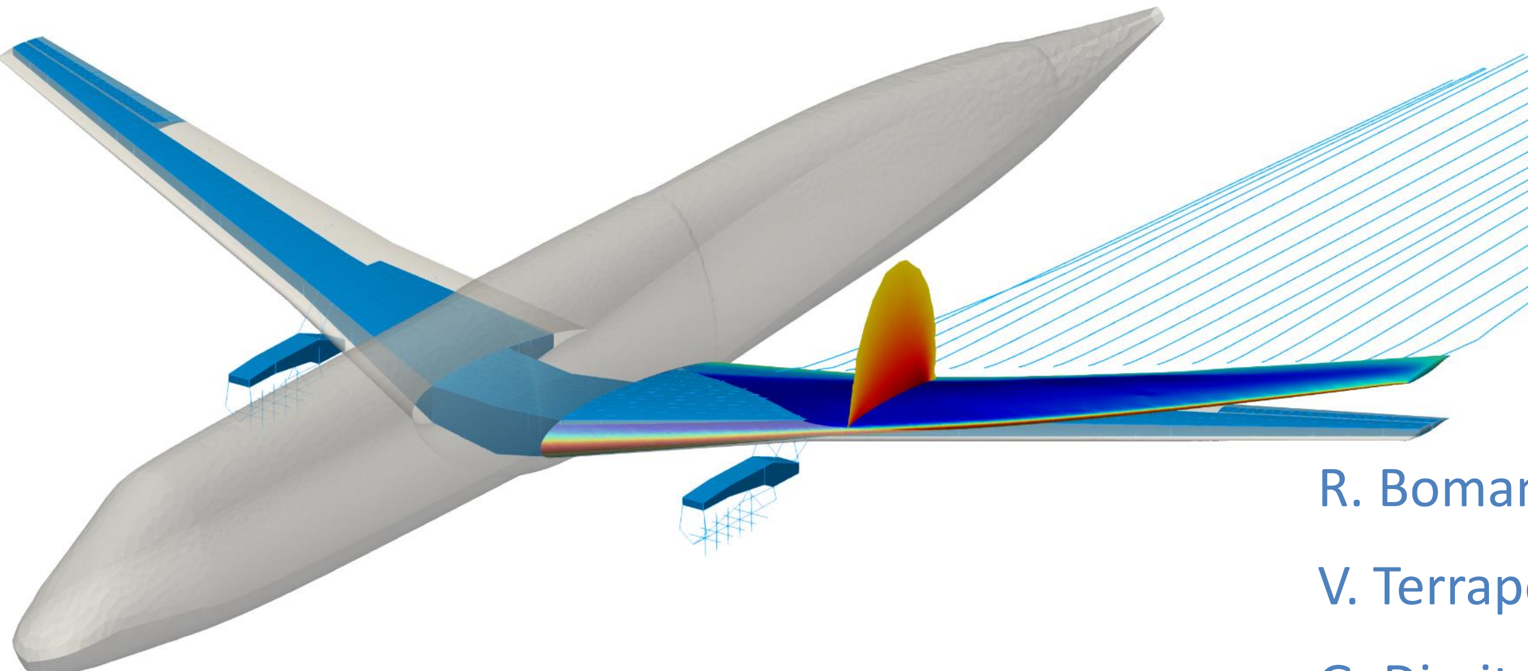
Fast full potential based aerostructural optimization calculations for preliminary aircraft design

Adrien Crovato



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Madrid, June 2022

Aeroelasticity in aircraft design

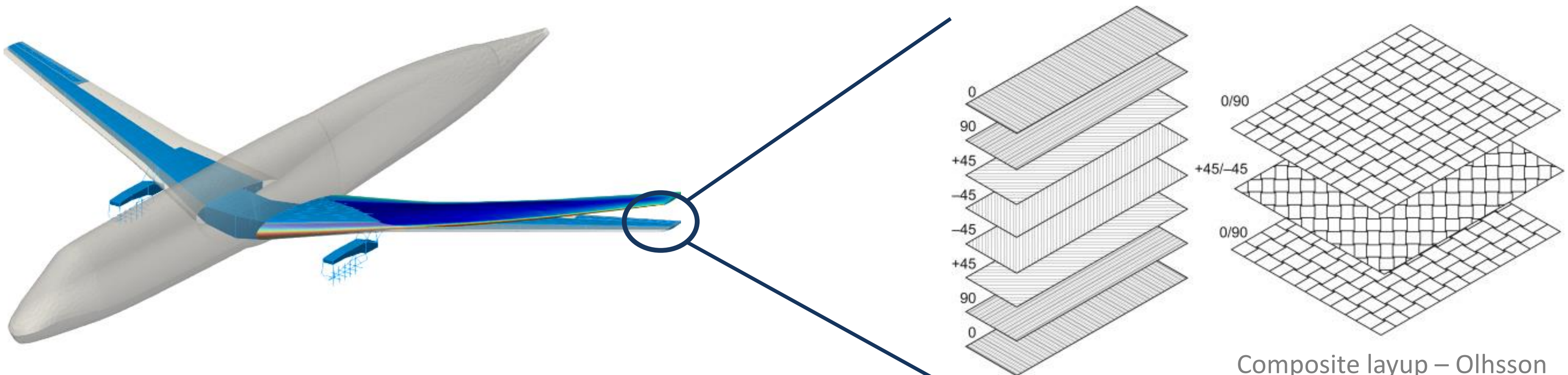
More traffic

Less emissions

More profit

Fuel consumption must be reduced!

