570 Vdc – 1400 Vdc
- LVDC
  - 28Vdc – 400 Vdc
- DC/AC
  - Motor controllers
- Isolated DC/DC
  - Secondary loads

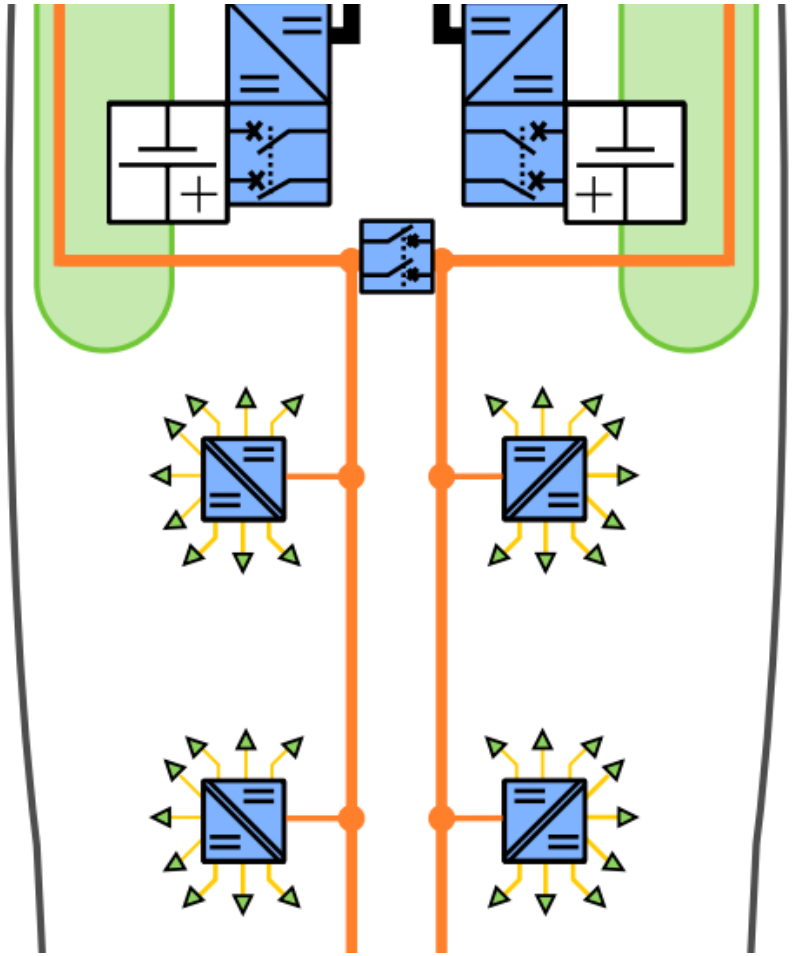


H. Schefer, L. Fauth, T. H. Kopp, R. Mallwitz, J. Friebe and M. Kurrat, "Discussion on Electric Power Supply Systems for All Electric Aircraft," in IEEE Access, vol. 8, pp. 84188-84216, 2020, doi: 10.1109/ACCESS.2020.2991804.

UNIVERSITY OF TWENTE.

A distribution example

- HVDC/kHVDC
  - 570 Vdc – 1400 Vdc
- LVDC
  - 28Vdc – 400 Vdc
- DC/AC
  - Motor controllers
- Isolated DC/DC
  - Secondary loads

