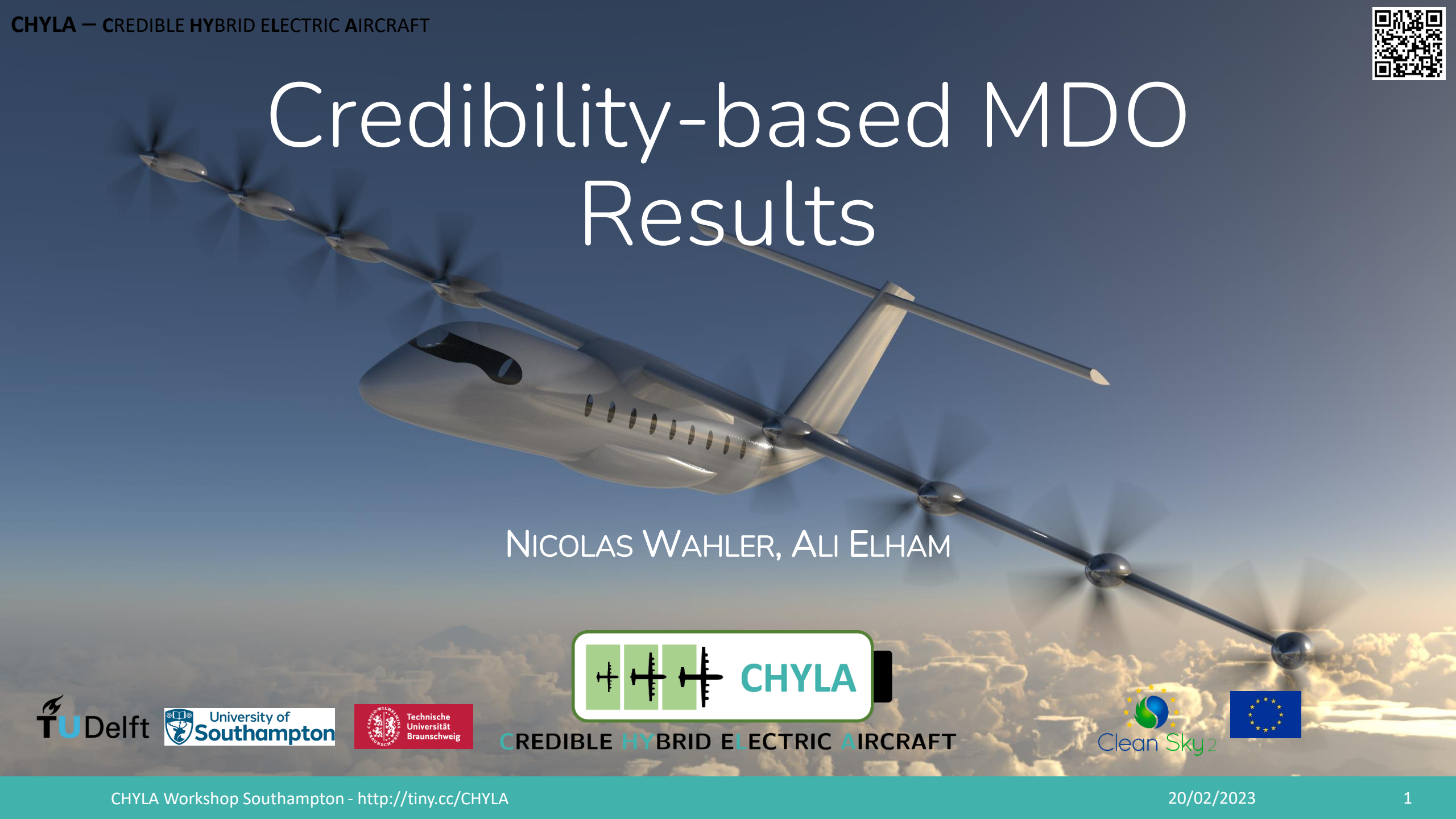
Credibility-based MDO Results



NICOLAS WAHLER, ALI ELHAM

CHYLA

CREDIBLE HYBRID ELECTRIC AIRCRAFT

Credibility Quantification

Credibility quantification

- Different parameters have different levels
  - Data
  - Forecasts
  - Variability
  - TRL
- Different approaches necessary for each type of data
- Determining what type of distribution is sensible or possible

Uncertain variables

- Energy storage
  - Gravimetric energy density of batteries
- Electric motors
  - Gravimetric power density of electrical machines
  - Volumetric power density of electrical machines
- Airframe parameters
  - Structural wing weight reductions
  - Area of laminar flow over the wing

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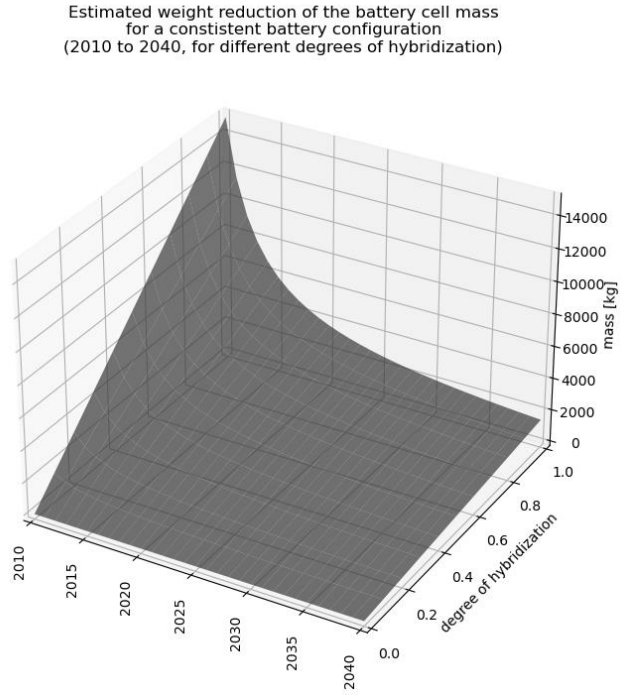
Battery gravimetric density

- Most challenging parameter for electric flight

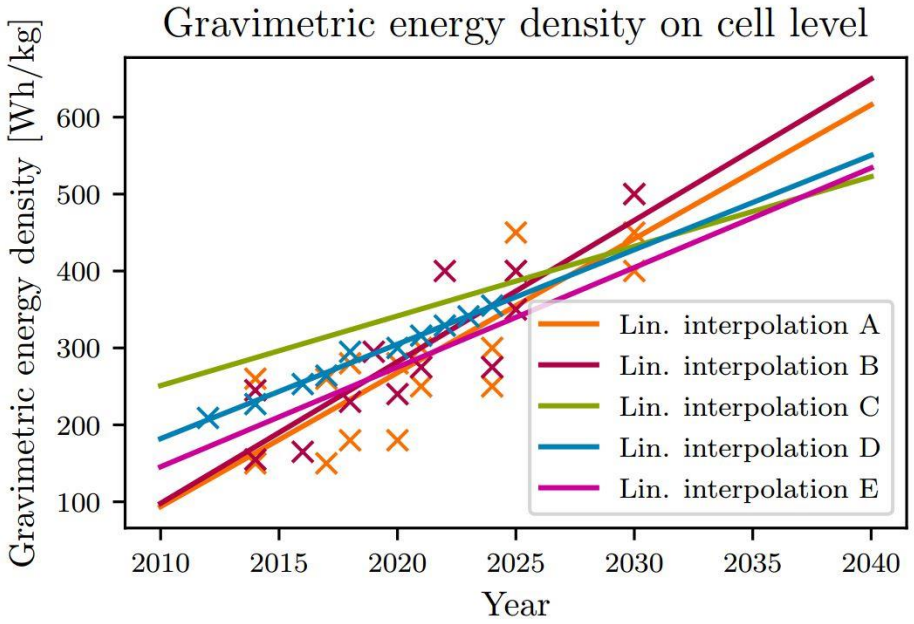
- Battery performance also dependent on cell composition
  - Generic approach necessary
  - Transformation from **cell** to **pack** level

