

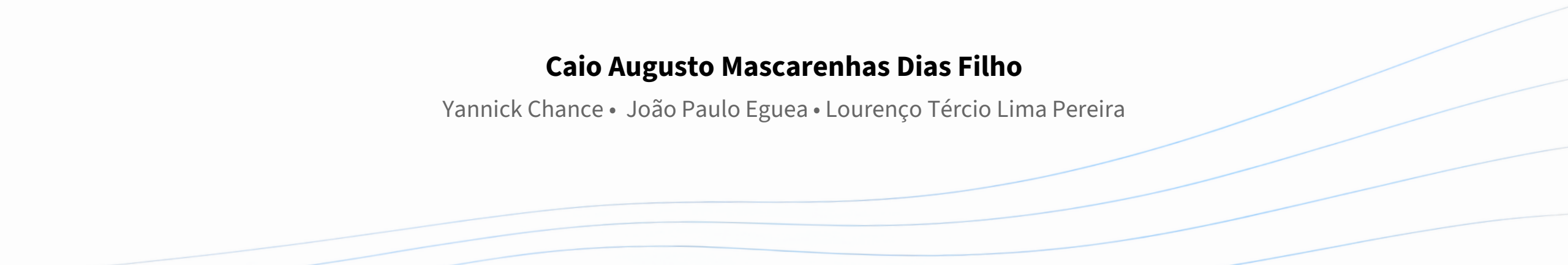
A Data-Driven Framework for Optimal Pressure Sensor Placement in **Wind-Tunnel Testing**

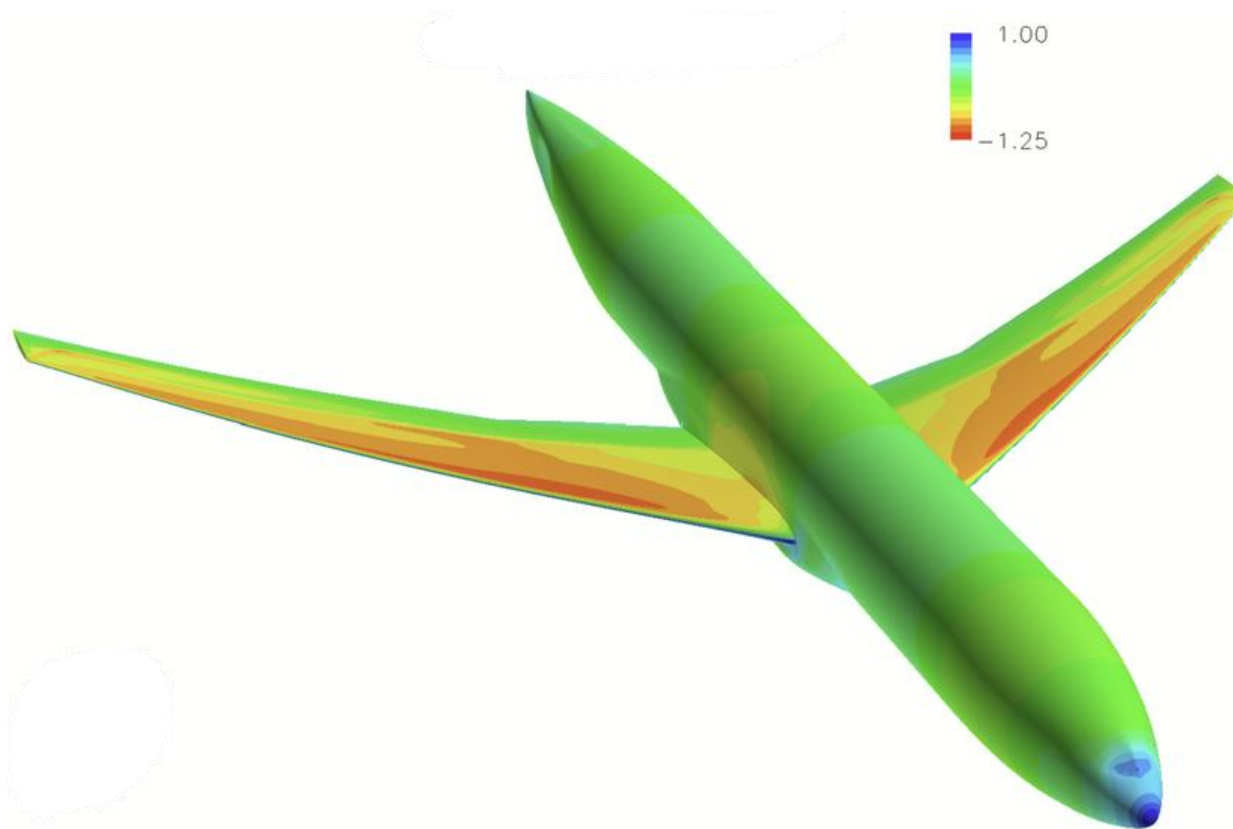
NWTF AI-Enabled Wind-Tunnel Experiments Forum 2026