Aerostructural optimization



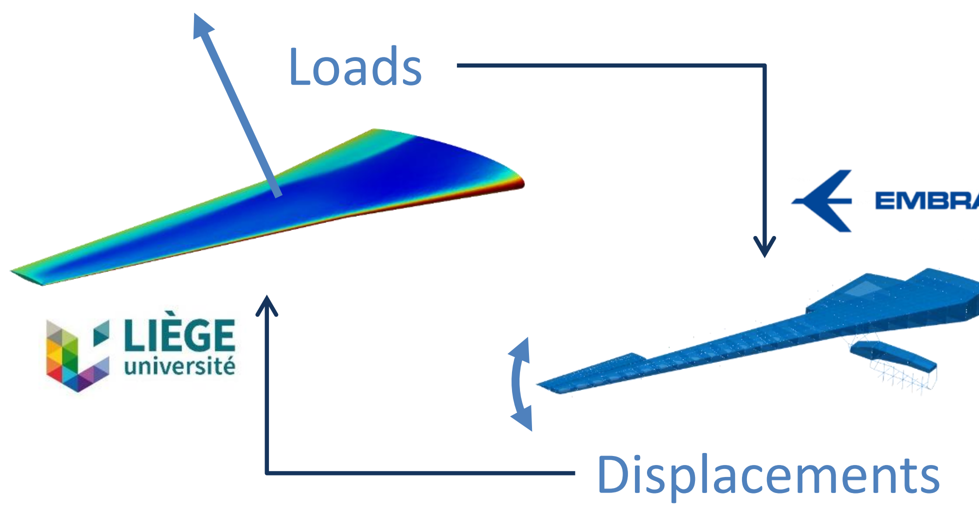
Composite layup – Olhsson

Optimize aircraft

- Decrease burned fuel

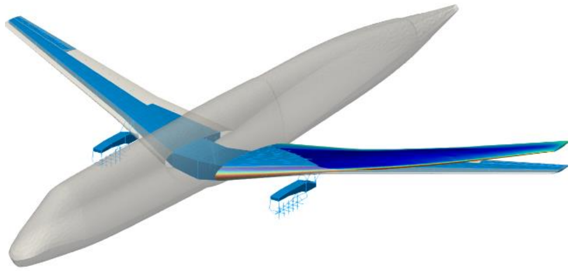
Such that

- Sustain ultimate loads in various flight conditions
- Stable aeroelastic behavior



Preliminary aircraft design

Conceptual → **Preliminary** → Detail



Numerical model (9%)

- Global design
- Optimization
- Performance

- **Optimization formulation**
- **Level of fidelity selection**

Gradient-based optimization

$$\begin{cases} R\big(u(p+\delta \mathrm{p})\big) = 0 \\ d_p F = \Delta \left\{ \dfrac{F\big(u(p+\delta p)\big)}{\delta p} \right\} \end{cases}$$

$$d_p F(u;p) \rightarrow 0$$
$$R(u;p) = 0$$

$$d_p F = \partial_p F - \underbrace{\partial_u F \partial_u R^{-1}}\partial_p R$$

Adjoint $\partial_u R^{\mathrm{T}} \lambda = \partial_u F^{\mathrm{T}}$

Independent on number of design variables

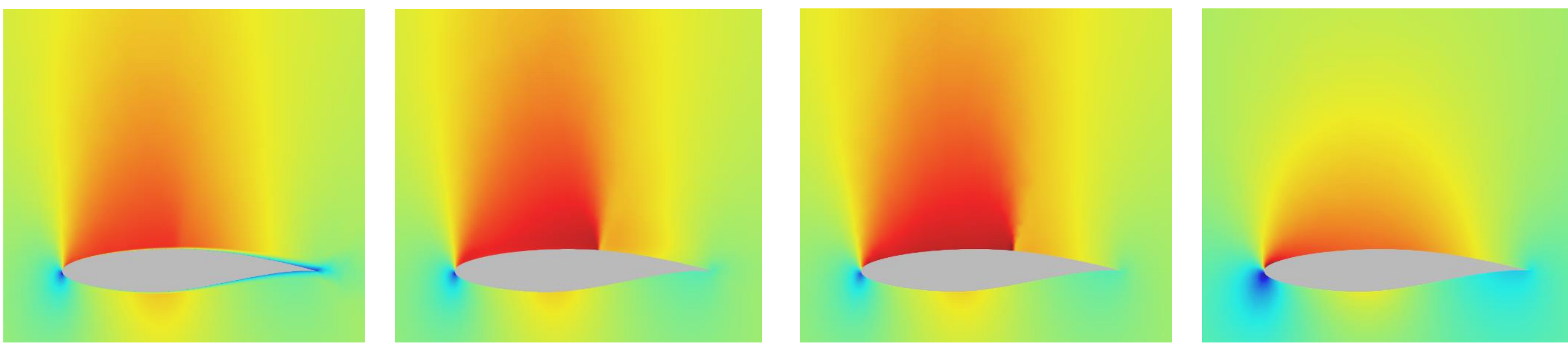
Aerodynamic models in aircraft design

RANS equations	Euler equations	Full potential equation	Linear potential equation
• Subsonic	• Subsonic	• Subsonic	• ~**Subsonic**
• Supersonic	• Supersonic	• Supersonic	• ~**Supersonic**
• Transonic	• Transonic	• ~**Transonic**	• ~~**Transonic**~~
• Viscous	• **Inviscid**	• Inviscid	• Inviscid