- Lithium-based batteries will remain predominant
  - Advances in cathode and anode materials



Battery gravimetric density

- Future performance predictions
  - Wide range of literature
  - Range of applications for more robust results
- Time-based regression over datapoints
  - Linear interpolation for mean
  - Normal distribution for credibility



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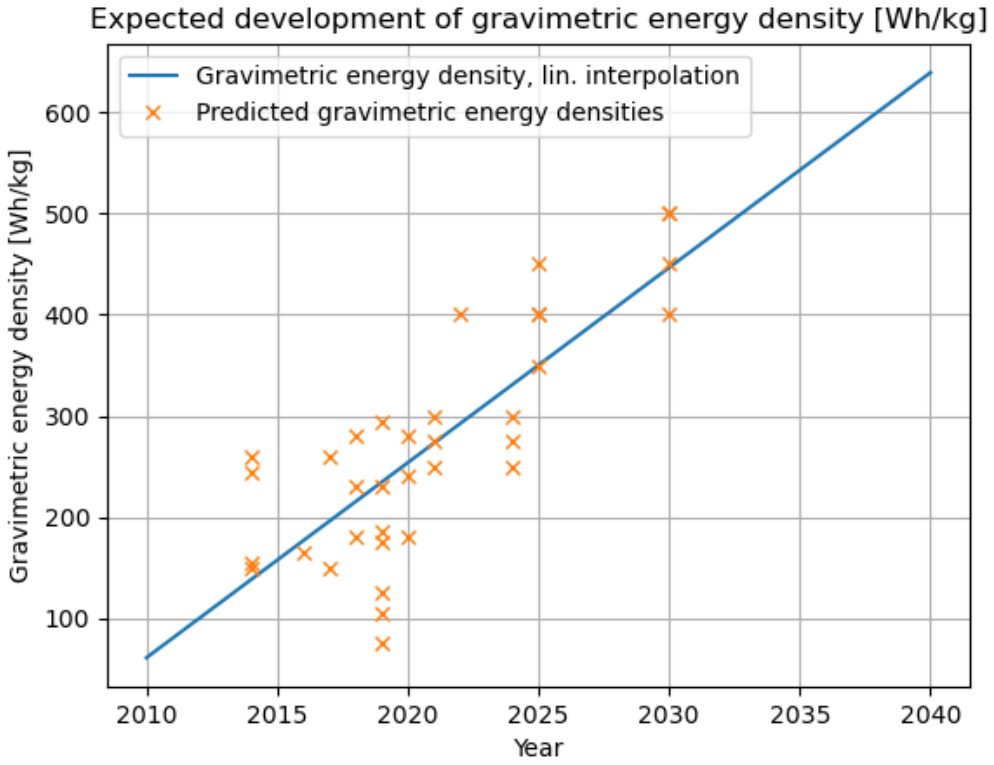
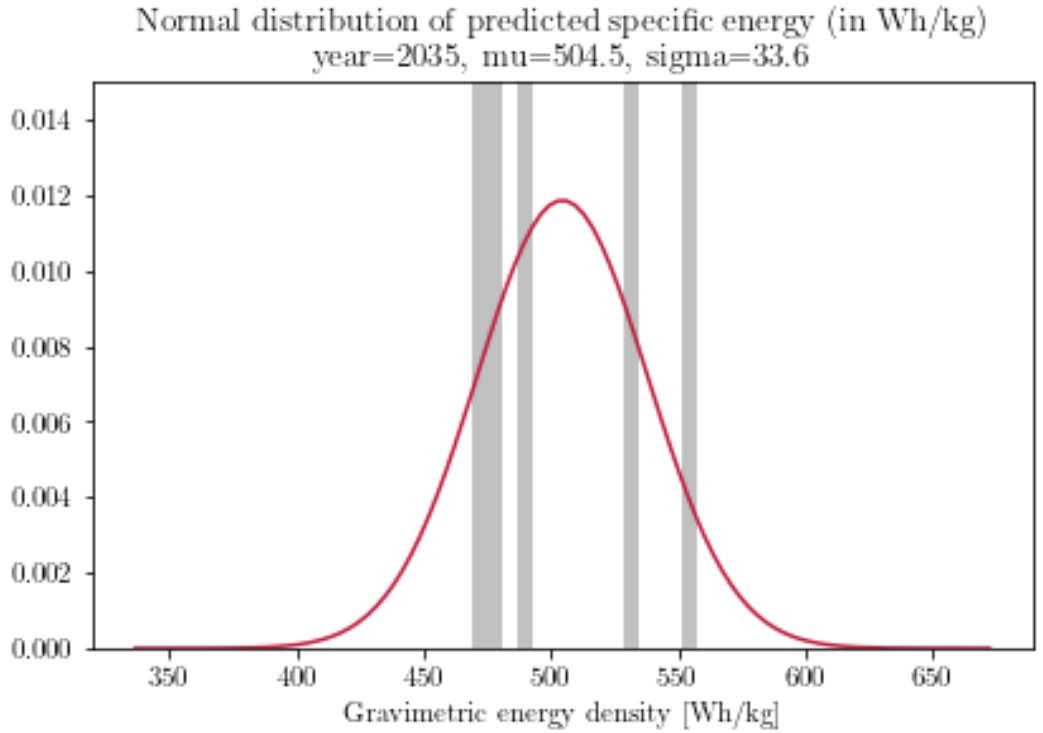
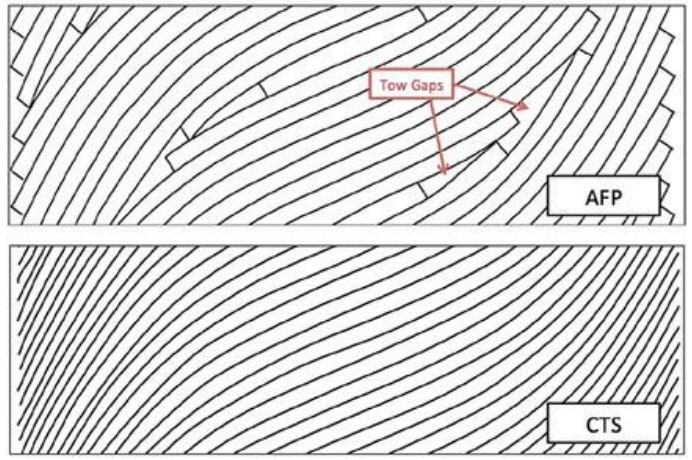
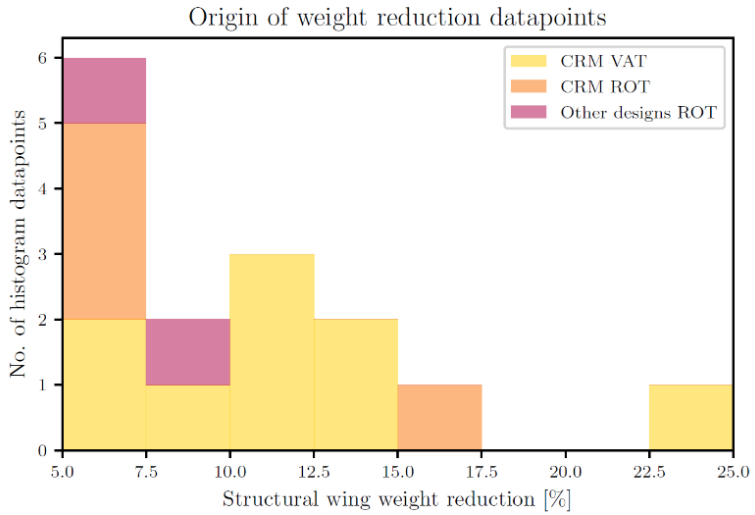