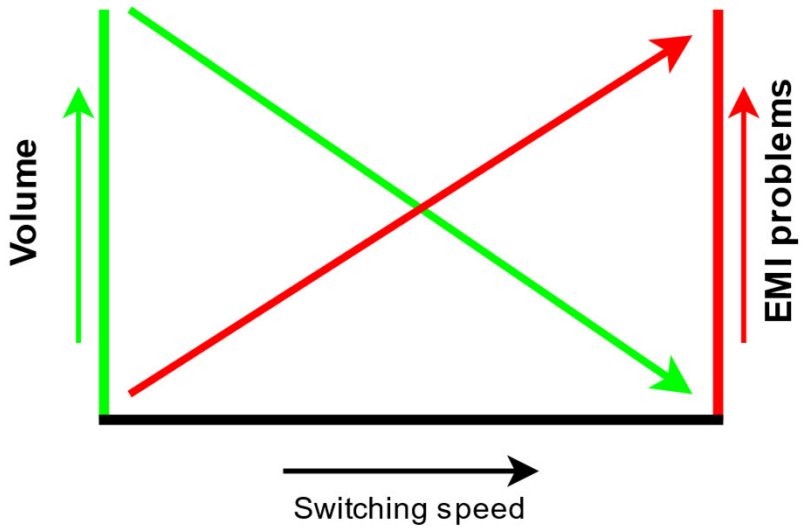


H. Schefer, L. Fauth, T. H. Kopp, R. Mallwitz, J. Friebe and M. Kurrat, "Discussion on Electric Power Supply Systems for All Electric Aircraft," in IEEE Access, vol. 8, pp. 84188-84216, 2020, doi: 10.1109/ACCESS.2020.2991804.

The intersection between PE and EMC

- Switching speeds
- Power levels
- All go up

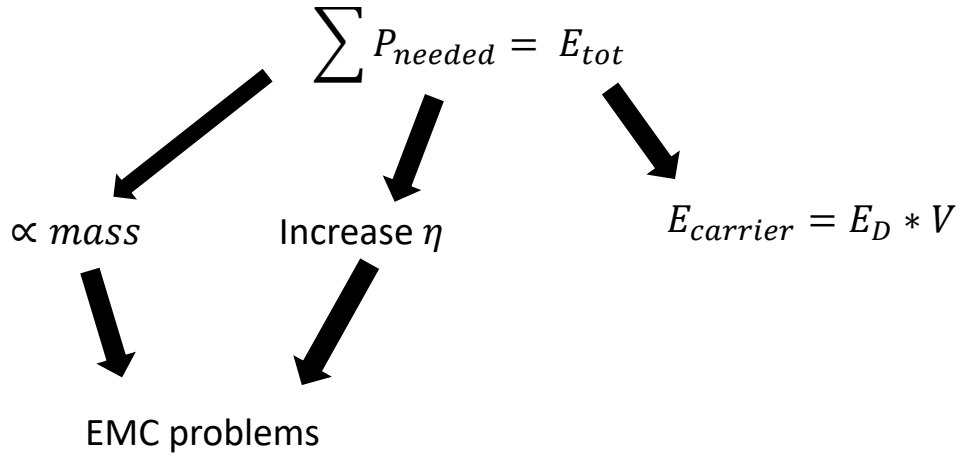
$$\sum P_{needed} = E_{tot}$$



UNIVERSITY OF TWENTE.

Increase of Efficiency

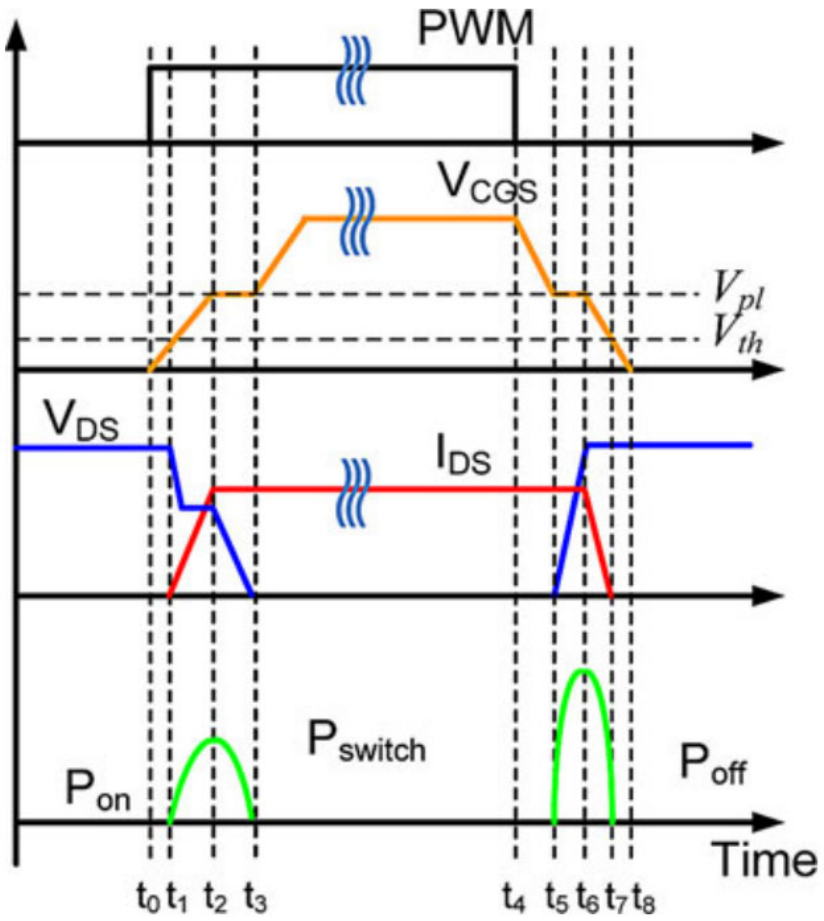
- Silicon
- Silicon Carbide
- Gallium Nitride



