Structural Optimisation for Mass Estimation of Large-Aspect-Ratio Wings with Distributed Hybrid Propulsion

João Fernandes de Carvalho

Funded by the European Union

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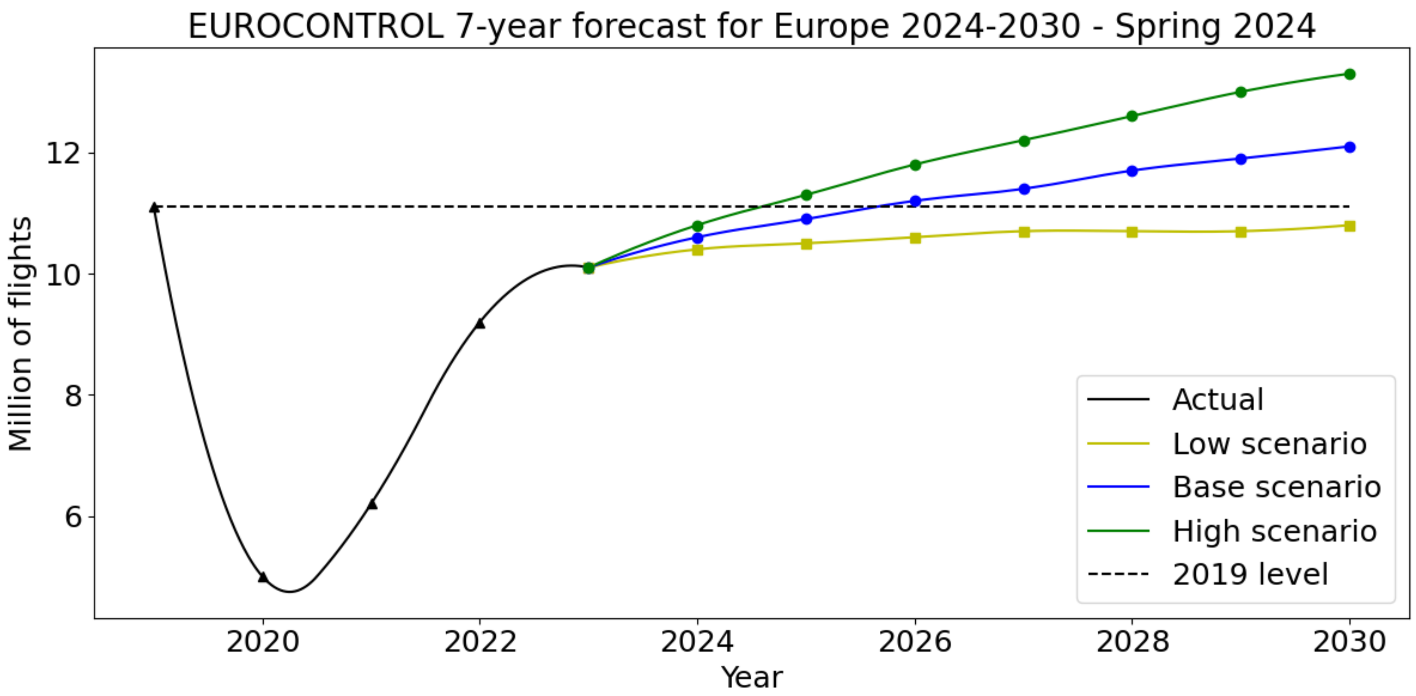
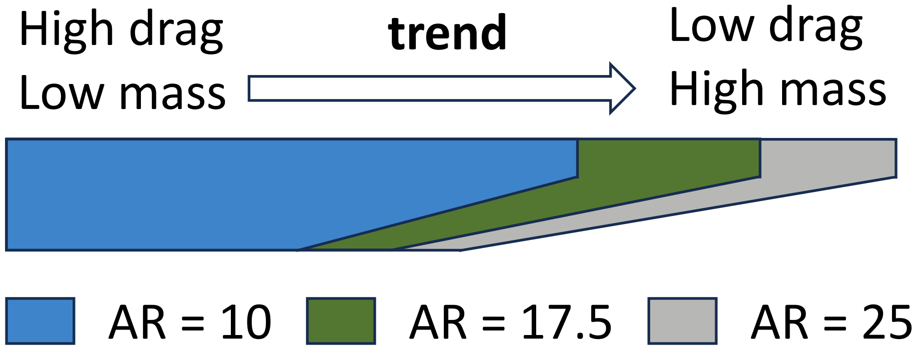
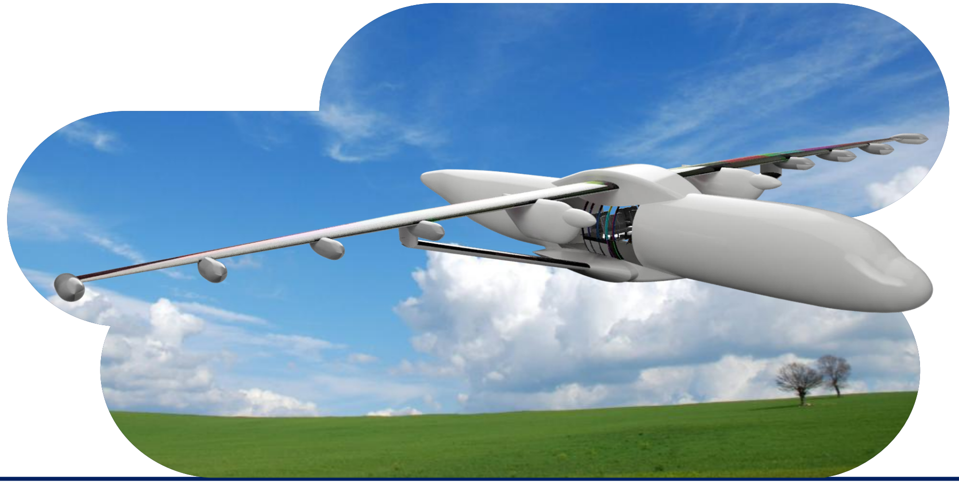
Introduction







[1] www.eurocontrol.int/publication/eurocontrol-forecast-2024-2030

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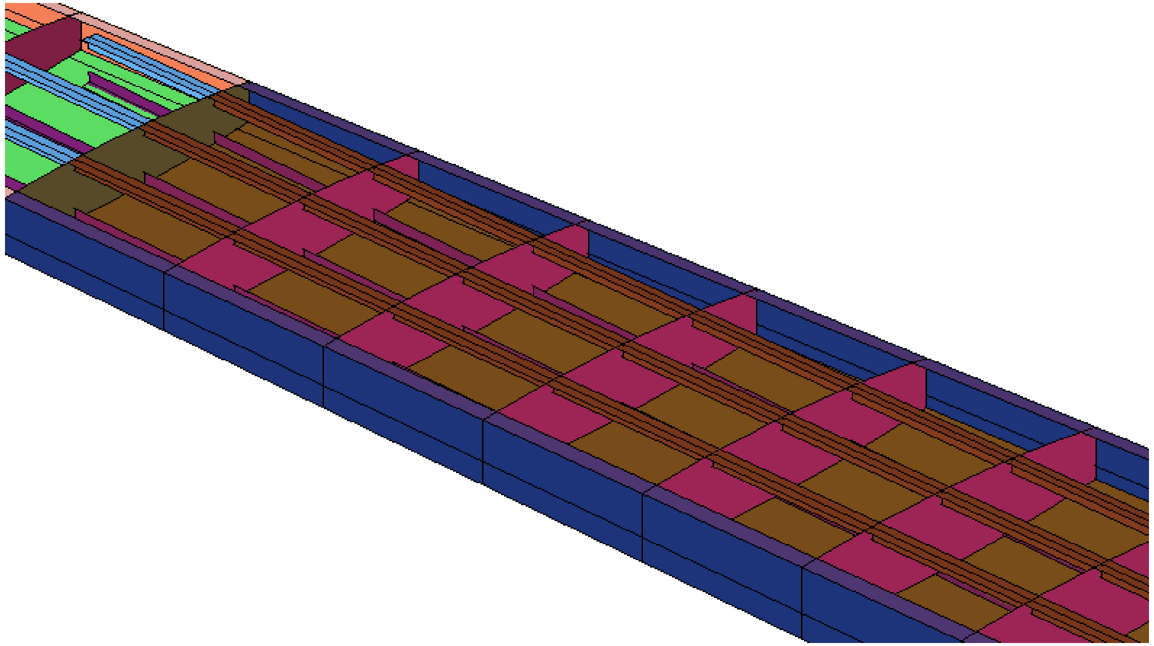
Automated Parametric Finite Element Model Generation

1. **Geometry generation:**
   - Define structural geometry
   - Assign meta-data (material, properties, etc.)