Structural weight reductions

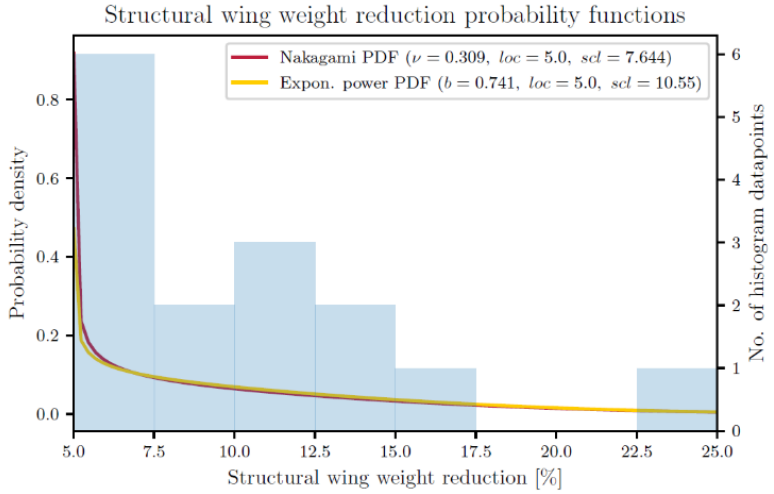
- Future optimisation in CFRP lay-up methods
- Better tailoring to required loads and stiffness
  - Ply rotation
  - Variable angle tow steering (1D & 2D)
- High-fidelity simulations and optimisations
  - NASA CRM wing design (AR-9 and AR-13.5)
  - Other wing applications (FEM)

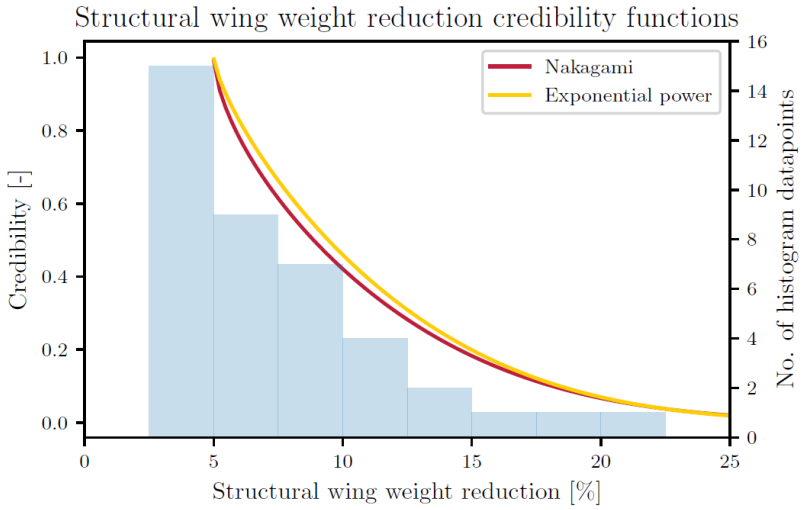




Curve fitting to credibility

- Fitting of best distribution with Kolmogorov-Smirnov test
  - Suitable due to scarcity of data
- Exponential functions best fit
- Sensible starting point and distribution
  - Small reductions still possible with optimisation of current methods





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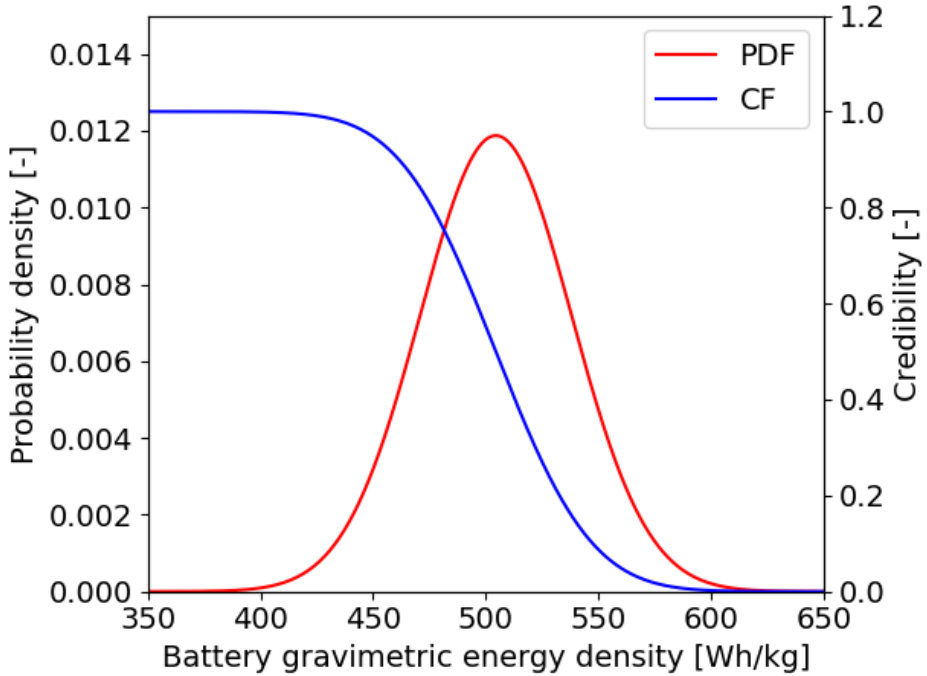