→ Inviscid (RANS equations → Euler equations)

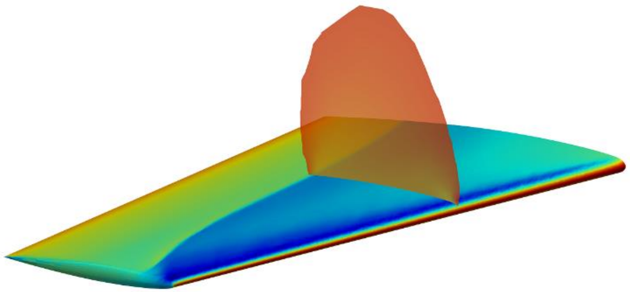
→ Isentropic (Euler equations → Full potential equation)

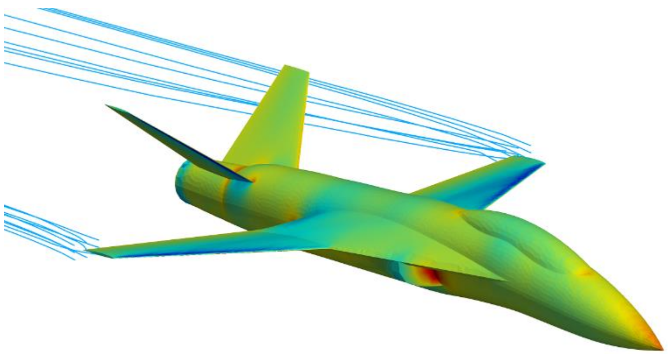
→ Linear (Full potential equation → Linear potential equation)

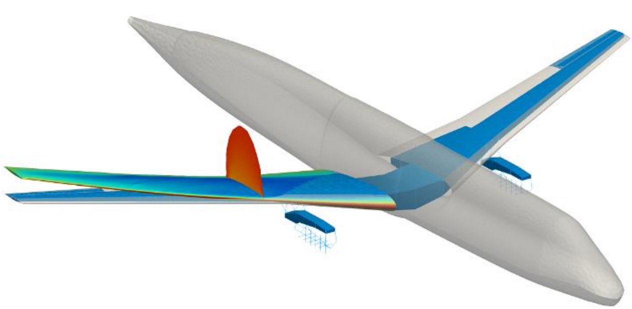


Mach number

DART







Discrete Adjoint for Rapid Transonic Flows

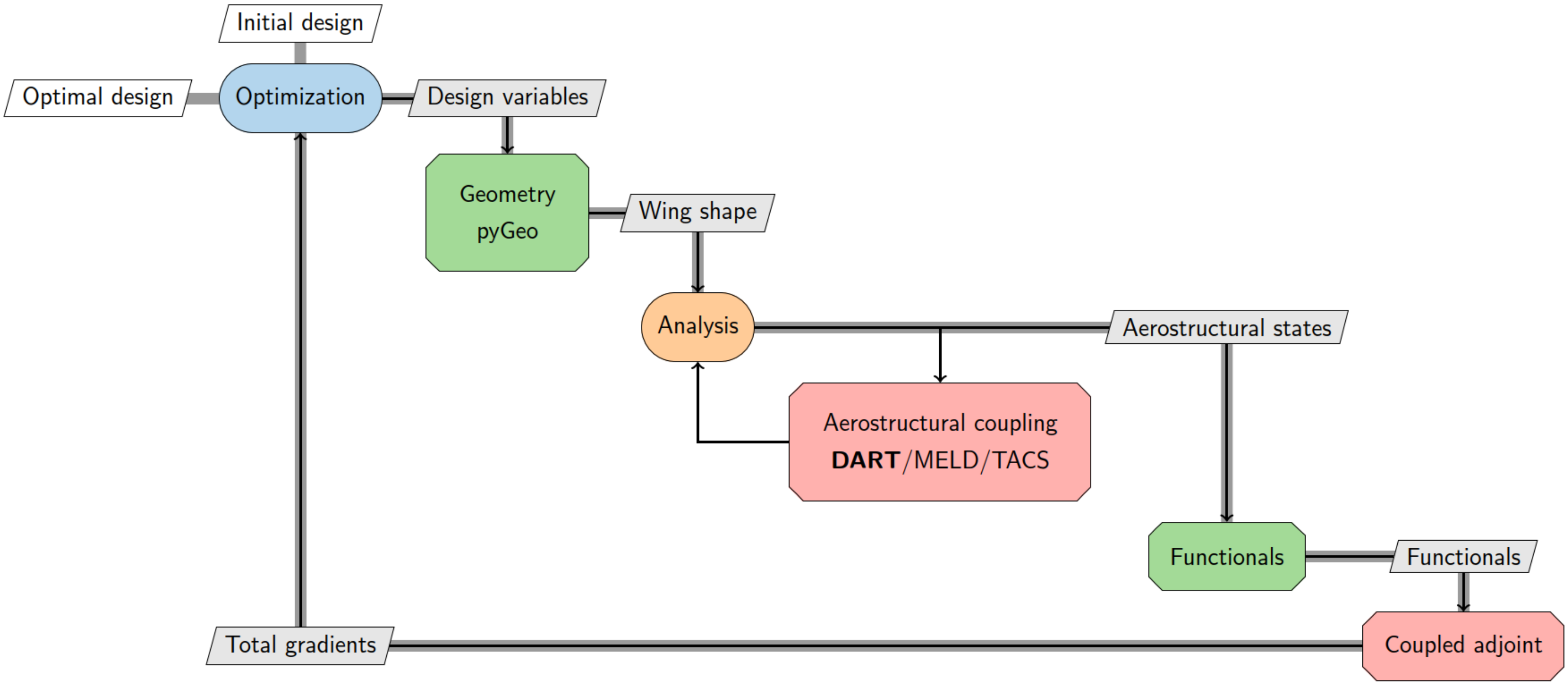
- Steady full potential formulation
- Finite element discretization
- Unstructured tetrahedral grid
- Analytical discrete adjoint
- Mesh morphing
- C++ with python API