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NASA Common Research Model pressure distribution.
Adapted from Vassberg *et al.* (2012).

Surface pressure distribution

- Reveals the **local flow behavior**.
- Yields the **integrated aerodynamic forces**.



Wing model with a conventional tap layout.



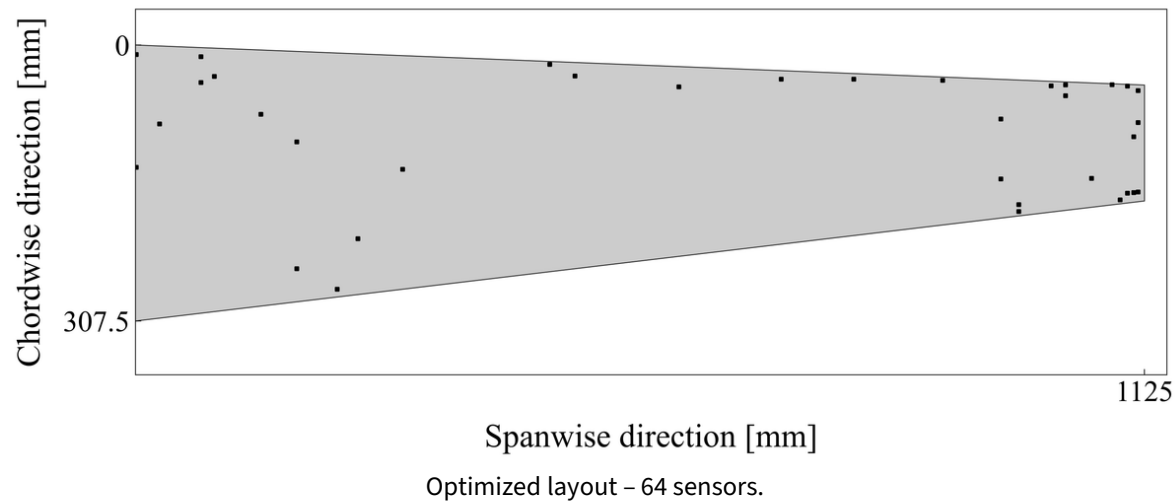
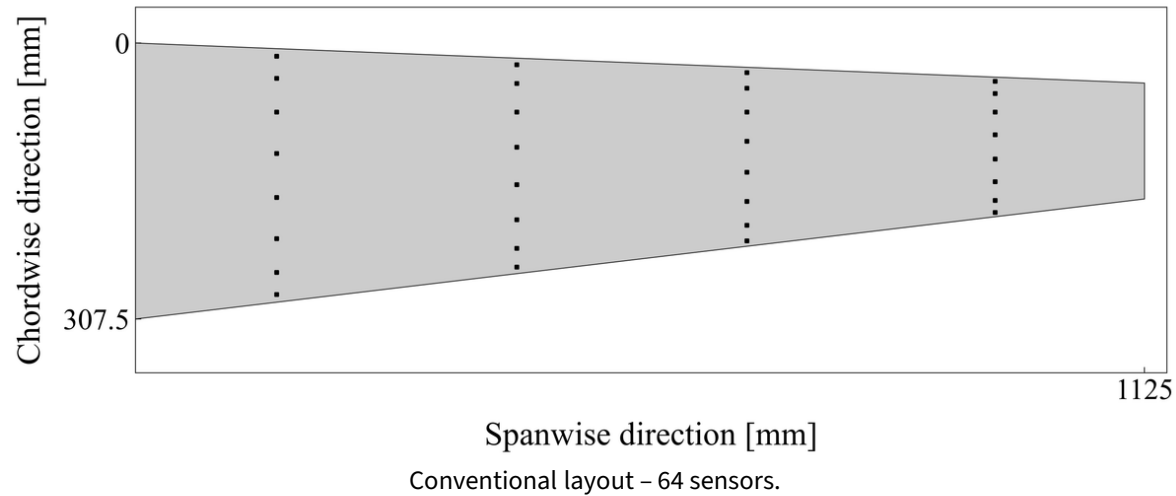
Wing-propeller model internal wiring.