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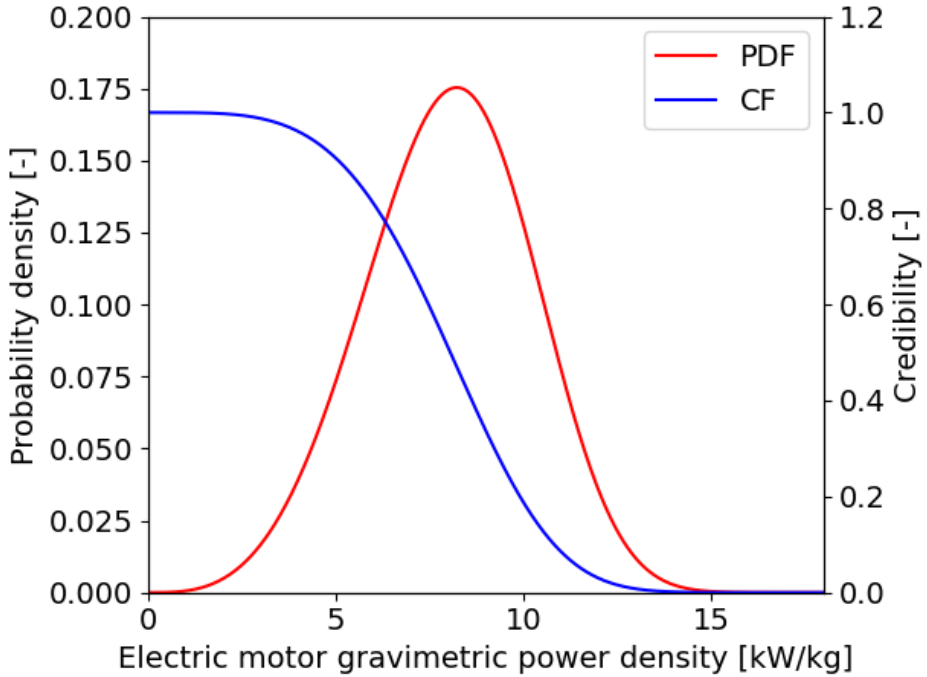

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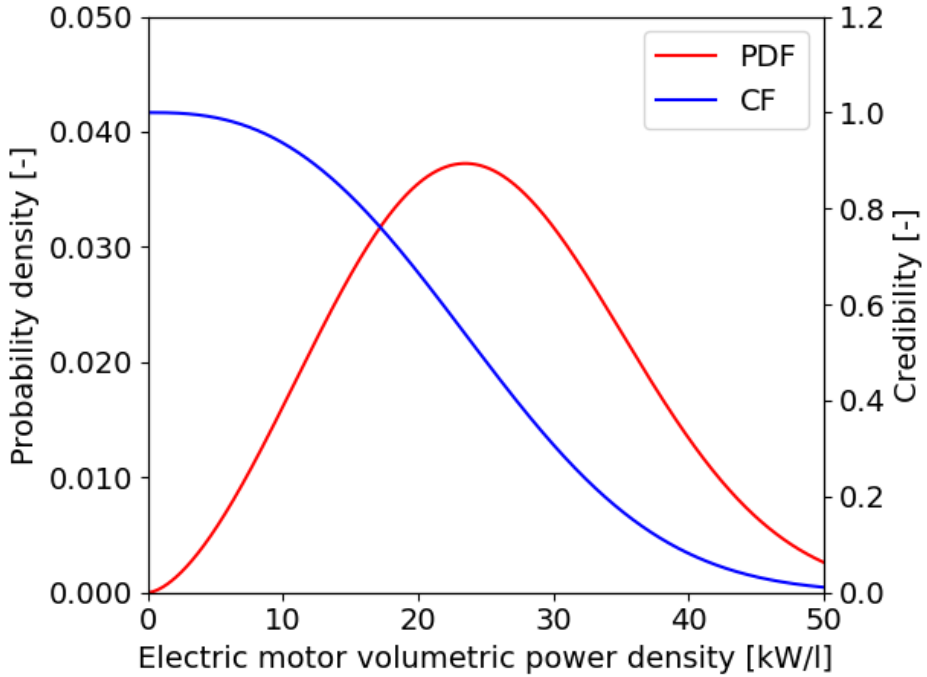

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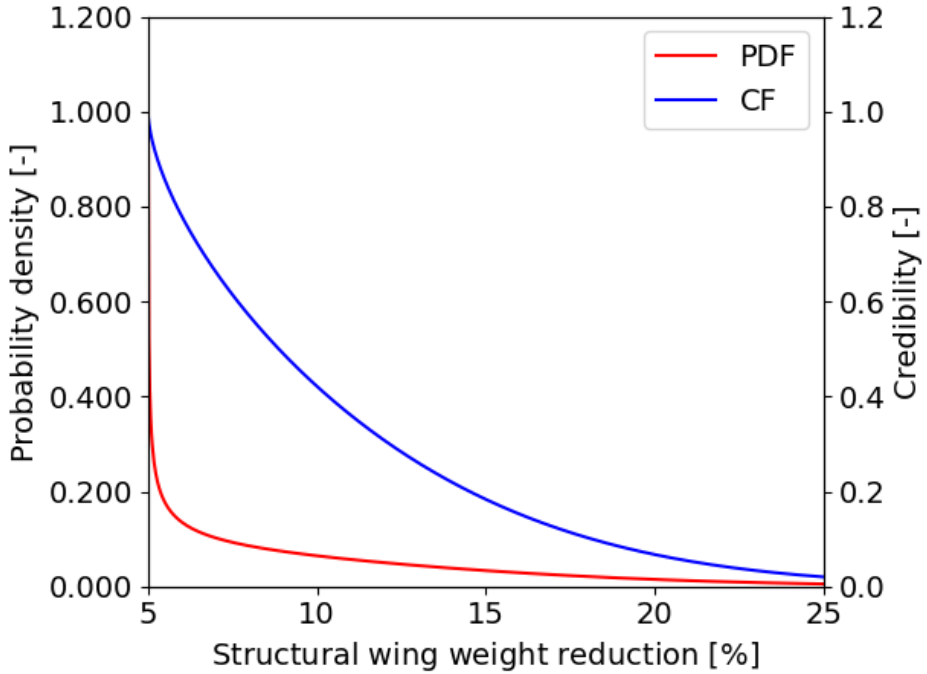