Performance (712Ke – 4.3GB @ 3.4GHz)

- Solution – 100 s
- Morphing – 25 s
- Gradient – 45 s

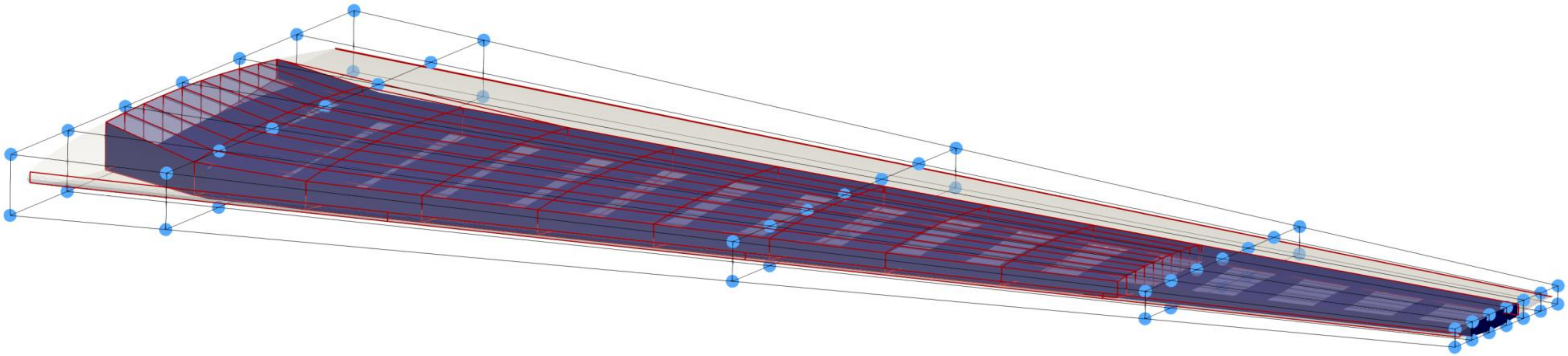
https://gitlab.uliege.be/am-dept/dartflo