J. Fu, Z. Zhang, Y. -F. Liu, P. C. Sen and L. Ge, "A New High Efficiency Current Source Driver With Bipolar Gate Voltage," in IEEE Transactions on Power Electronics, vol. 27, no. 2, pp. 985-997, Feb. 2012, doi: 10.1109/TPEL.2010.2077741.

Increase of Efficiency

- Silicon
- Silicon Carbide
- Gallium Nitride

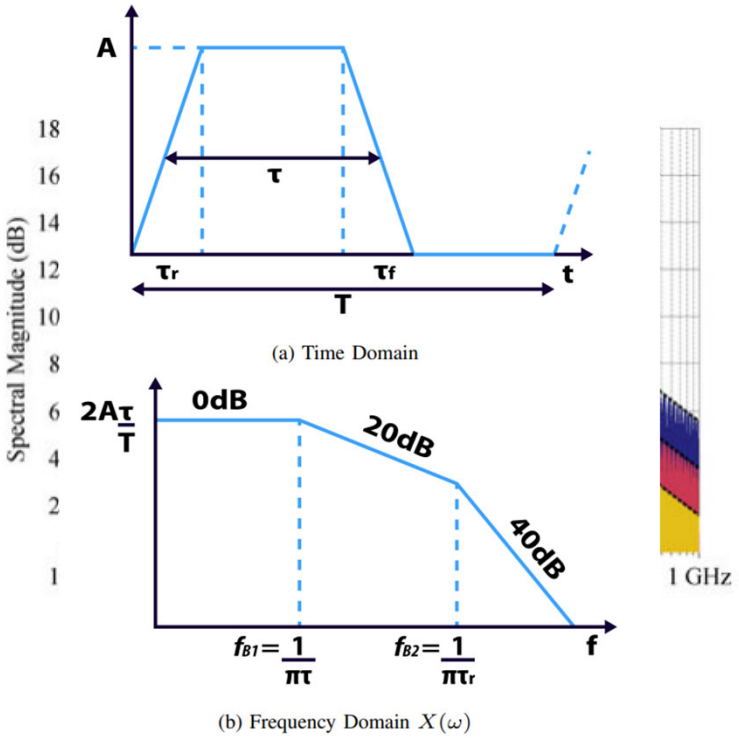


J. Fu, Z. Zhang, Y. -F. Liu, P. C. Sen and L. Ge, "A New High Efficiency Current Source Driver With Bipolar Gate Voltage," in IEEE Transactions on Power Electronics, vol. 27, no. 2, pp. 985-997, Feb. 2012, doi: 10.1109/TPEL.2010.2077741.

UNIVERSITY OF TWENTE.