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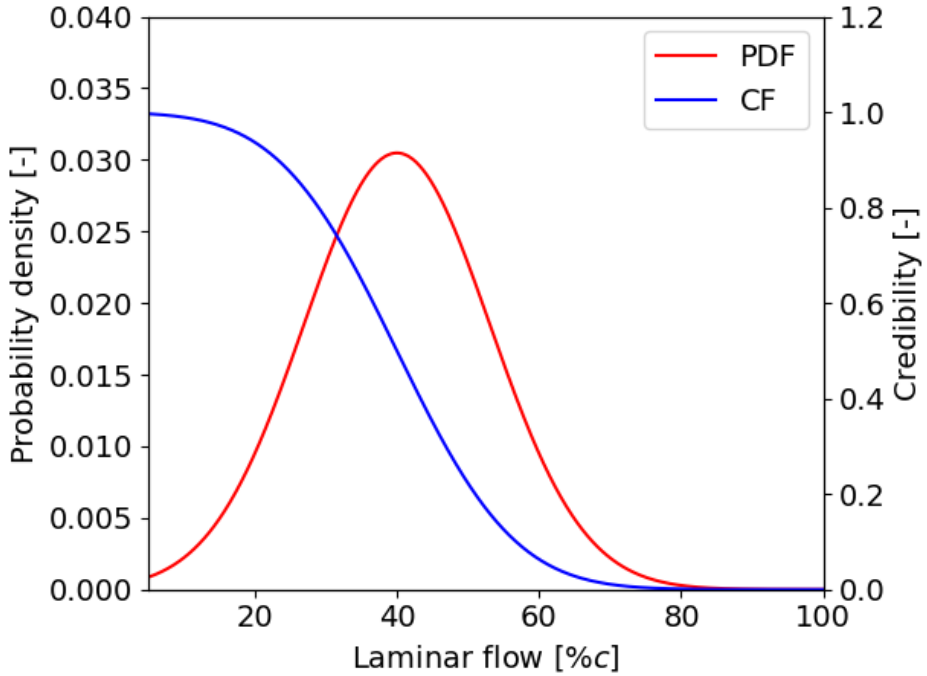

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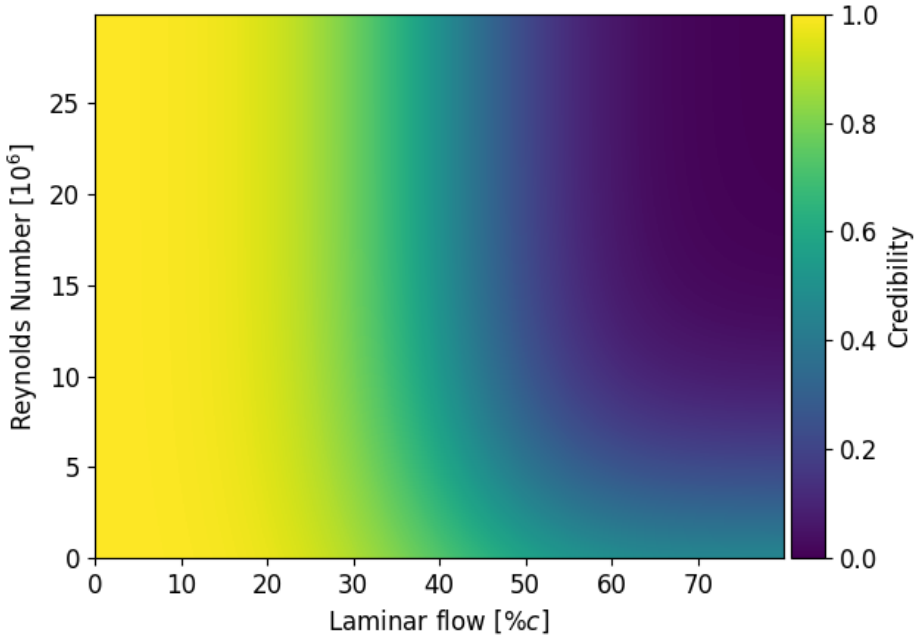
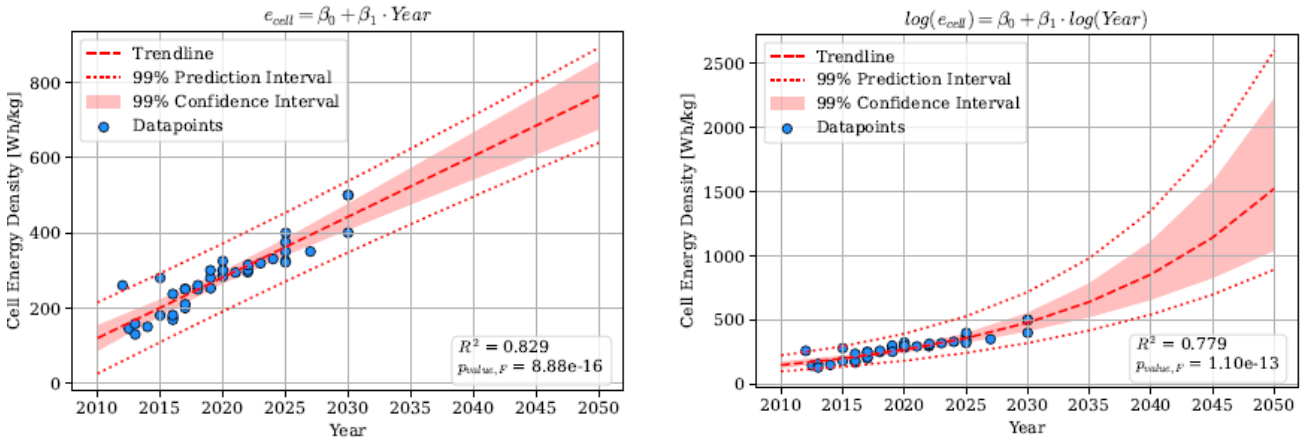
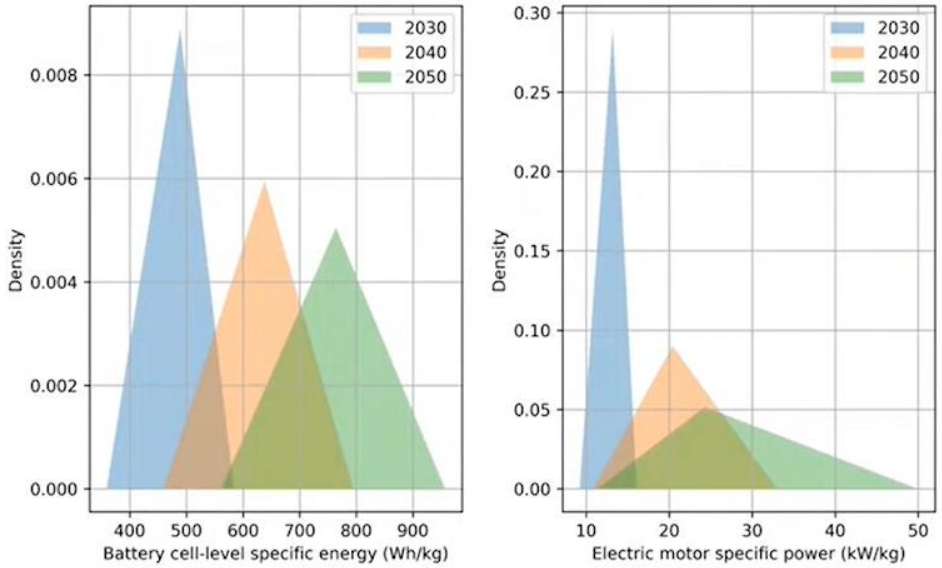


Verification with other literature

- Expected values 2035
  - Battery: 504 Wh/kg
  - Motor: 10.1 kW/kg



Spinelli, A., Krupa, G. P., & Kipouros, T. (2023). Set-Based Design Space Exploration to Investigate the Effect of Energy Storage Durability on the Energy Management Strategy of a Hybrid-Electric Aircraft. In *AIAA SCITECH 2023 Forum* (p. 0837).