Pressure tap measurements

- Practical and reliable, but **inherently sparse**.
- Constrained by the **internal model space**.
- Even more limited in **complex configurations**.

Conventional tap layouts

- Not optimized for **aerodynamic information gain**.
- Yields only **discrete reference points**.

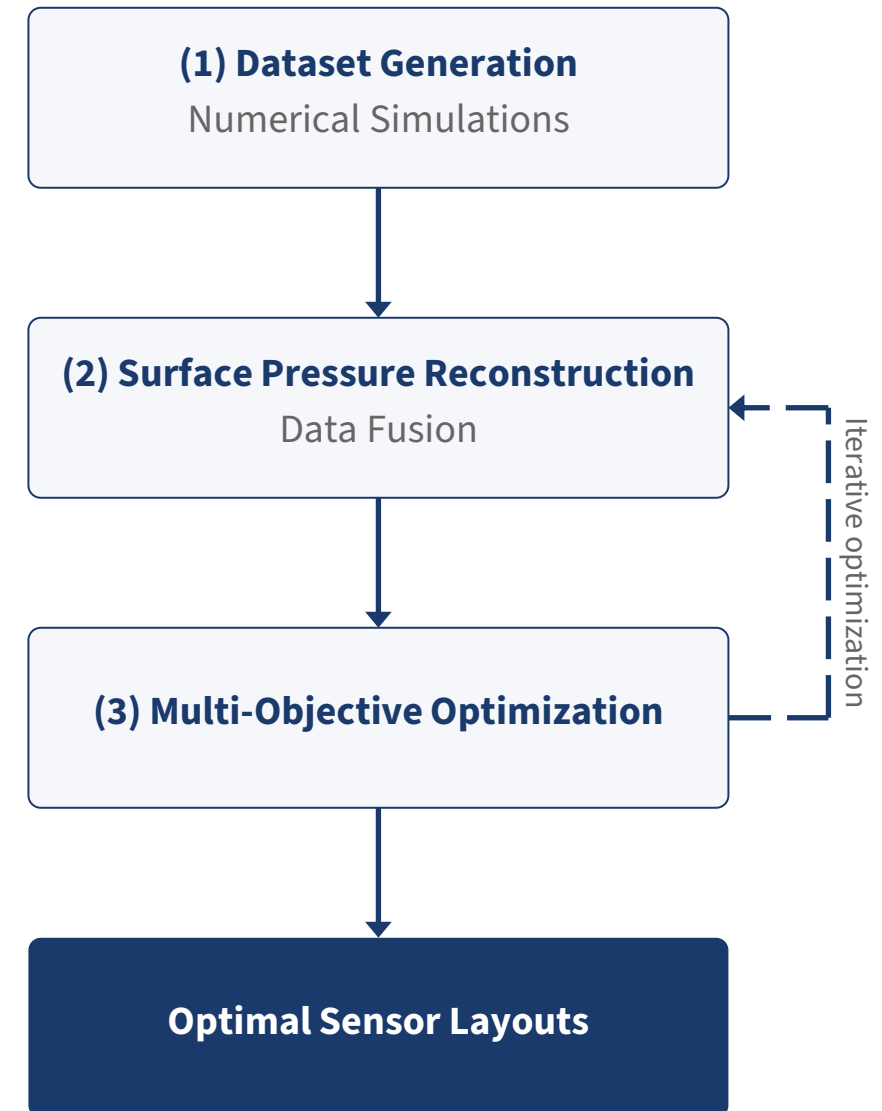


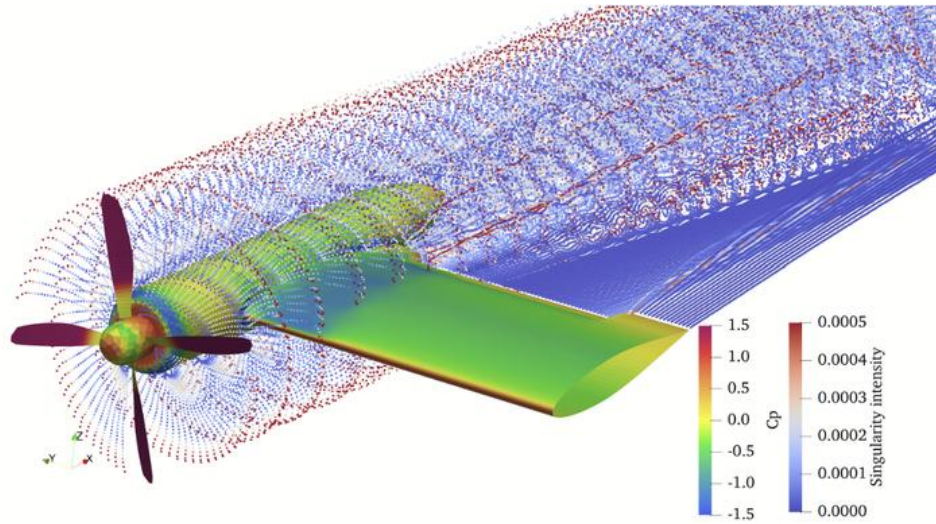
Where should we place our sensors?

- **Count and position** optimized simultaneously.
- Sensors concentrated in **aerodynamically informative regions**.

OPSET (*Optimal Placement of Sensors for Experimental Tests*)

- Optimizes **sensor layout** → maximize **aerodynamic information gain**.
- Exploits **data fusion: sparse measurements + numerical simulations** → complete pressure field.
- Reconstruction accuracy sensitive to **sensor placement** → quality guides **optimal positioning**.





Wing-propeller interaction simulation (DUST).
Niro (2023).

DUST – a mid-fidelity aerodynamic solver

- Models surfaces via **potential flow elements** and shed wake via **vortex particle method**.