Switching speed

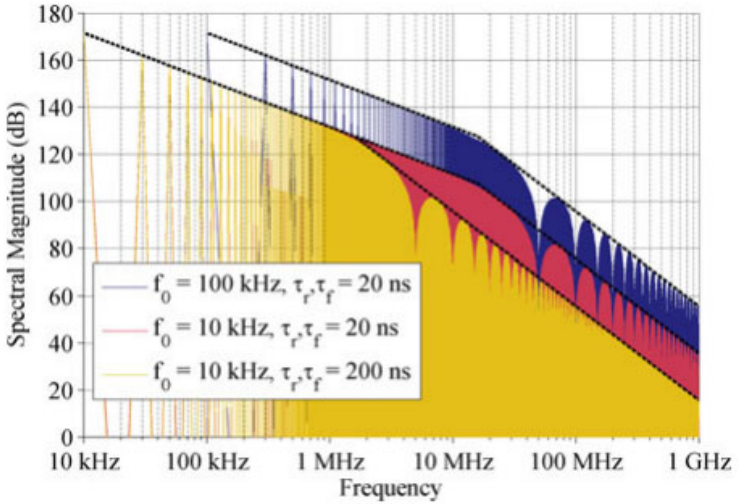
- Smaller size
- Higher emissions



L. Malburg, N. Moonen, J. L. Rotgerink and F. Leferink,

Switching speed

- Smaller size
- Higher emissions



L. Malburg, N. Moonen, J. L. Rotgerink and F. Leferink,

So how can we use it?

- Interleaving

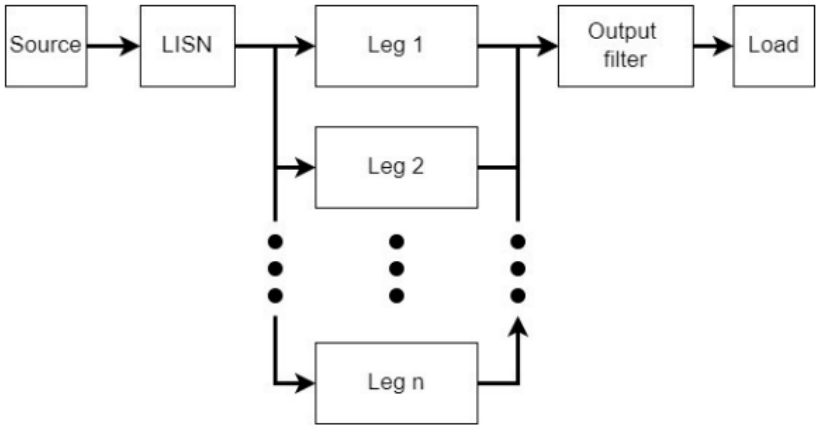
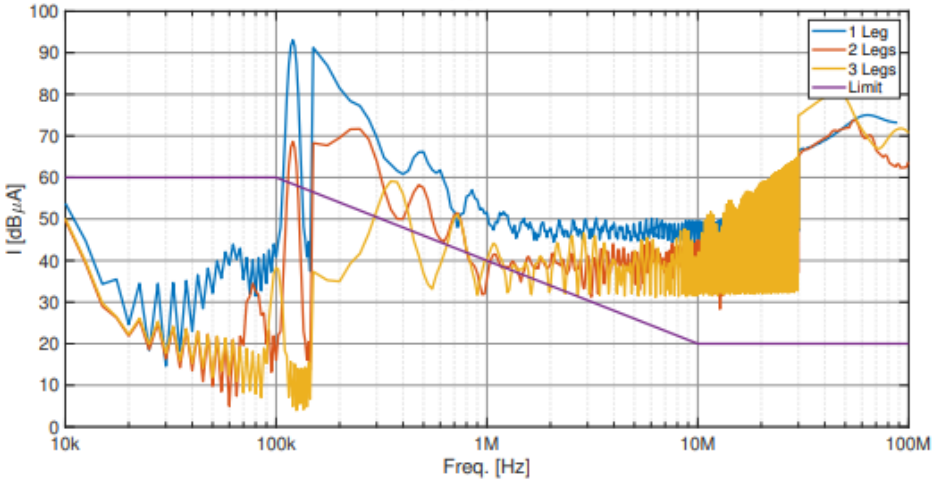


Fig. 3. Block diagram of a standard interleaved forward converter, with LISN present

P. Koch, J. Dijkstra and N. Moonen, "Design of EMI Improved Isolated DC/DC Converter for Space-based Applications," 2022 International Symposium on Electromagnetic Compatibility – EMC Europe, Gothenburg, Sweden, 2022, pp. 484-489, doi: 10.1109/EMCEurope51680.2022.9900956.