2. **Mesh discretization:**
   - Discretize geometry into finite elements
   - Retrieve created elements using associated tags

3. **FEM model generation:**
   - Create element sets
   - Assign materials and properties based on tags
   - Define local coordinate systems
   - Assign material orientations
   - Define offsets
   - Add non structural mass contributions
   - Apply boundary conditions and external loads



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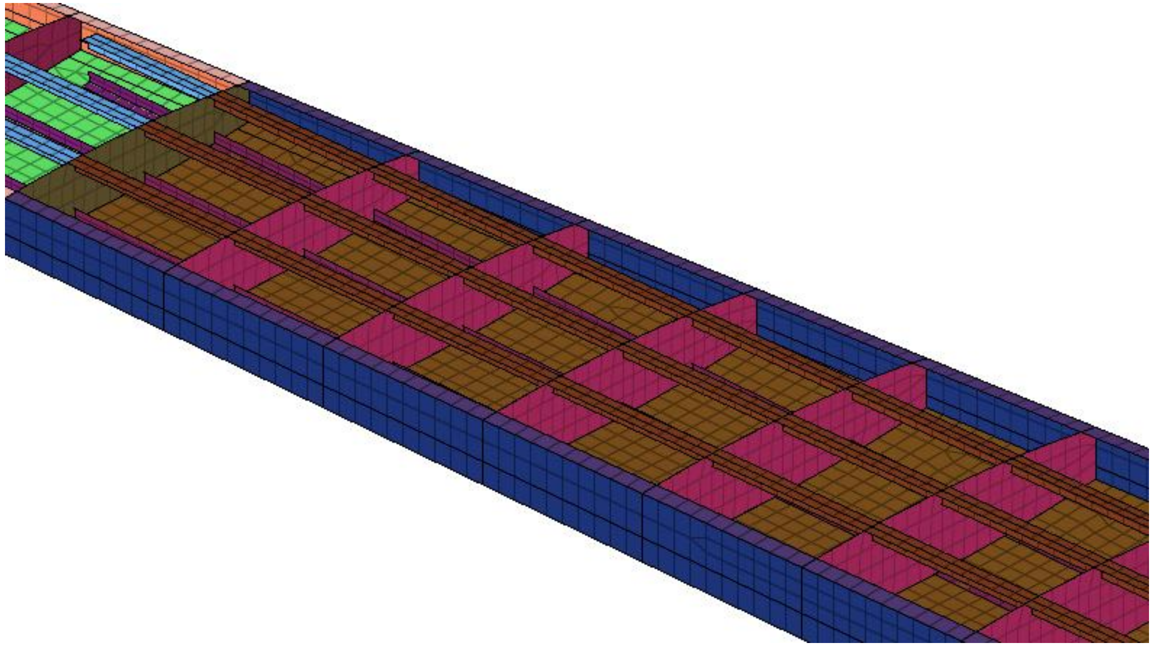

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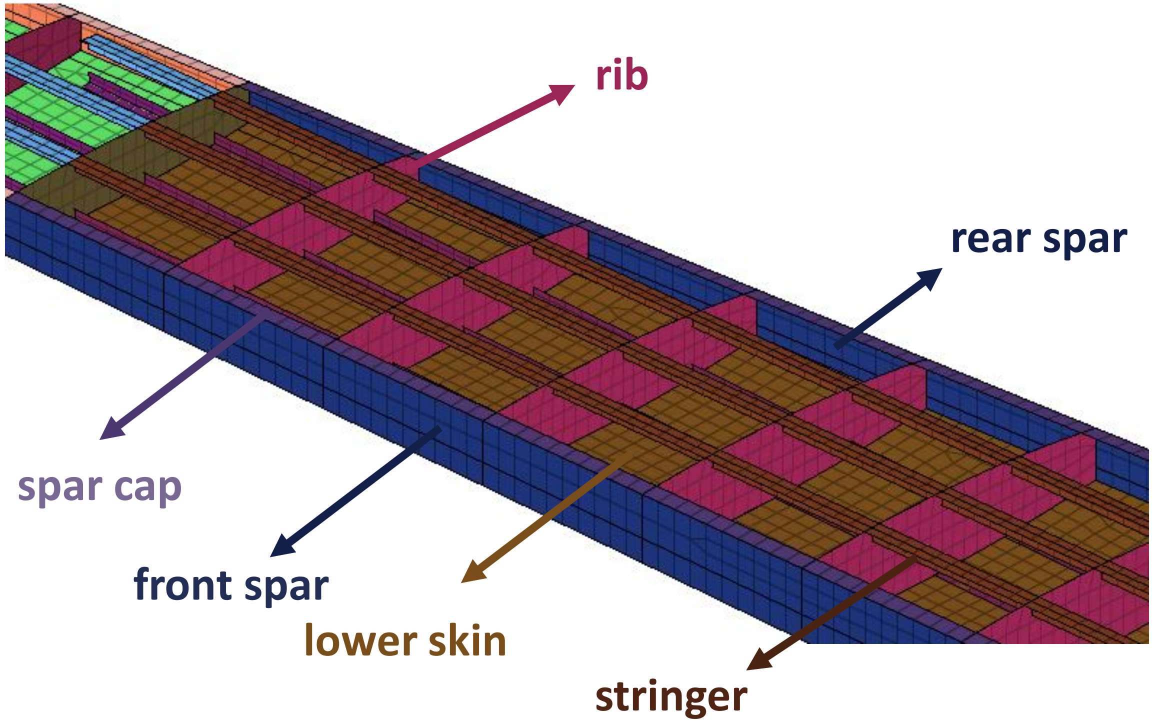