Optimization framework



https://openmdao.org
https://github.com/openmdao/mphys

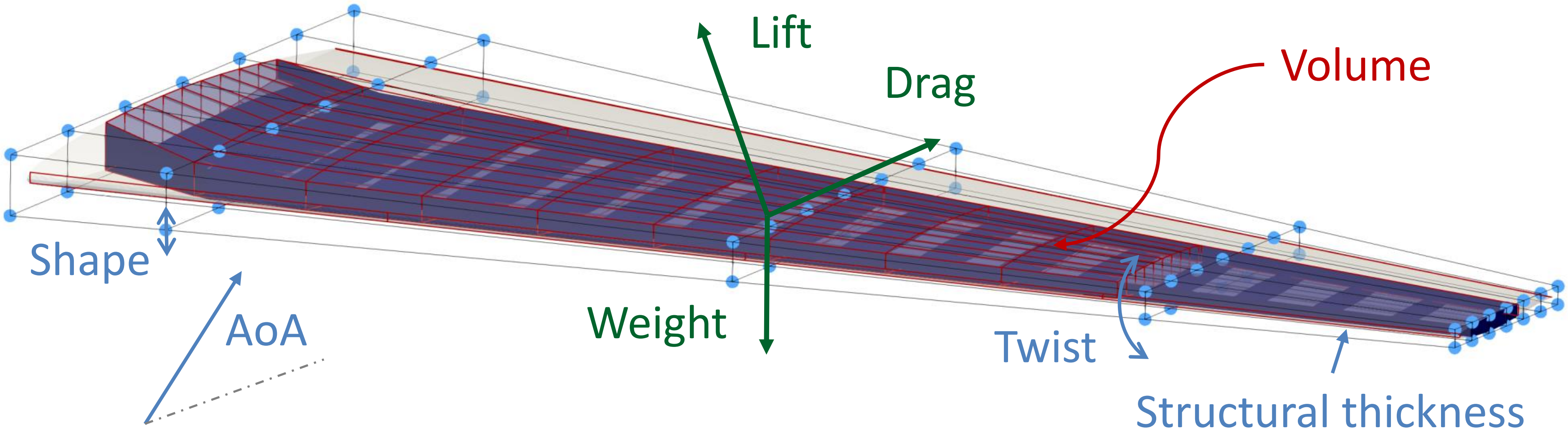
Aerostructural optimization – RAE 2822



Cruise: $M\ 0.82 - FL\ 350$

Maneuver: $M\ 0.78 - FL\ 200$

Aerostructural optimization – RAE 2822

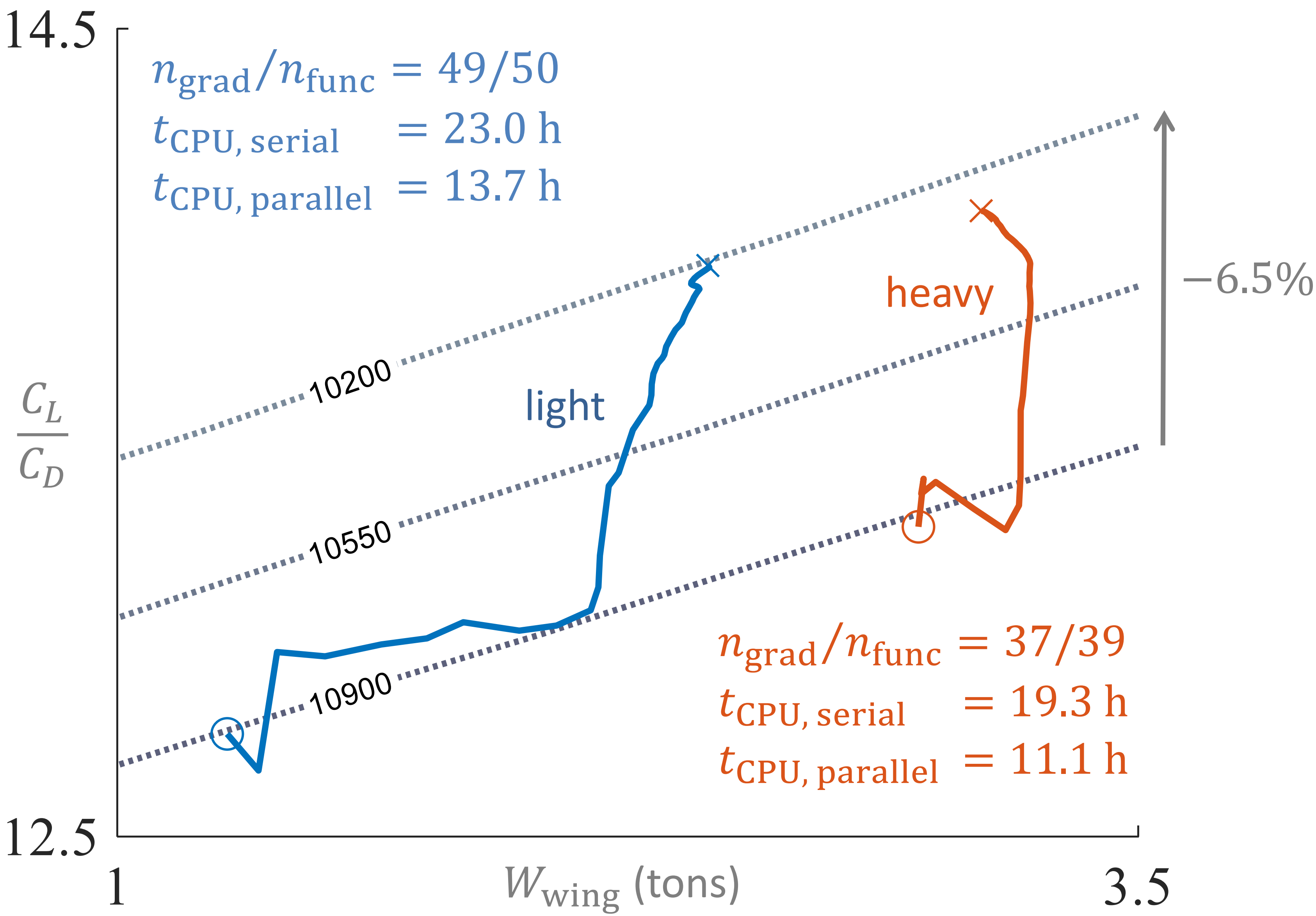


$$\text{min} \quad \text{Fuel} = \text{Breguet}(\text{Lift}, \text{Drag}, \text{Weight})$$

$$\text{w. r. t.} \quad \text{AoA}, \text{Shape}, \text{Twist}, \text{Structural thickness}$$