So how can we use it?

- Interleaving



(b) Addition of an input capacitor

P. Koch, J. Dijkstra and N. Moonen, "Design of EMI Improved Isolated DC/DC Converter for Space-based Applications," 2022 International Symposium on Electromagnetic Compatibility – EMC Europe, Gothenburg, Sweden, 2022, pp. 484-489, doi: 10.1109/EMCEurope51680.2022.9900956.

So how can we use it?

- Interleaving

N-Legs	C_1 (μF)	L_1 (μH)	C_d (mF)	R_d (Ω)	C_{pi} (nF)
1	300	10	3.0	0.1	300
2	60	1	0.6	0.2	500
3	10	0.6	0.05	0.2	300

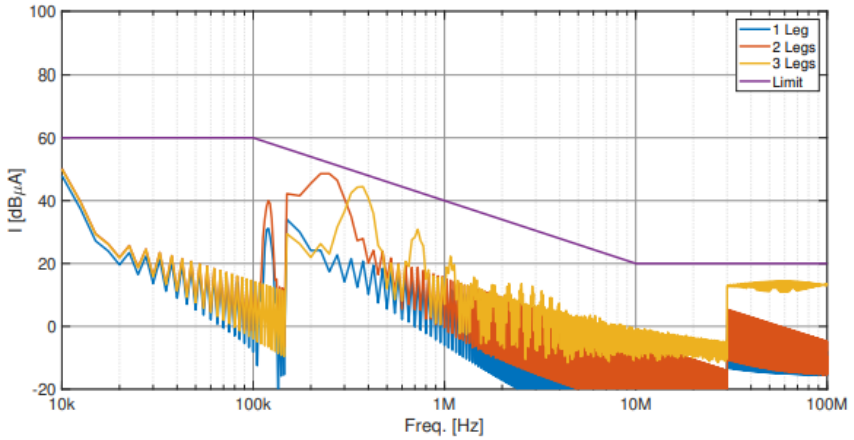
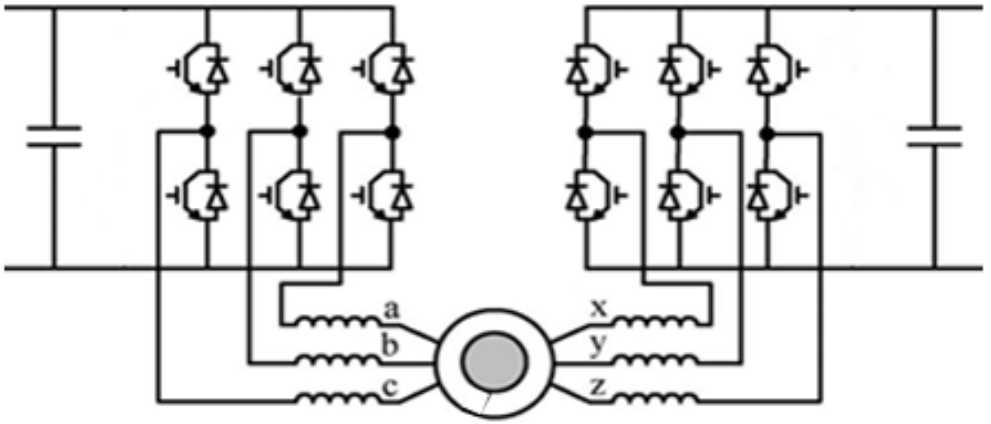


Fig. 11. DM noise after filtering

P. Koch, J. Dijkstra and N. Moonen, "Design of EMI Improved Isolated DC/DC Converter for Space-based Applications," 2022 International Symposium on Electromagnetic Compatibility – EMC Europe, Gothenburg, Sweden, 2022, pp. 484-489, doi: 10.1109/EMCEurope51680.2022.9900956.