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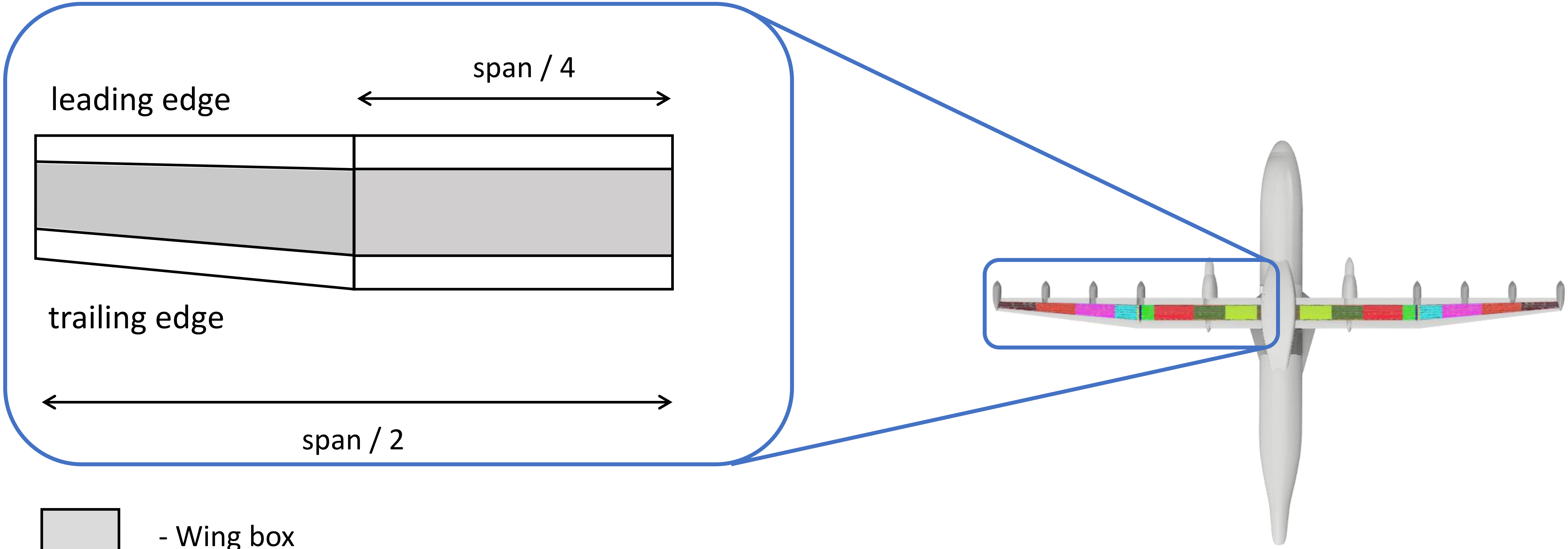
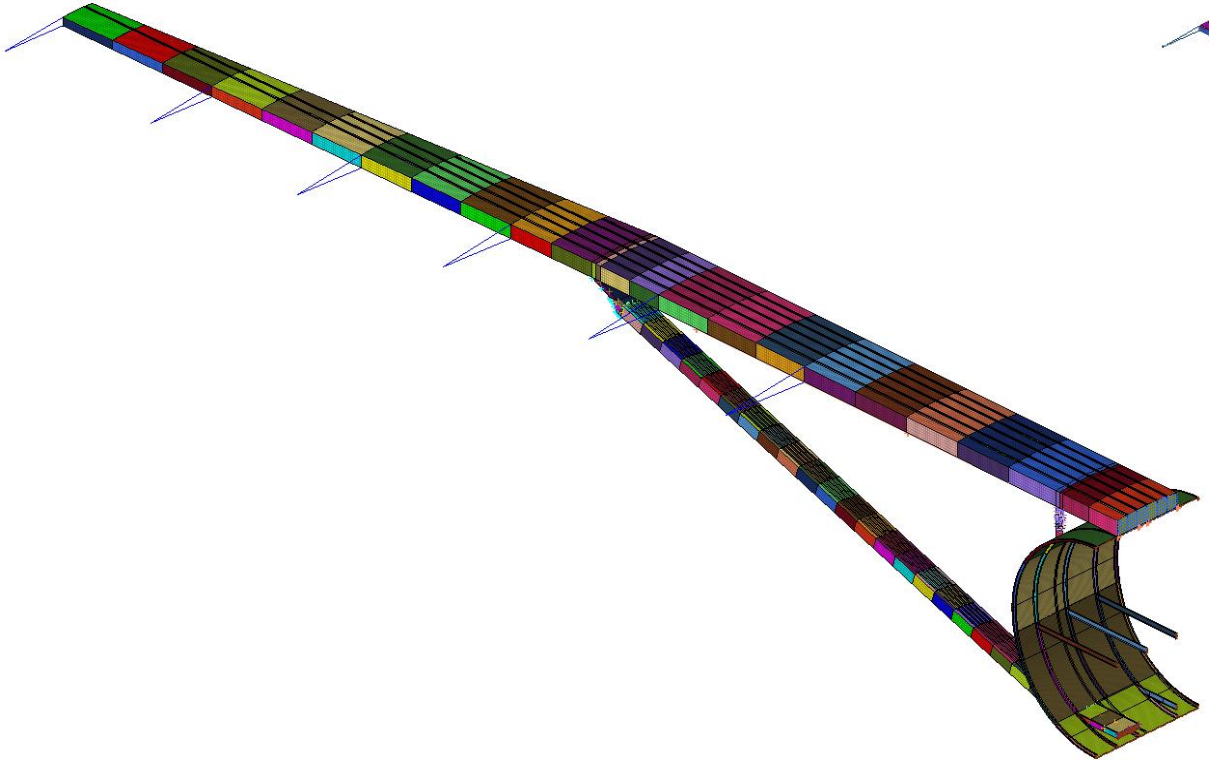
Strut Braced Wing Aircraft: Wing Planform

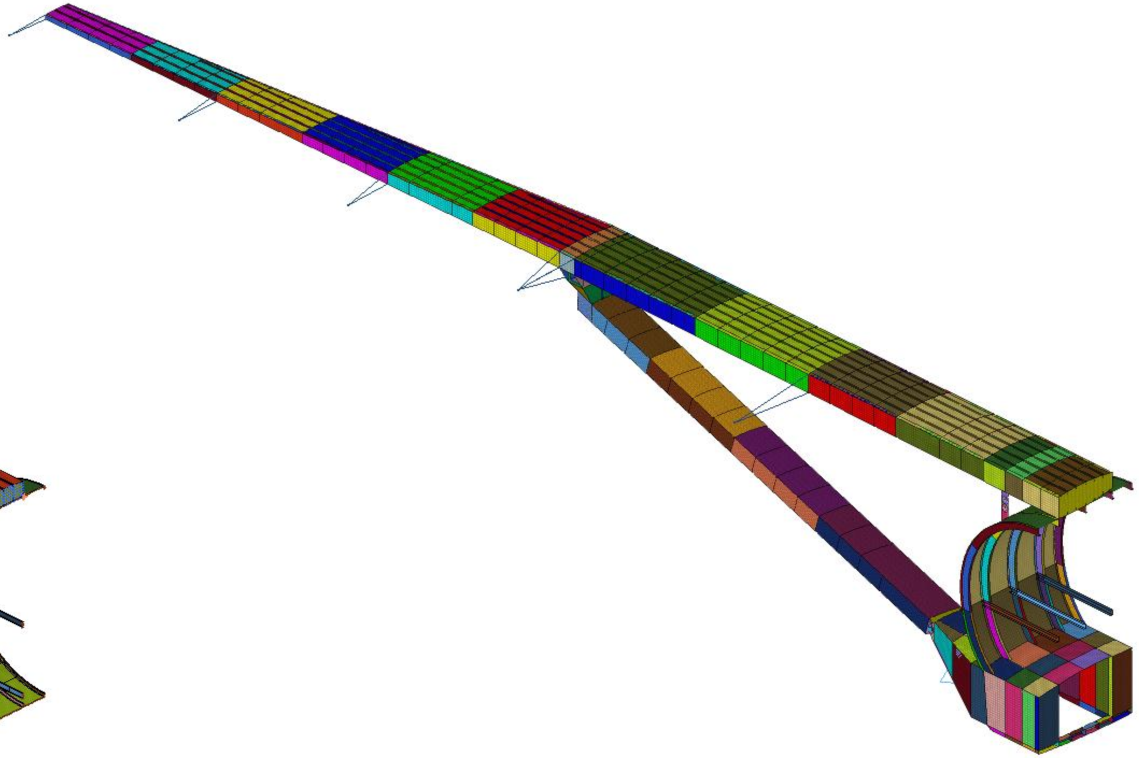


- Wing box

Strut Braced Wing Aircraft: Overview

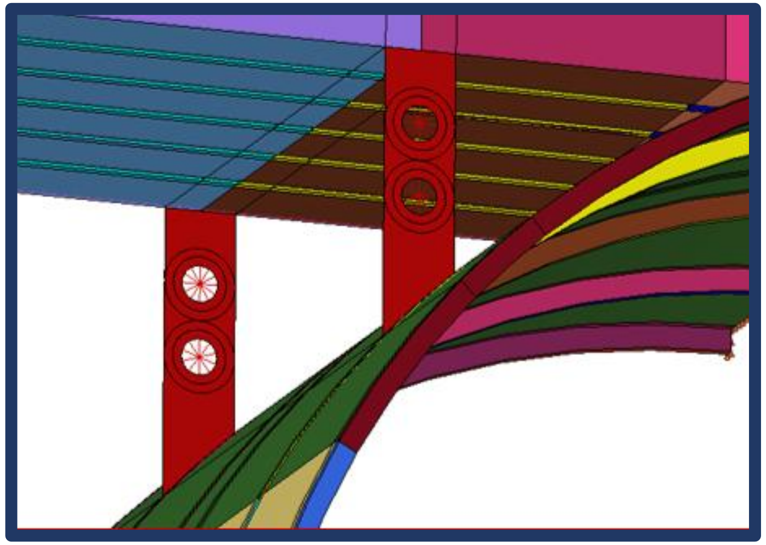


IND1



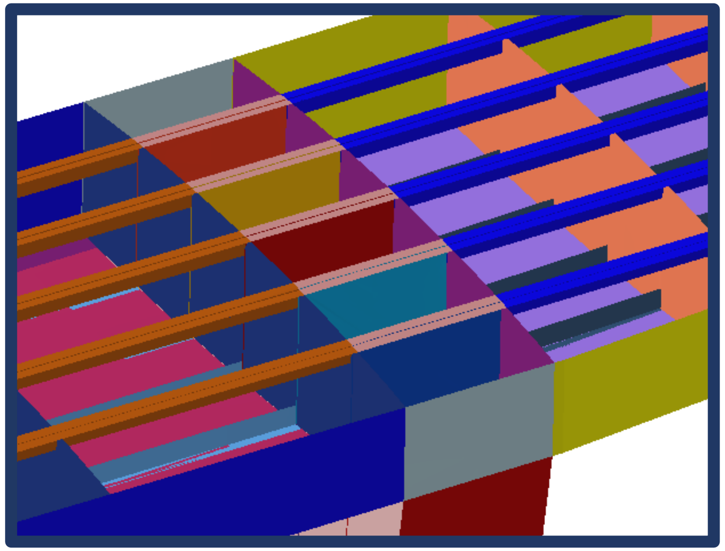
IND2 (in progress)