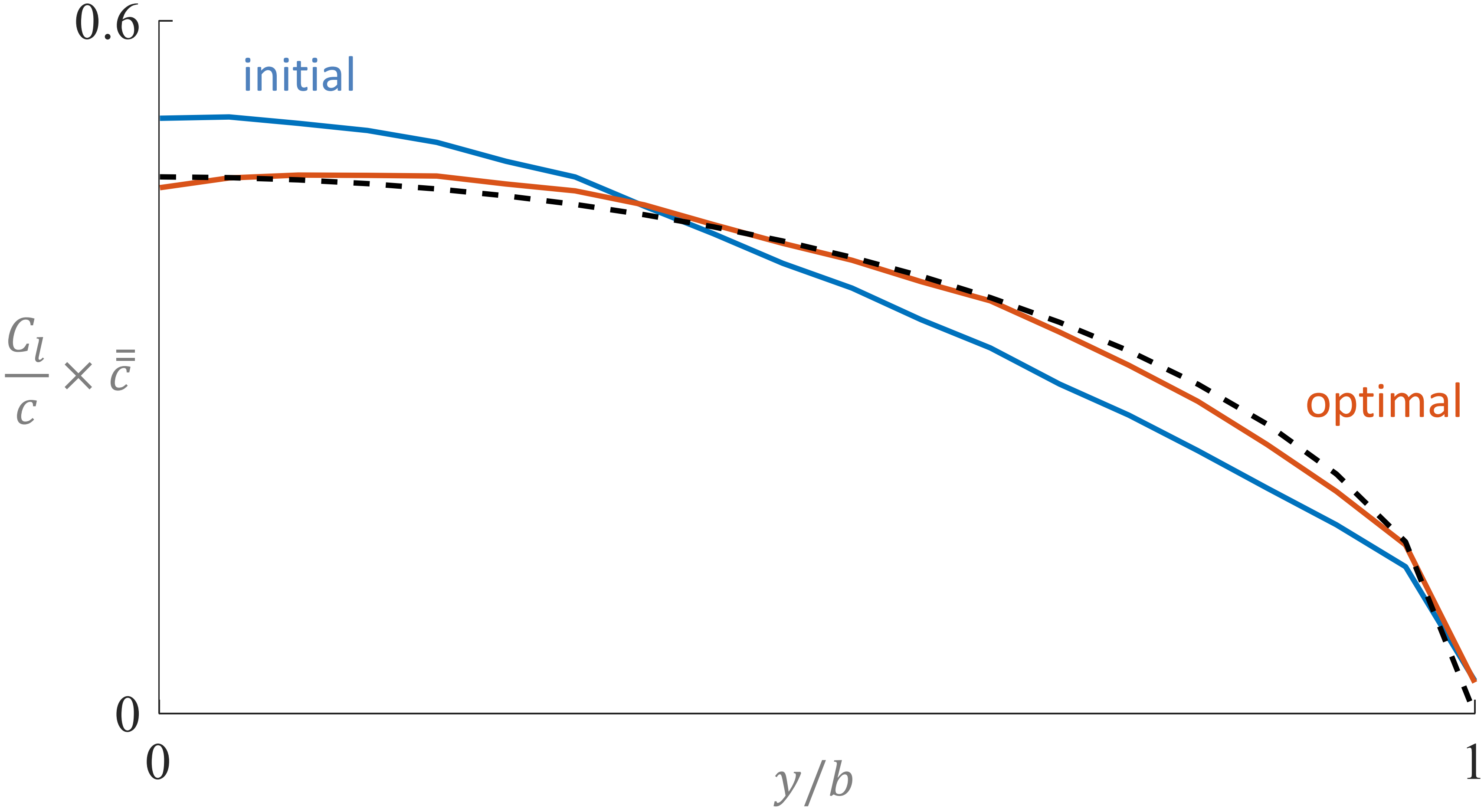
$$\text{s. t.} \quad \text{Load factor}$$
$$\text{Internal volume}$$
$$\text{Structural adjacency}$$
$$\text{Structural failure}$$