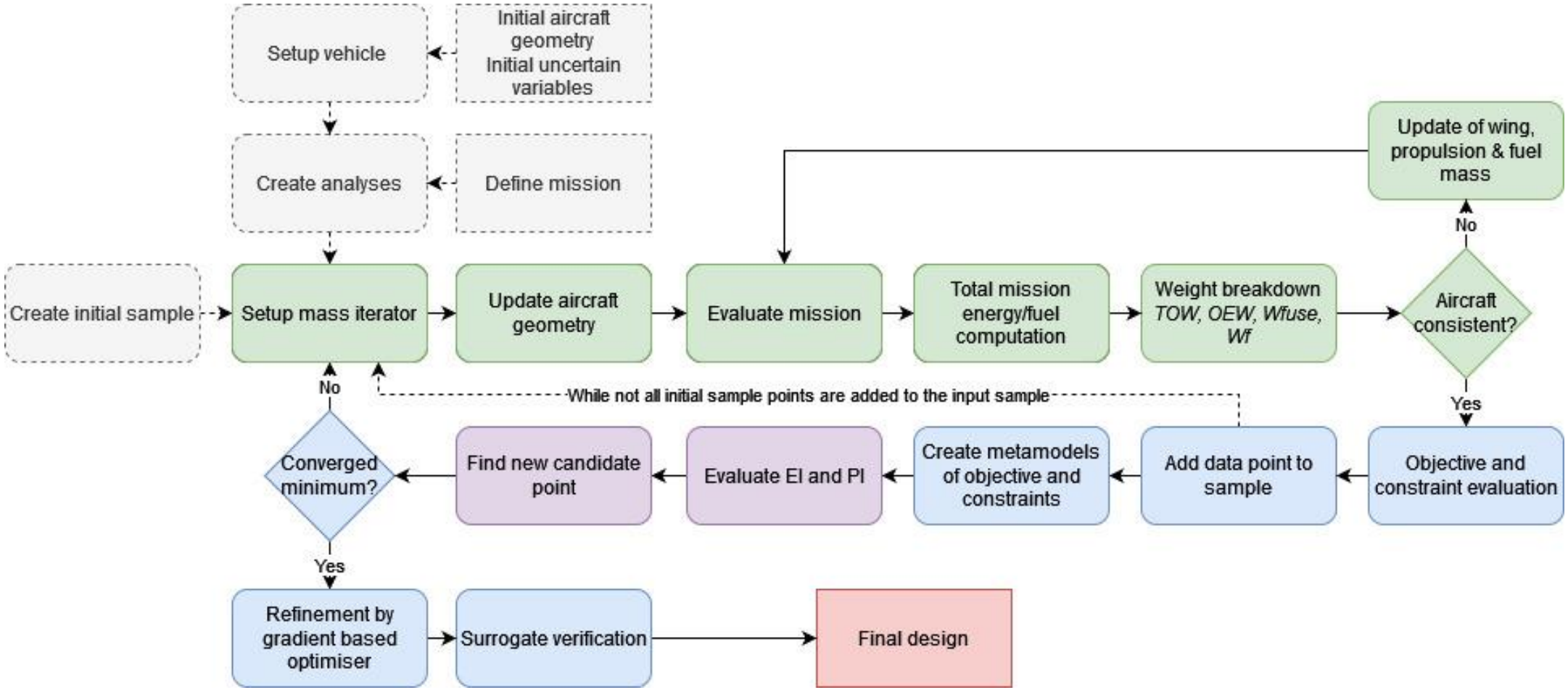
Uzodinma, J., Zaidi, T., Walter, M., Gautier, R., & Mavris, D. N. (2023). Uncertainty Quantification on a Parallel Hybrid-Electric Propulsion EPFD Vehicle. In *AIAA SCITECH 2023 Forum* (p. 0839).

Optimisation procedure

Credibility-based MDO

- In combination with an ‘optimised’ aircraft
  - Stage 2 of the design process
- Used to further explore potential and scalability vs. acceptable risk
- Sensitivity study for the given aircraft

Optimisation framework



Optimisation formulation

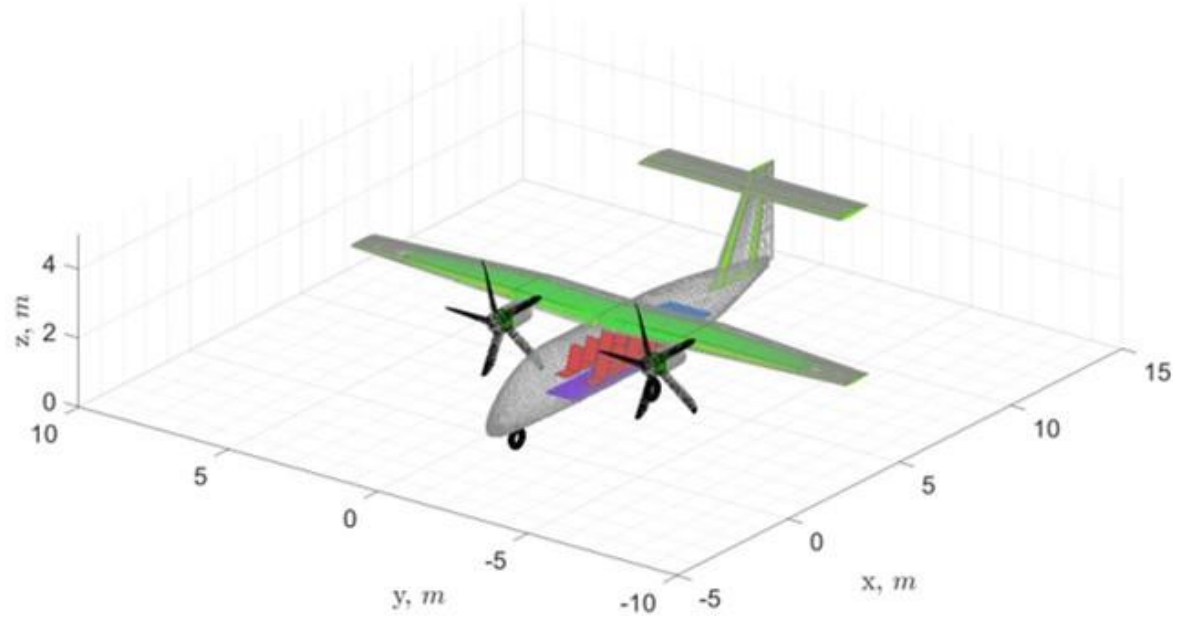
- Maximum mission range
- Uncertain parameter as inputs
- Credibility constraints
  - Per parameter
  - Average
- Fixed design point

$$
\begin{aligned}
\min \quad & -R \\
\text{s.t.} \quad & C_i \geq C_{i,l} \qquad \forall \mathrm{i} = 1, .., \mathrm{n} \\
& \frac{1}{n}\sum C_i \geq \frac{1}{n}\sum C_{i,l} \\
& MTOM \leq MTOM_l \\
\textit{or} \quad & b \leq b_l
\end{aligned}
$$