Strut Braced Wing Aircraft: Connection Details



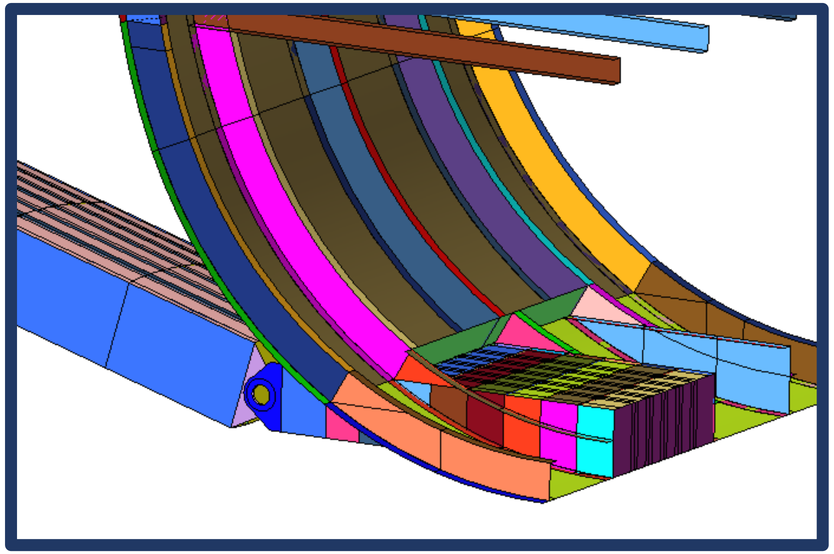
Wing-Fuselage

High wing connection between wing and fuselage.



Wing-Strut

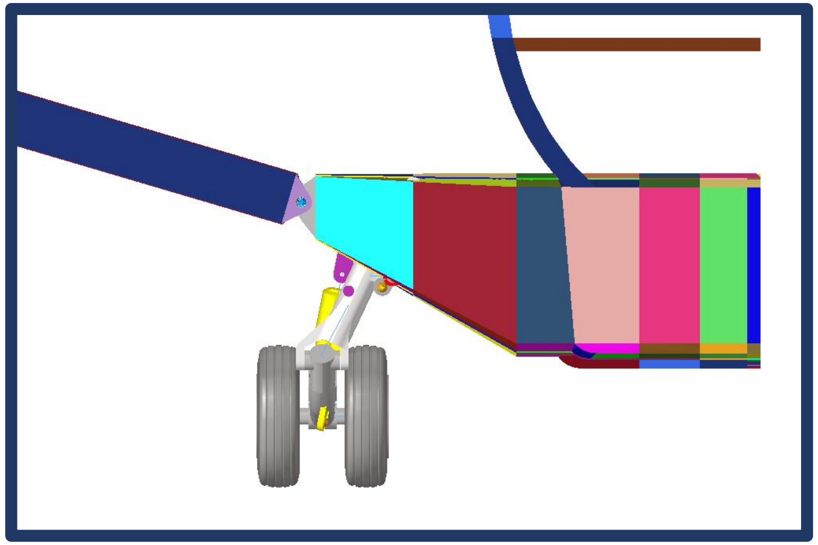
Multi-spar bay on the intersection between wing and strut.

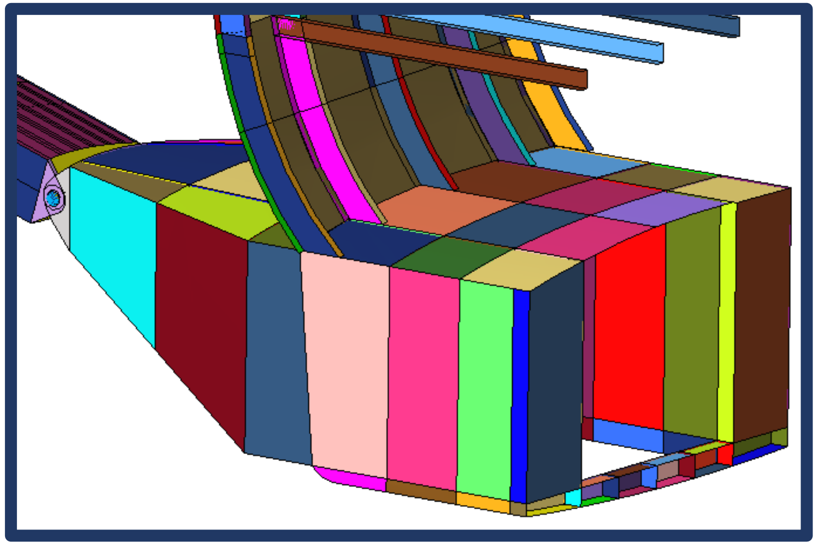


Strut-Fuselage (IND1)

The strut wing box is structurally integrated with the fuselage through direct intersection.

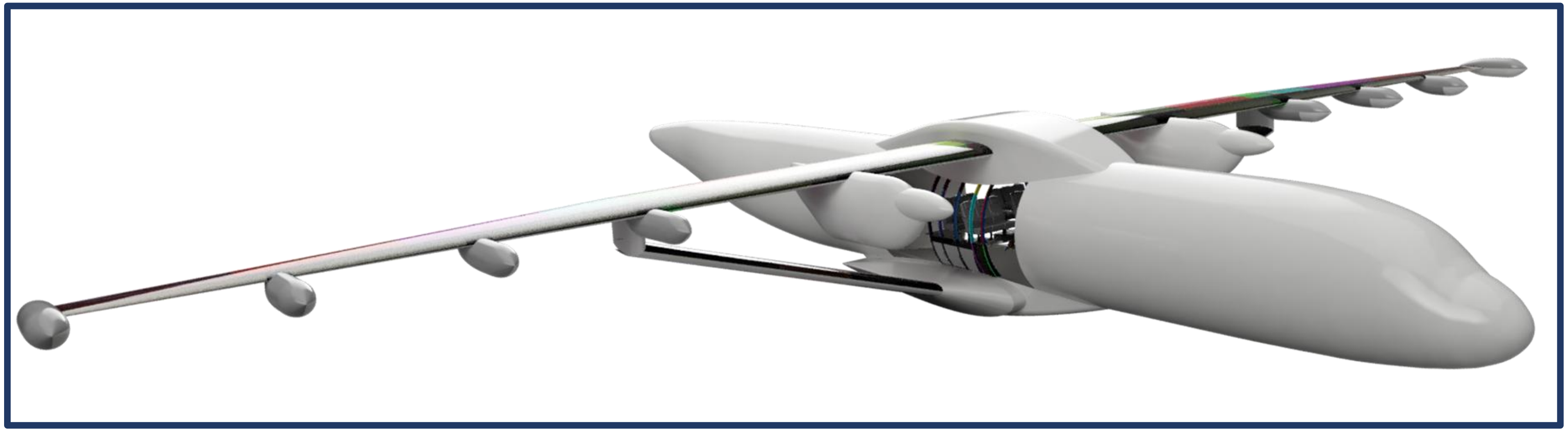
Strut Braced Wing Aircraft: Landing Gear Integration (IND2)