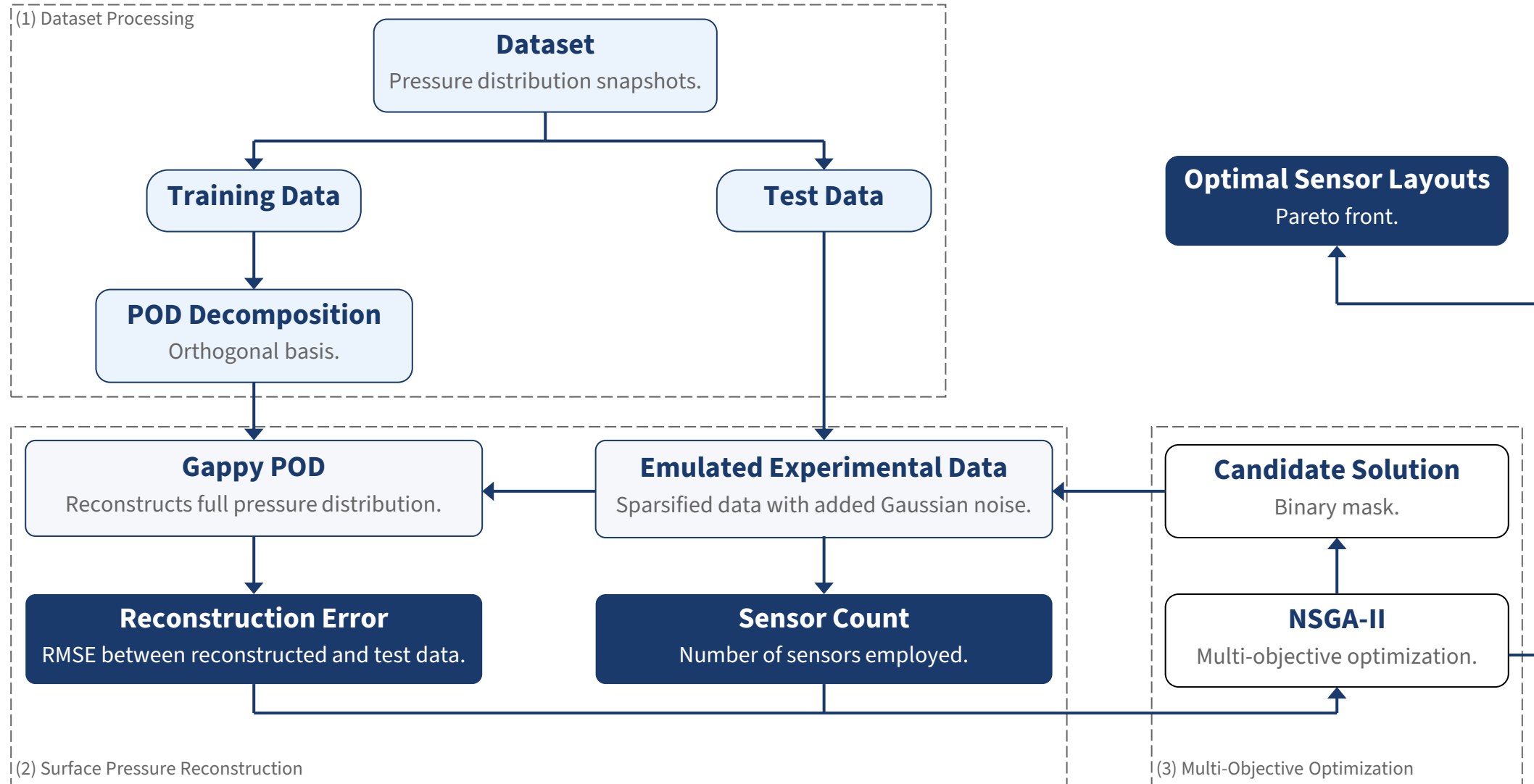
Advantages

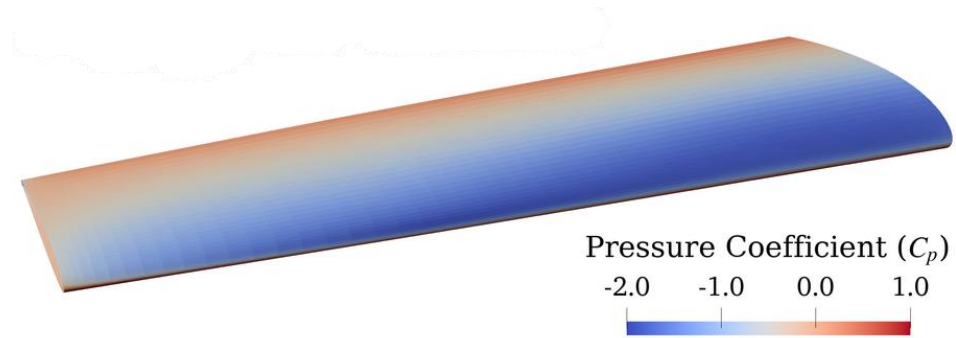
- More efficient than **high-fidelity** solvers.
- Extendable to **wing-propeller interaction**.