Power Levels

- 1.26 MW

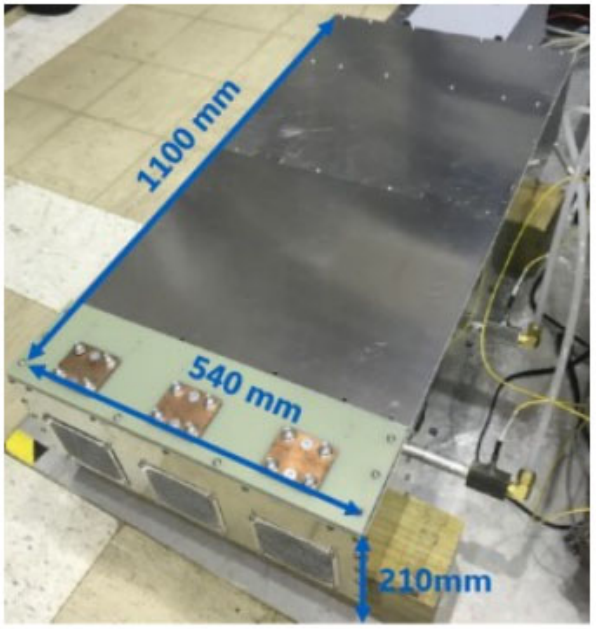


Dual-bridge Converter

D. Zhang, J. He, D. Pan, M. Dame and M. Schutten, "Development of A High-Power Density Megawatt-Scale Medium-Voltage Power Converter for Aircraft Hybrid-Electric Propulsion Systems," 2019 AIAA/IEEE Electric Aircraft Technologies Symposium (EATS), Indianapolis, IN, USA, 2019, pp. 1-6, doi: 10.2514/6.2019-4472.

Power Levels

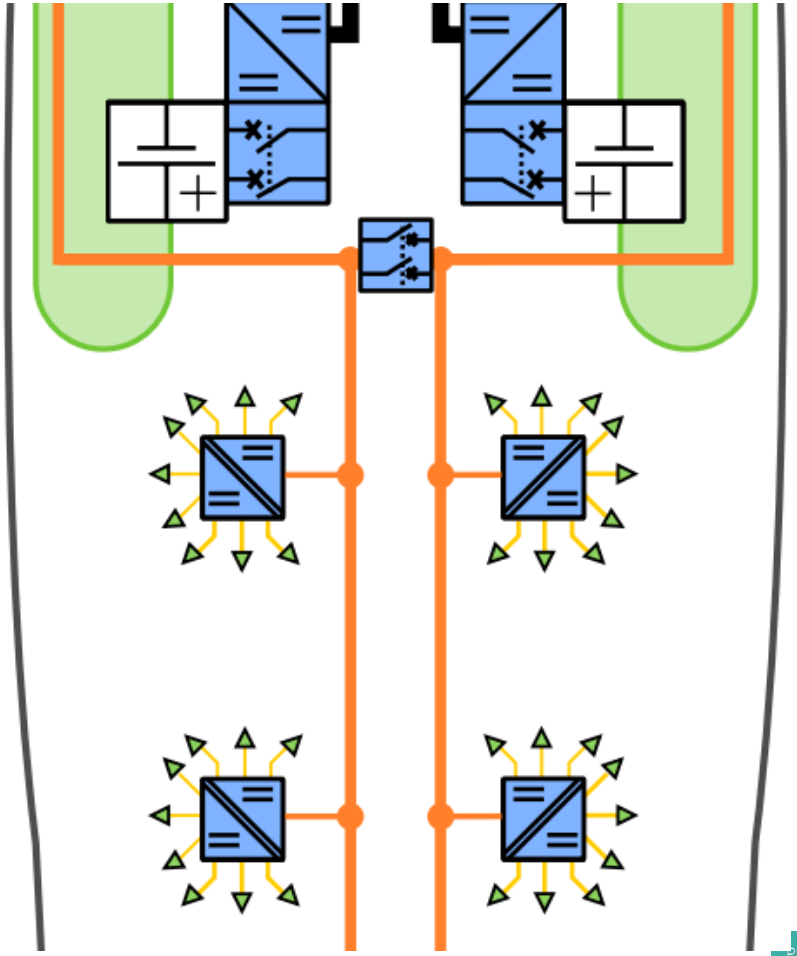
- 1.26 MW



- Weight common mode choke?
  - 10-20 kg

D. Zhang, J. He, D. Pan, M. Dame and M. Schutten, "Development of A High-Power Density Megawatt-Scale Medium-Voltage Power Converter for Aircraft Hybrid-Electric Propulsion Systems," 2019 AIAA/IEEE Electric Aircraft Technologies Symposium (EATS), Indianapolis, IN, USA, 2019, pp. 1-6, doi: 10.2514/6.2019-4472.