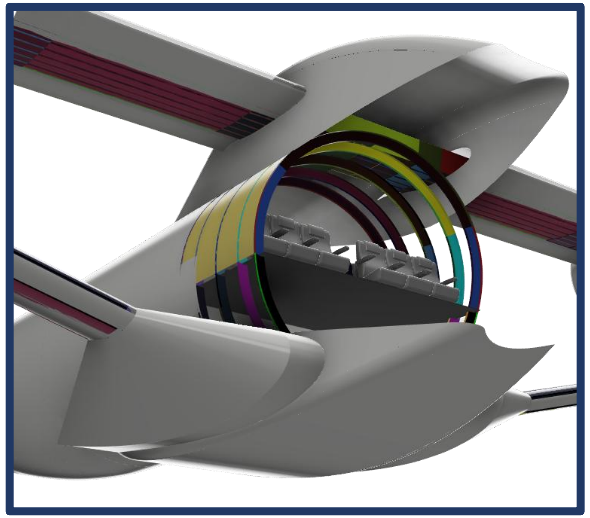


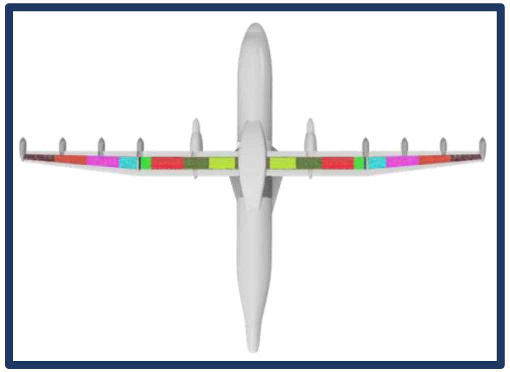


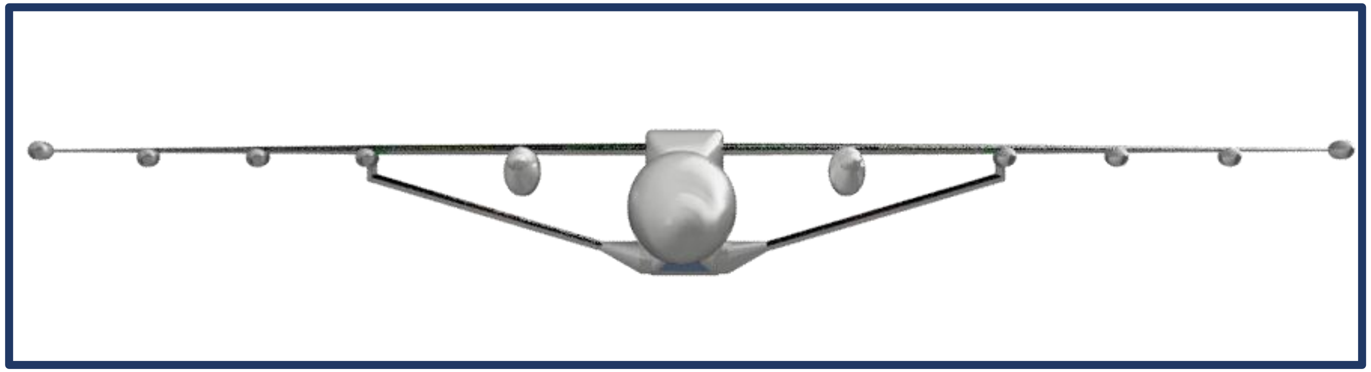
- Redesign of the fuselage–strut attachment to enable the landing integration while satisfying aerodynamic and structural constraints;
- Evaluation of the landing gear kinematics to ensure compact stowage and proper ground clearance;
- Introduction of landing gear load cases on the GFEM.

Strut Braced Wing Aircraft: Overview









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Structural Sizing: Design Optimization

Minimize: Mass

By varying: Thicknesses

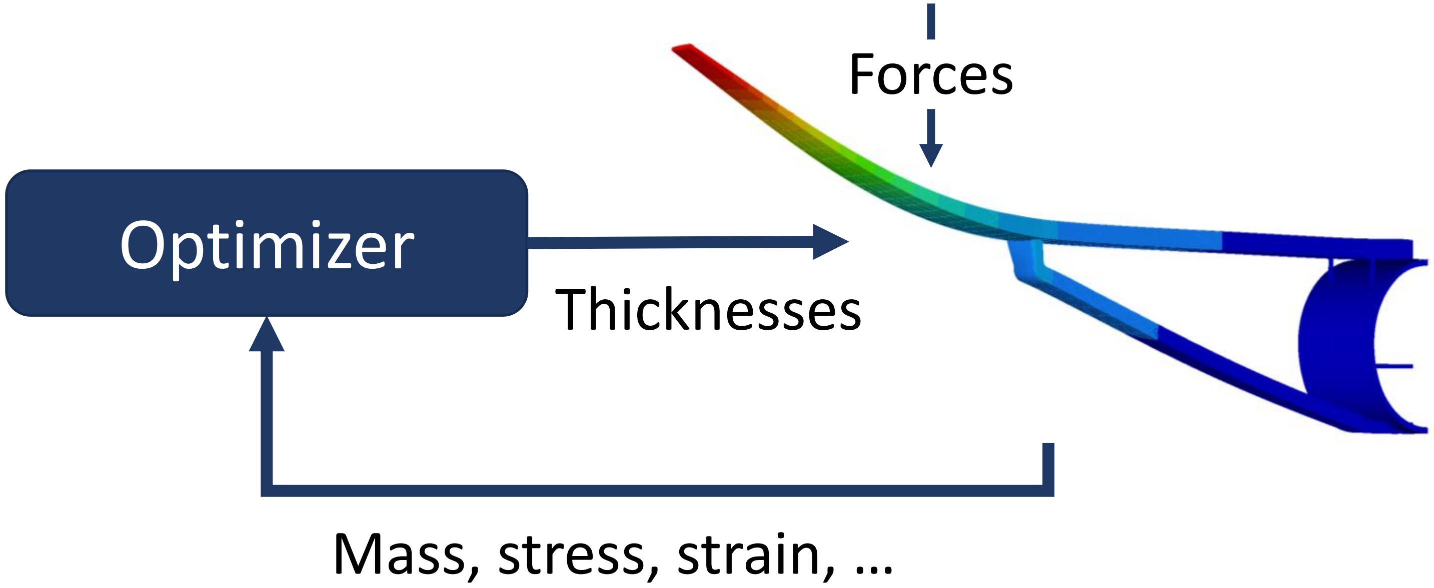
Subject to:

- **Minimum thicknesses**

- **Composite Sizing Constraints**

- **Strength Constraints:**
    - **Composite**: Maximum allowable strain of 3500 µm in tension and compression @ -1.5g, 3.75g;
    - **Metal:** 70% of the Von Mises Stress for metals: 289.56 MPa @ -1g, 2.5g ;

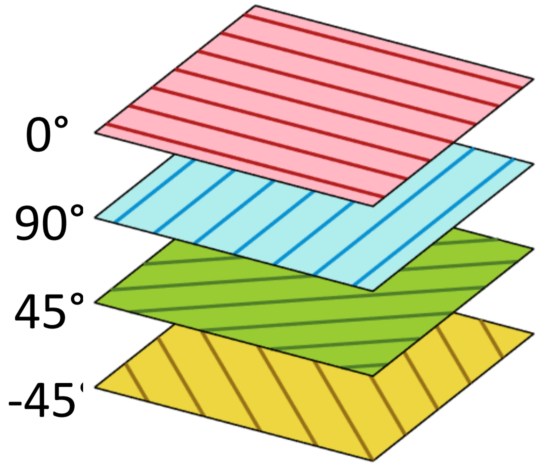
- **Buckling Constraints:**
    - Buckling factor greater than 1.5 @ -1g, 2.5g ;



Structural Sizing: Composite Sizing Constraints

- Discrete ply thickness;
- Maximum Total Stack Thickness below 75 mm;

- Ply share constraints:



Composite laminate

Component / Angle	0°	90°	±45°
Skin	33.3 %	16.6 %	25%
Spar Web	22.25 %	22.25%	27.75%
Spar Cap	57%	12.5%	15.25%
Stringer	50%	16.6%	16.6%