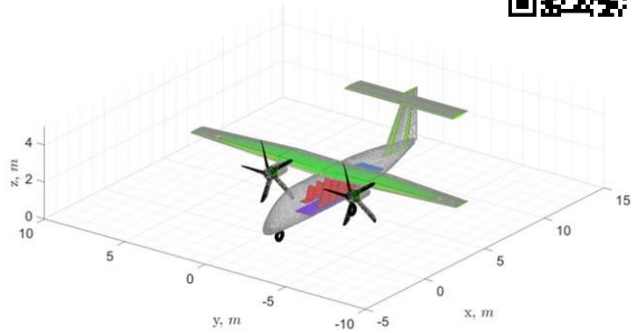
Results

Commuter case

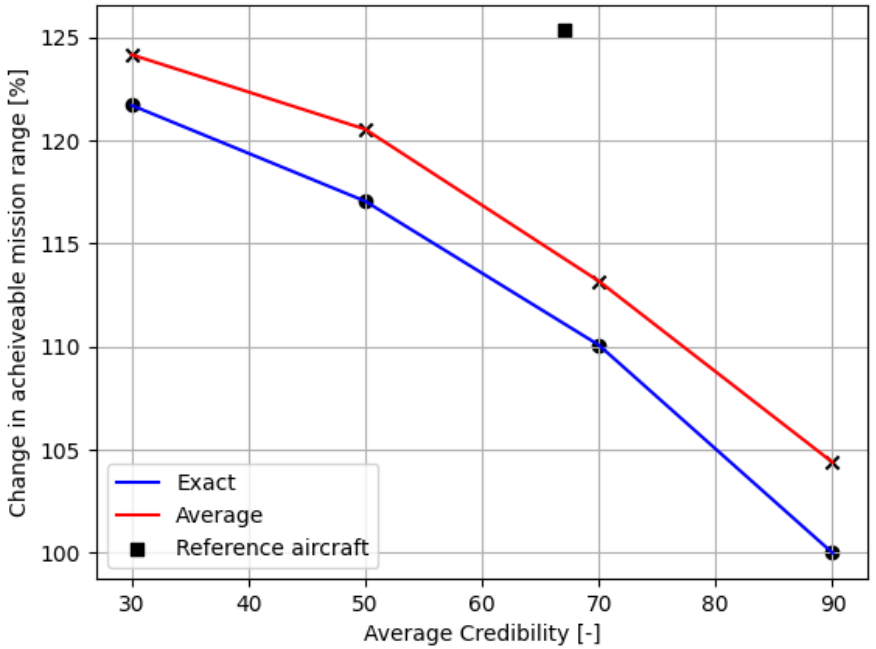
- EASA CS-23 commuter
  - 10 Passengers
  - Fully electric architecture
- Optimised for range
  - MTOM < 8618 kg (19,000lbs)
  - No reserve mission
- 19 Passenger concept in the future



Credibility-based optimisation



- Exact
  - Defined Credibility level
  - Only range is maximised
- Average
  - Component Credibility up to 10% less
  - Range and parameters optimized



Aircraft comparison – All parameters

Parameter	Reference	30% Cred	50% Cred	70% Cred	90% Cred
MTOM [kg]	8694	8620	8618	8612	8619
Wing [kg]	1087	722	768	807	826
Motor [kg]	313	117	121	121	131
Battery [kg]	2526	2908	2883	2858	2829
Area of Laminar Flow [%]	0 (100%)	67 (20%)	45 (60%)	31 (84%)	10 (98%)
Structural Wing Weight Red. [%]	0 (100%)	14.5 (20%)	10.4 (40%)	6.8 (68%)	5.1 (94%)
Battery Grav. Energy Density [Wh/kg]	643.5 (0.0017%)	530 (22%)	513 (40%)	496 (60%)	476 (80%)
Motor Grav. Power Density [kW/kg]	3.4 (99.7%)	9.0 (68%)	8.7 (72%)	8.7 (72%)	8.0 (80%)
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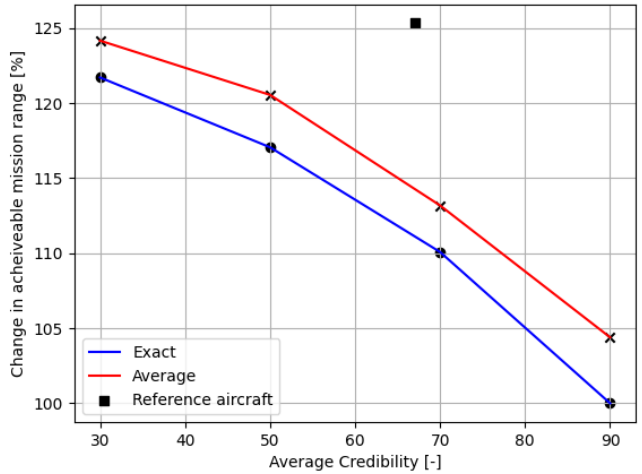

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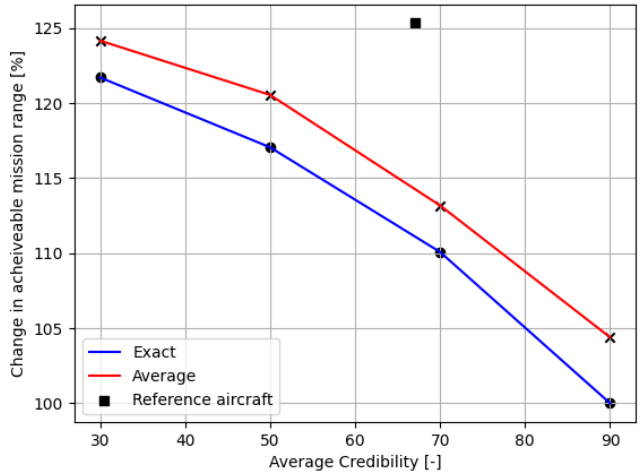

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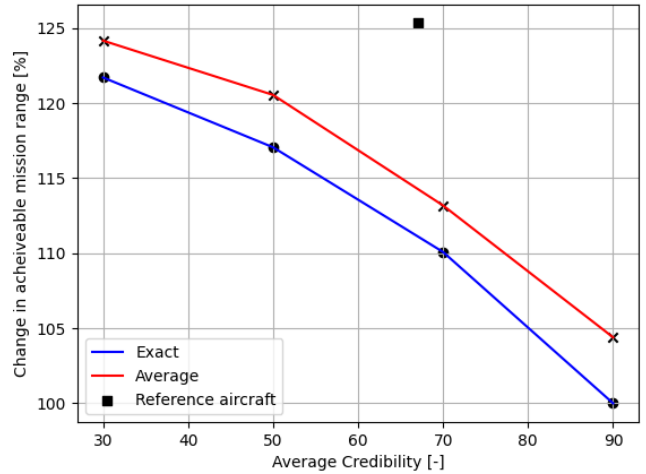