Multi-output Filter



H. Schefer, L. Fauth, T. H. Kopp, R. Mallwitz, J. Friebe and M. Kurrat, "Discussion on Electric Power Supply Systems for All Electric Aircraft," in IEEE Access, vol. 8, pp. 84188-84216, 2020, doi: 10.1109/ACCESS.2020.2991804.

Multi-output Filter

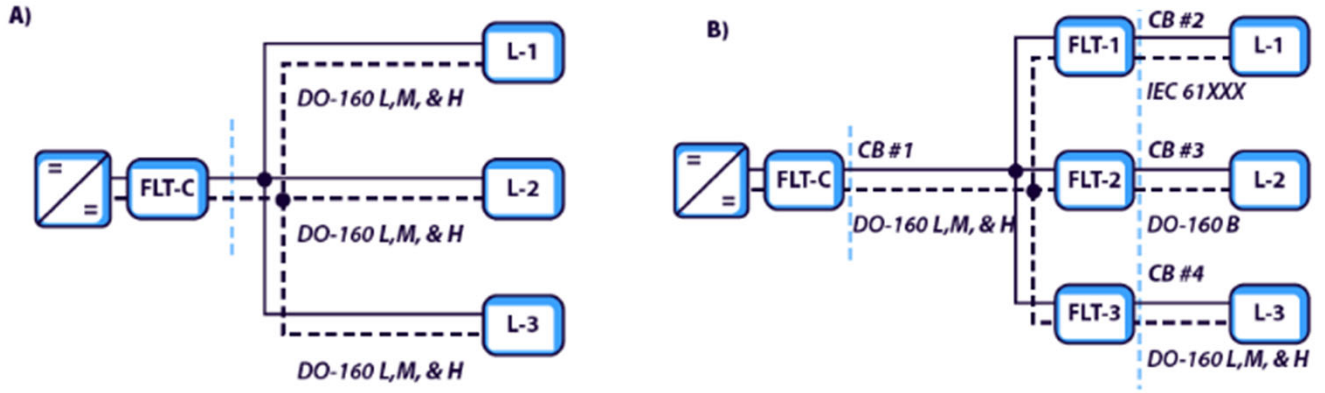
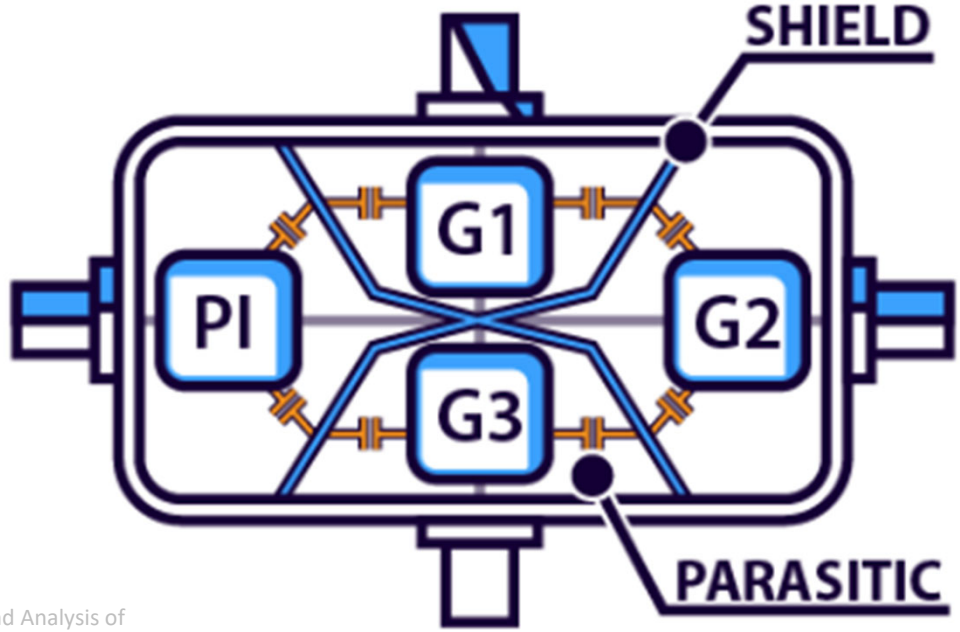


Fig. 2. Schematic comparing individual (A) and multi-output filter (B). Where in A), all filter designs are subjected to the same standard. In B), the implementation of current boundaries (CB 1-4) decouples the EMI allowing the designs to rely on different standards.