Structural Sizing: Parameterization

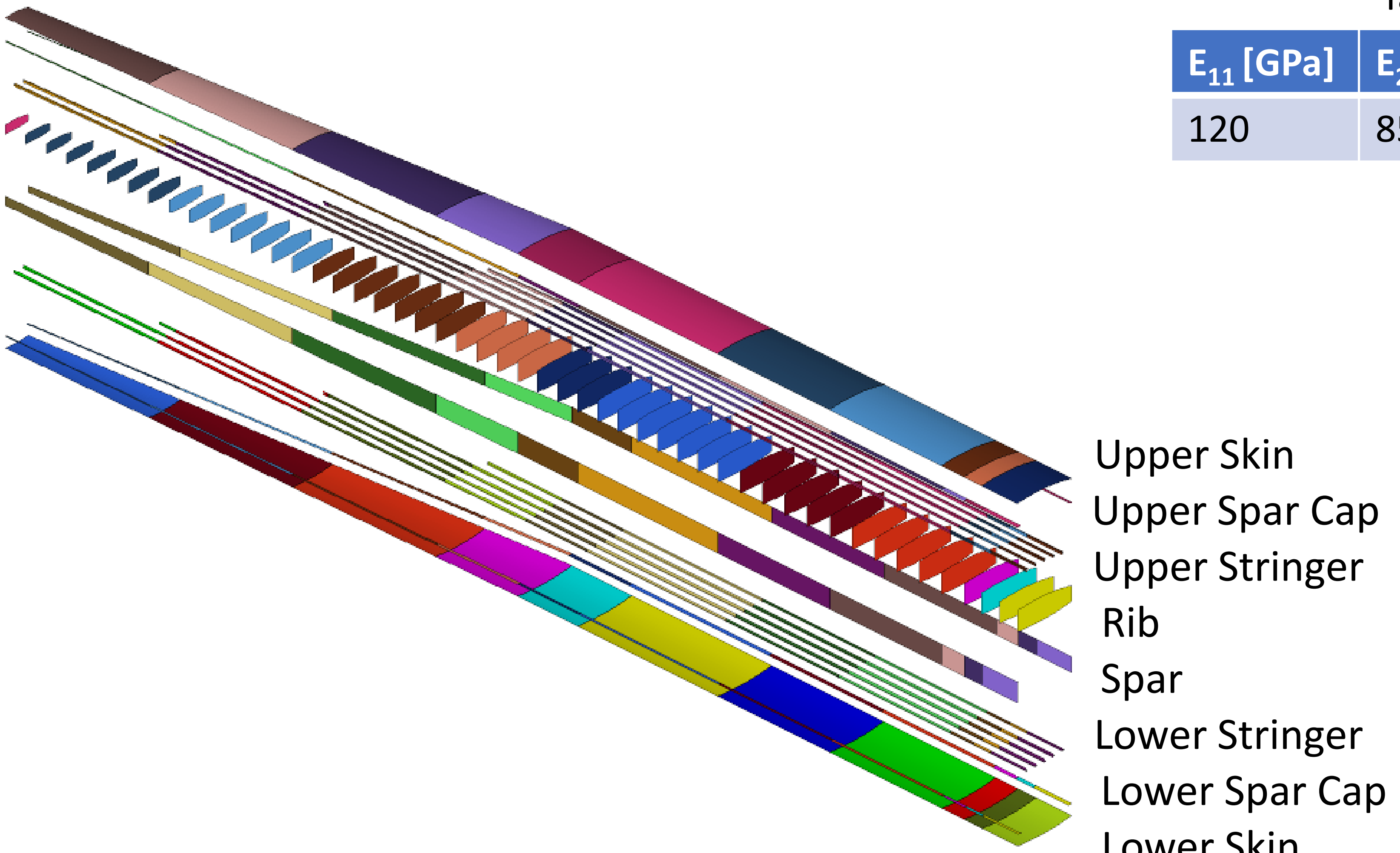


Table 1. CFRP[1] ply properties.

E_{11} [GPa]	E_{22}[GPa]	G_{12} [GPa]	ν	ρ [Kg/m3]
120	85	4	0.3	2.810

Table 2. Aluminium properties.

E [GPa]	G [GPa]	ν	ρ [Kg/m3]
71.7	26.95489	0.33	2.810

[1] - Carbon fibre reinforced polymer

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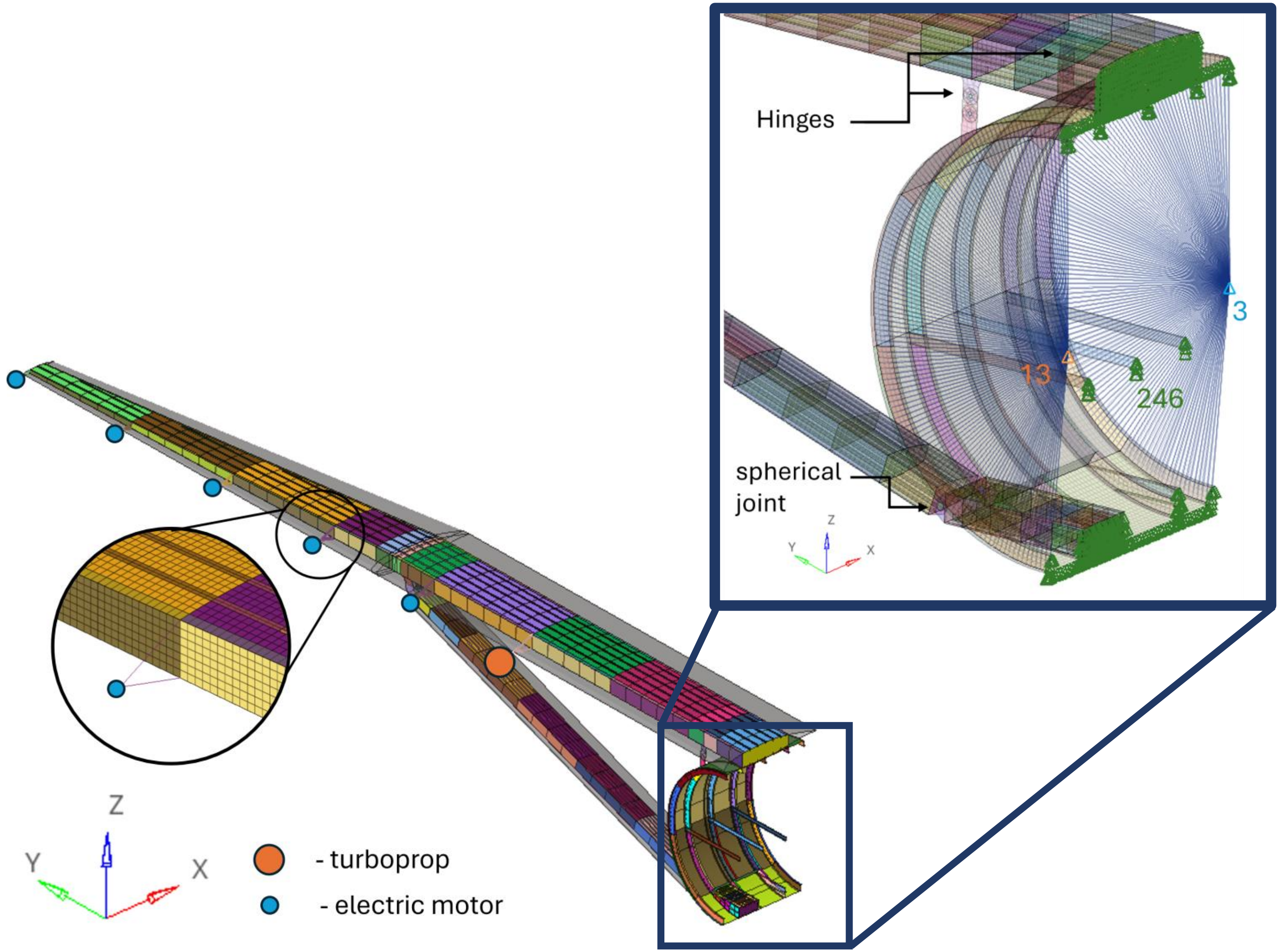
Results: Mass Estimation

Component	Parameter	Value
Wing	AR	21.617
	λ	0.42
	S_w [m^2]	122.4
	t/c_{root} [%]	18
	t/c_{tip} [%]	9
Strut	Chord [m]	1.5965