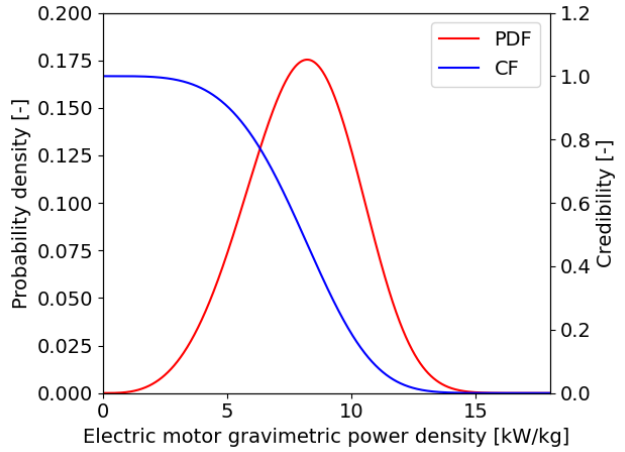

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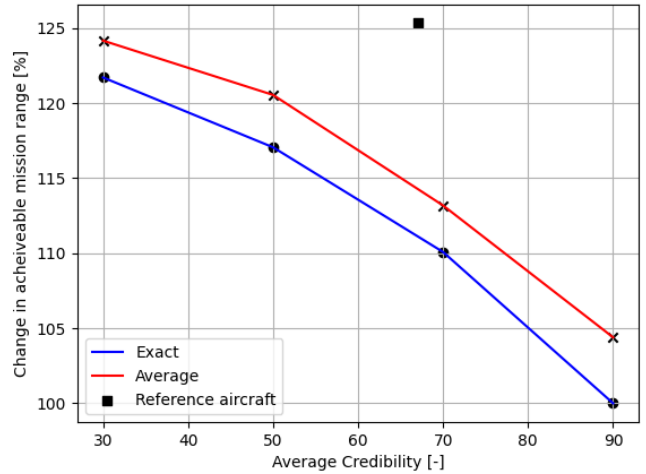

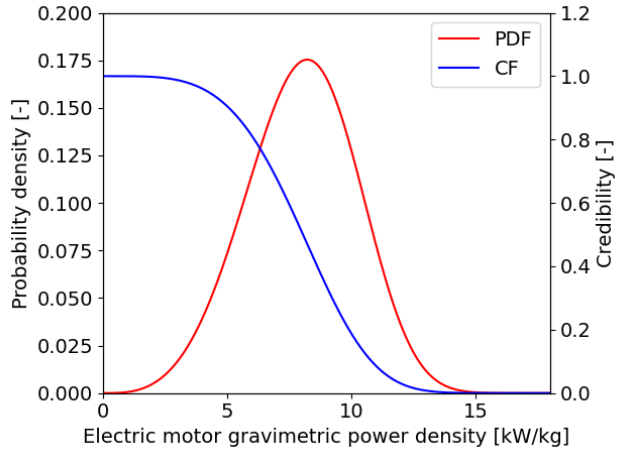

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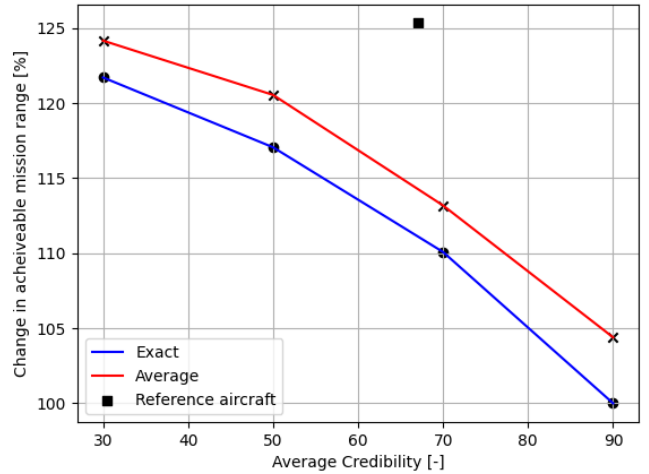

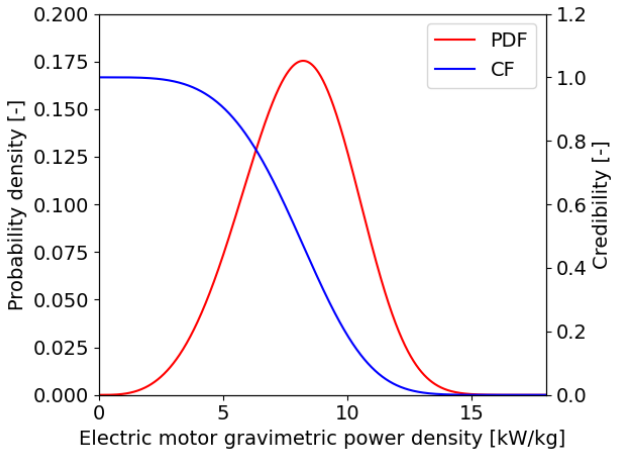

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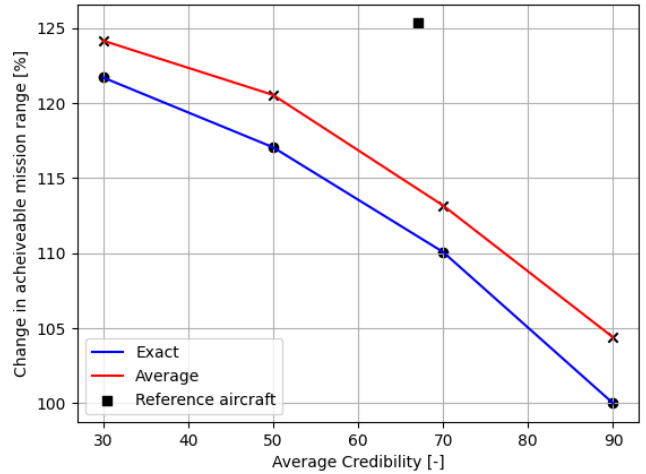

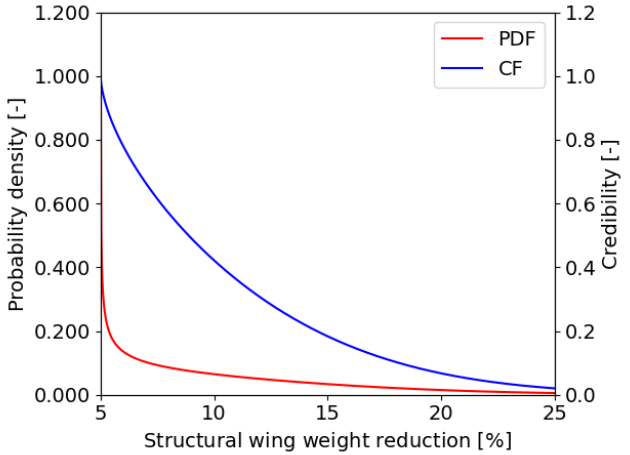

Thank you for your attention

CREDIBILITY-BASED MDO RESULTS

CHYLA

CREDIBLE HYBRID ELECTRIC AIRCRAFT