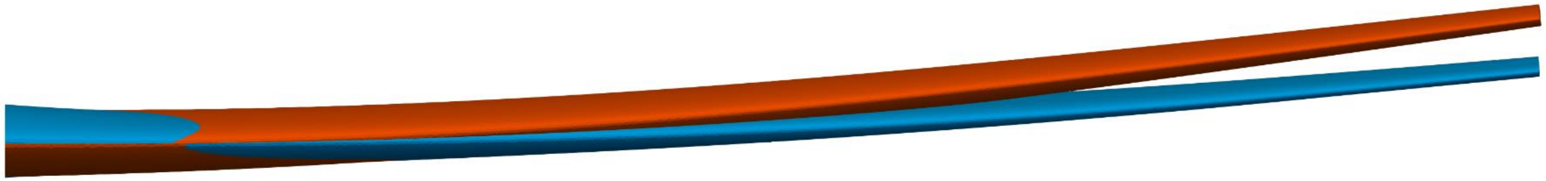
Fuel burn



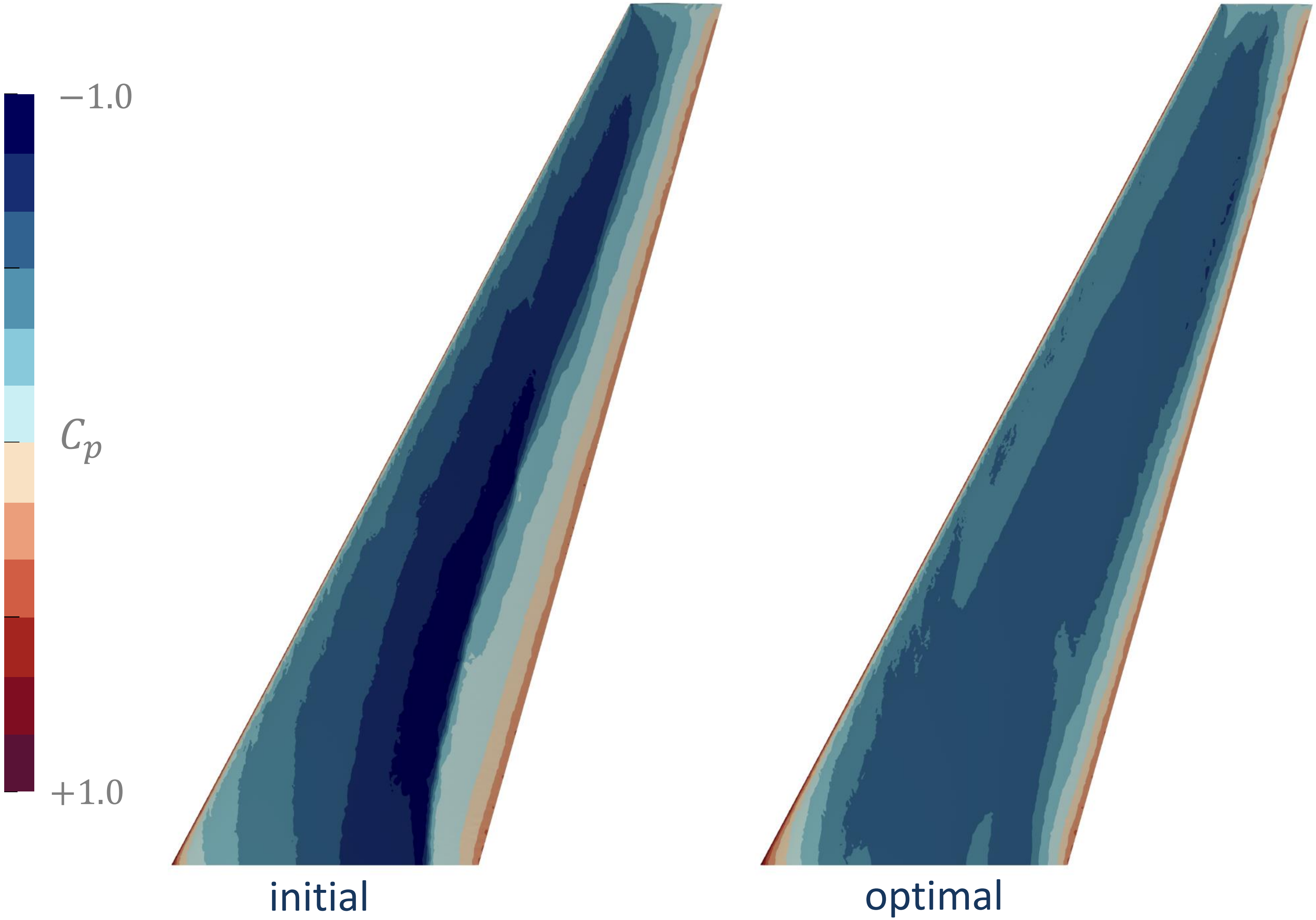
14.5
12.5
$n_{grad}/n_{func} = 49/50$
$t_{CPU, serial} = 23.0$ h
$t_{CPU, parallel} = 13.7$ h
10200
10550
10900
light
heavy
−6.5%
$n_{grad}/n_{func} = 37/39$
$t_{CPU, serial} = 19.3$ h
$t_{CPU, parallel} = 11.1$ h
$\frac{C_L}{C_D}$
1
W_{wing} (tons)
3.5