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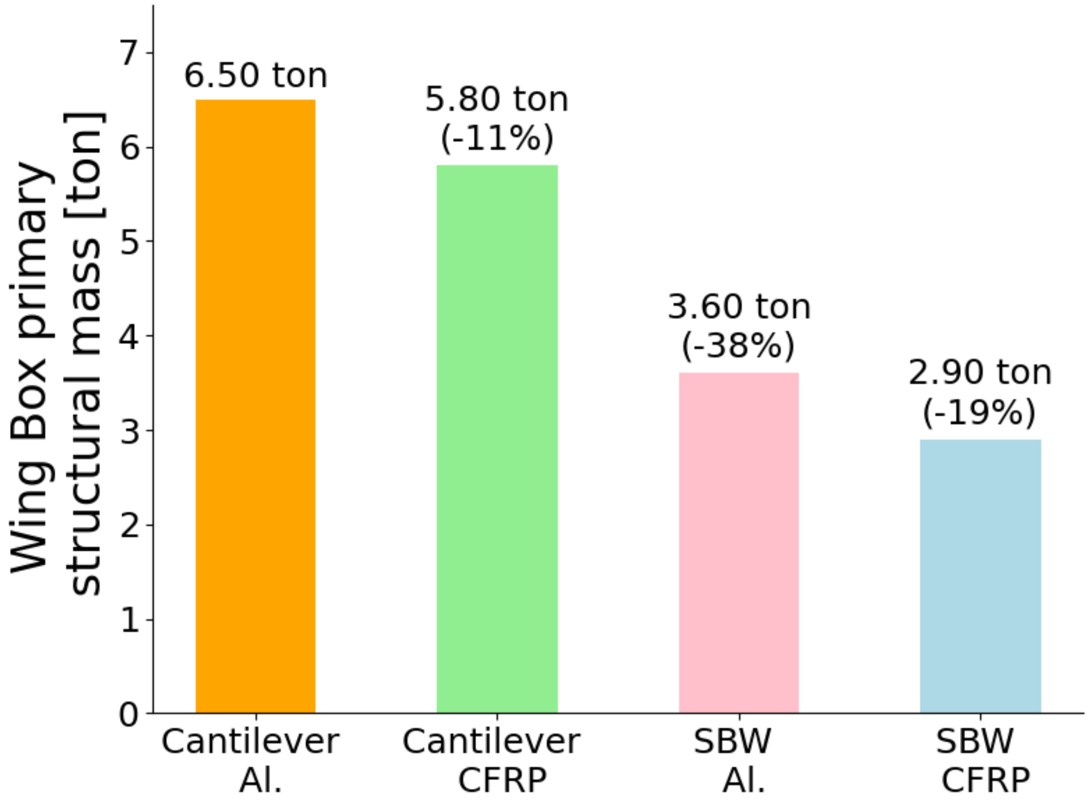
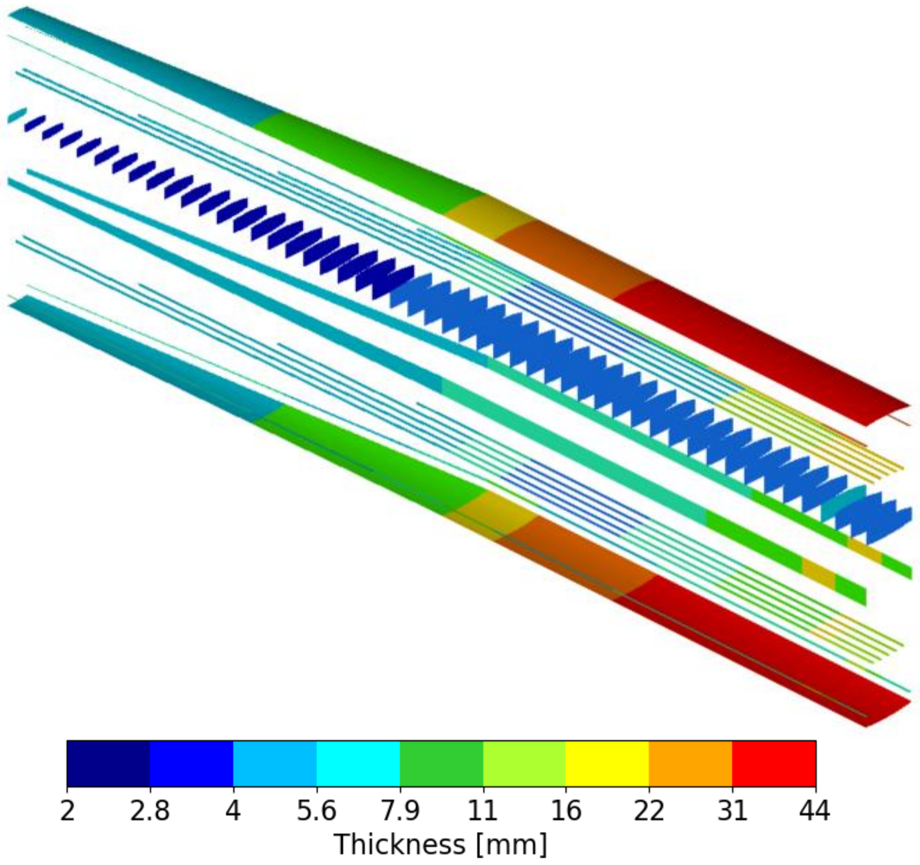
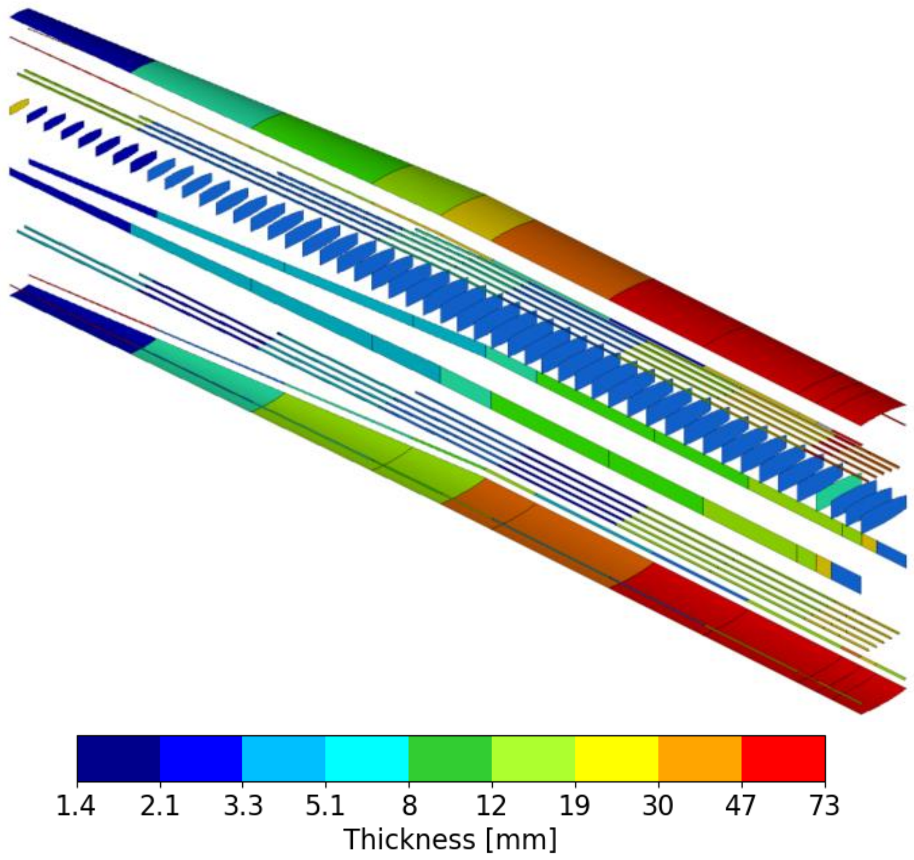