P. Koch, L. Malburg and N. Moonen, "Design and Analysis of Multi-Output EMI Filter for Zoning in Complex Electromagnetic Environments of All Electric Aircraft," accepted for publication at PEASA 2023, Nottingham, UK

UNIVERSITY OF TWENTE.

Multi-output Filter

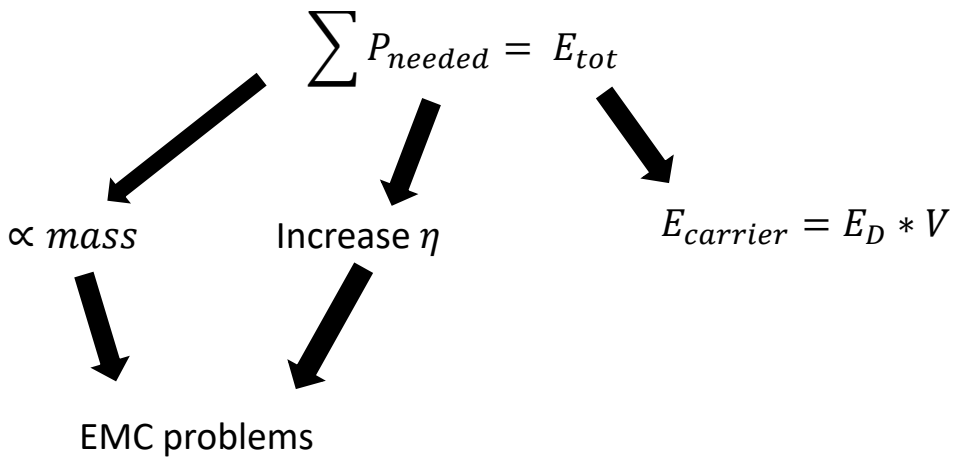


P. Koch, L. Malburg and N. Moonen, "Design and Analysis of Multi-Output EMI Filter for Zoning in Complex Electromagnetic Environments of All Electric Aircraft," accepted for publication at PEASA 2023, Nottingham, UK

UNIVERSITY OF TWENTE.

So when is it a marriage for success?

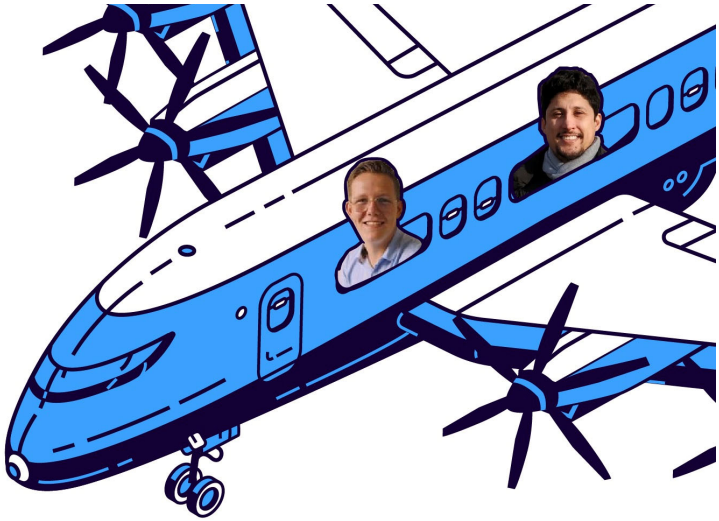
- Smart choices in PE
- EMC considered
- Coherent design



UNIVERSITY OF TWENTE.

Wrap up

- Any questions?



Patrick Koch
Leonardo Malburg

LUCHTVAART in transitie

UNIVERSITY OF TWENTE.

ENSIER