Lift distribution – cruise

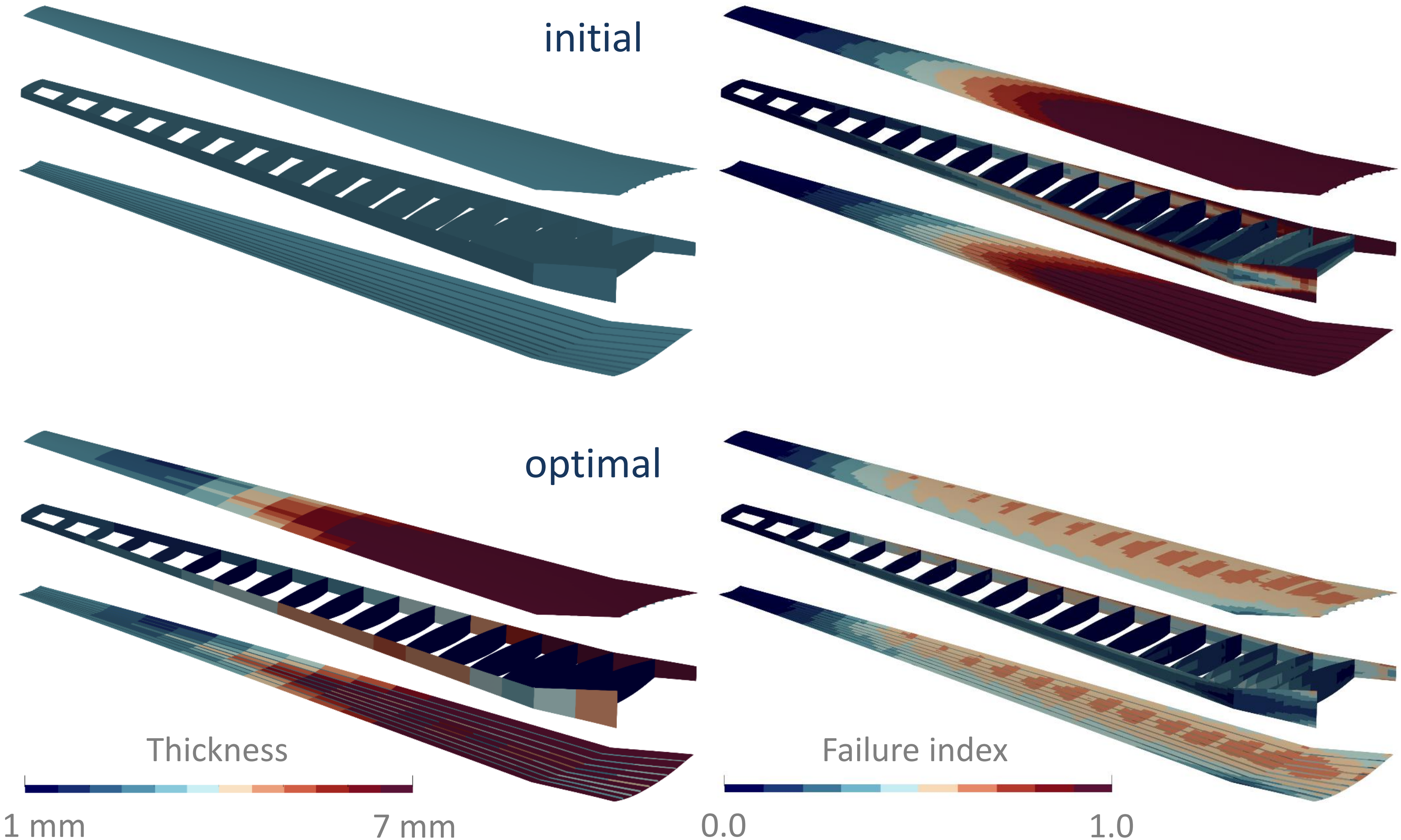




Pressure coefficient – cruise



Thickness and failure index – maneuver



Conclusion

Main points

- **Developed** finite element **full potential** analytical discrete **adjoint** formulation
- **Implemented DART** and **interfaced** with **OpenMDAO/MPHYS**
- **Validated** on **aerostructural** optimization

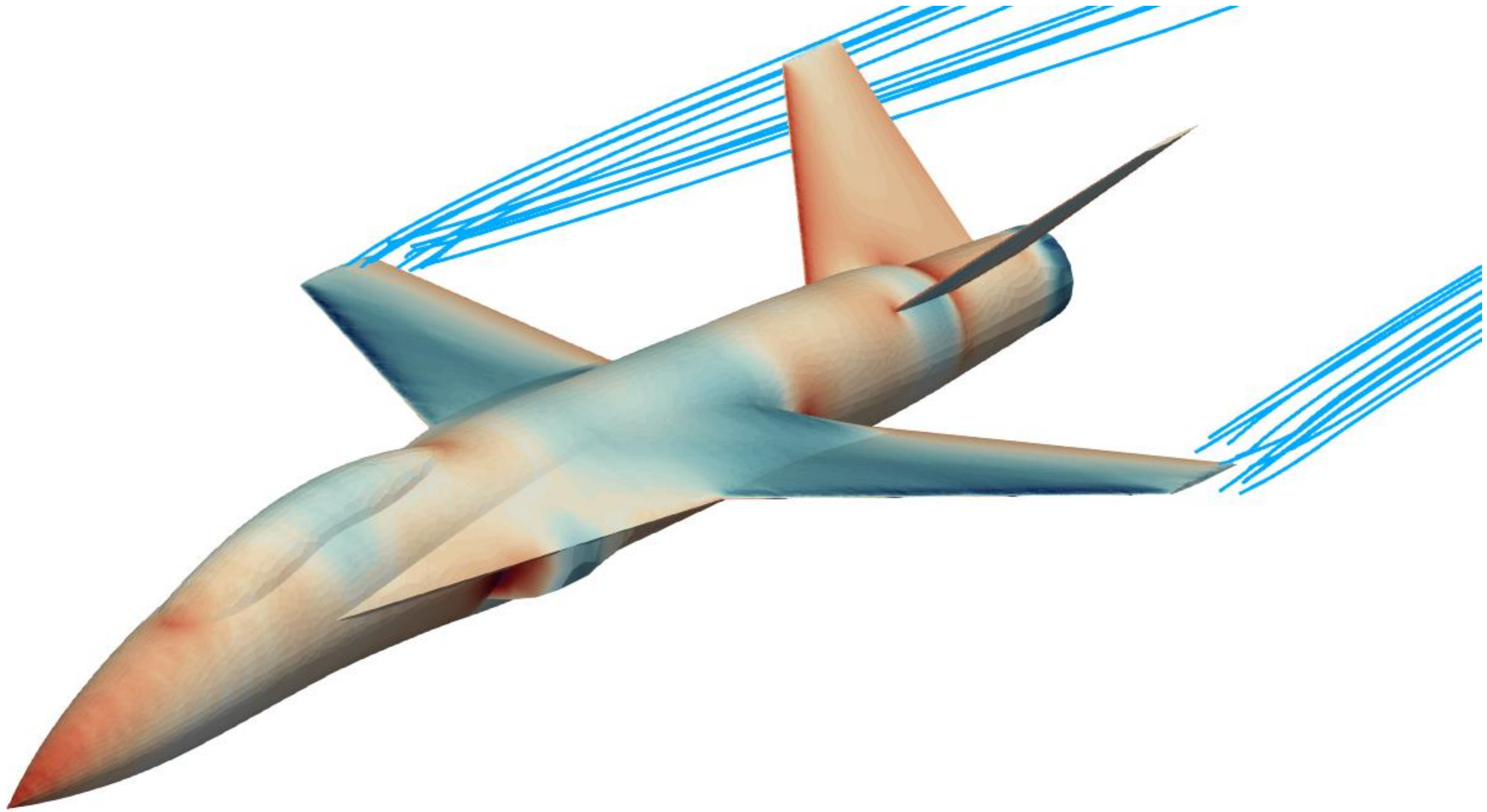
Next steps

- **Improve aerodynamic** model (viscous-inviscid interaction)
- **Use** realistic **composite** structure
- **Include** non-aerodynamic **loads**
- **Use full aircraft** configuration

IFASD 2022-178

AET for preliminary aircraft design

Adrien Crovato – Madrid, June 2022



https://acrovato.github.io