Results: Cantilever Wing Optimal Thickness Distributions

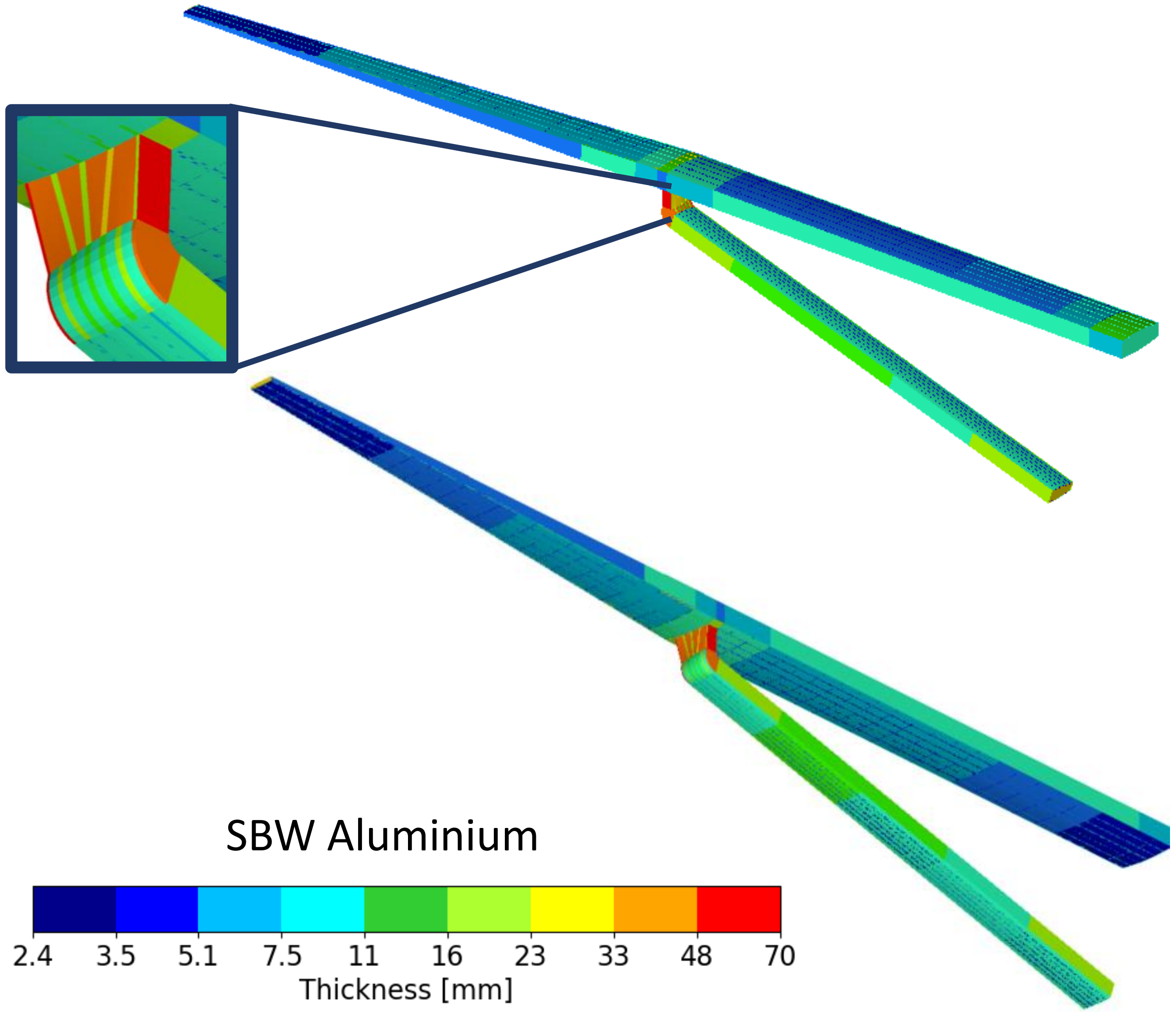


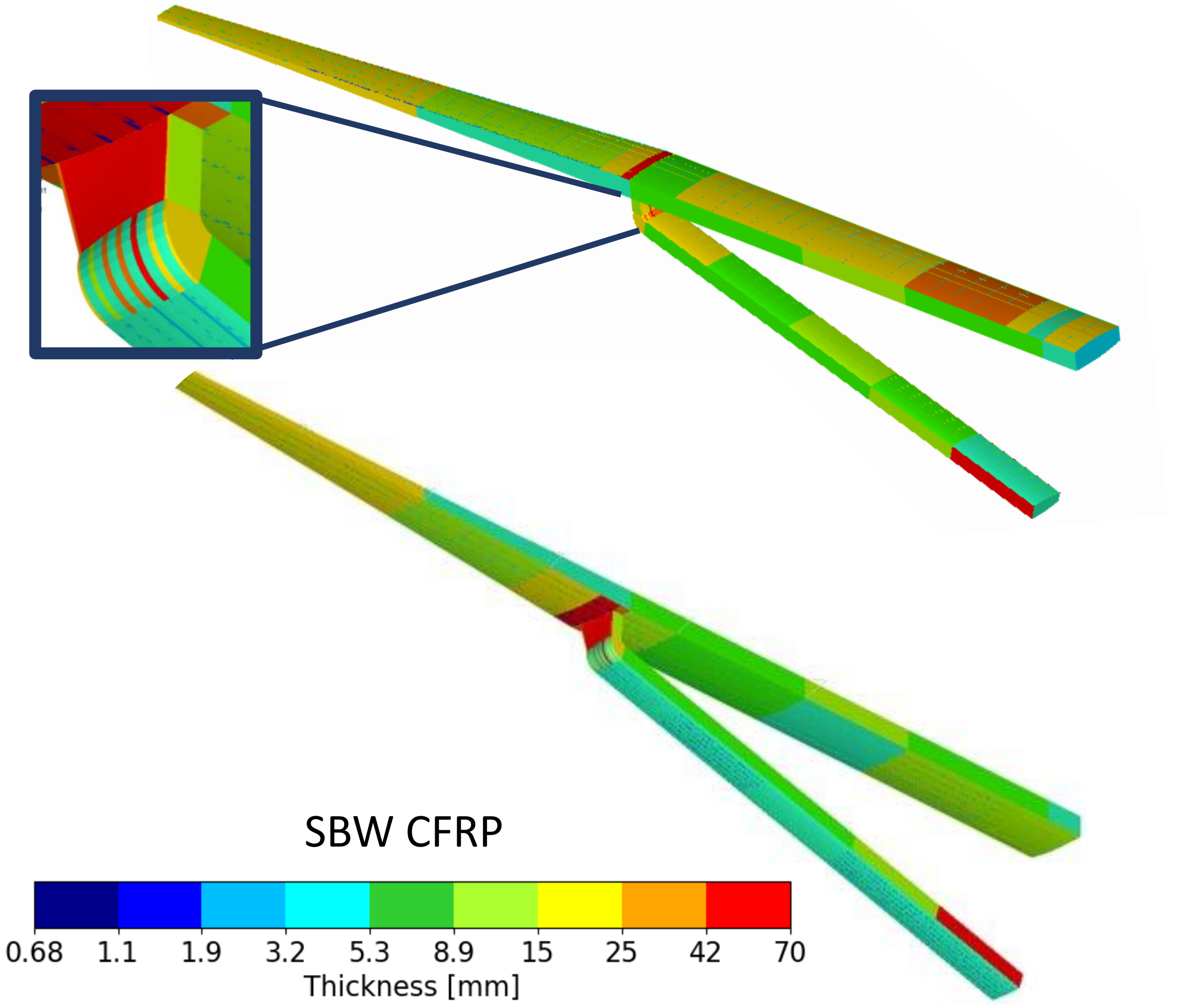
Cantilever Aluminium



Cantilever CFRP

Results: SBW Optimal Thickness Distributions





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Conclusions:

- **Structural Efficiency:** Strut-braced wings offer greater weight-saving potential than cantilever wings when considering high aspect ratios;
- **Physics-Based Weight Estimation:** New framework enables accurate mass predictions, improving over traditional empirical methods;
- **SBW Manufacturing Challenges:** Optimised thicknesses at the wing-strut connection may present manufacturability issues, depending on the design of that region;
- **Composites Potential:** High strength-to-weight ratio materials like composites can further enhance high aspect ratio SBWs structural performance and weight-saving potential.

Scientific Publications & Conferences:

Carvalho, J.; Cavallaro, R.; Cini, A. Structural Optimisation for Mass Estimation of Large-Aspect-Ratio Wings with Distributed Hybrid Propulsion. Eng. Proc. 2025, 90, 85. https://doi.org/10.3390/engproc2025090085

Thank you for your attention

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