Disadvantages

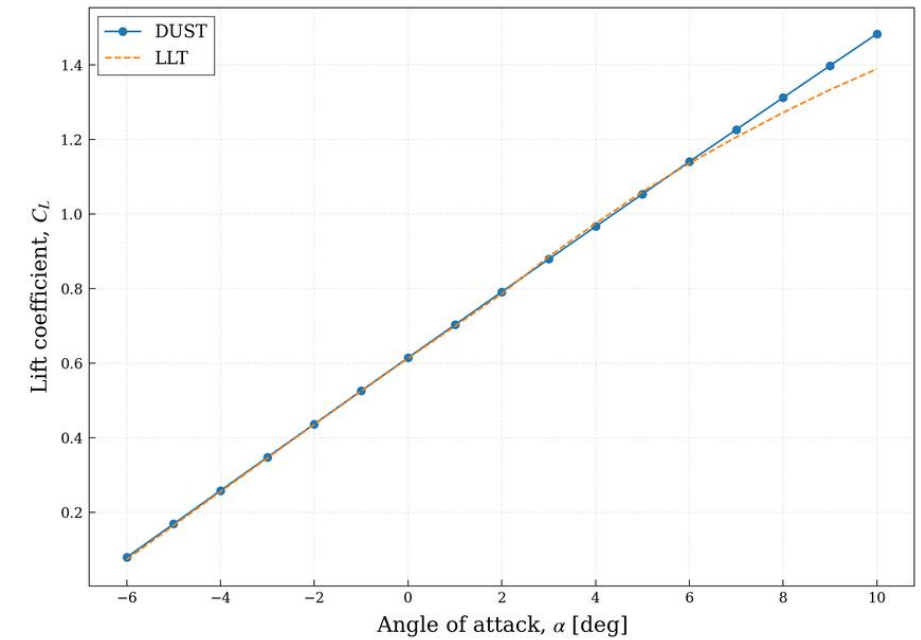
- Inviscid – reduced reliability at **high angles of attack**.

Tugnoli *et al.* (2021).





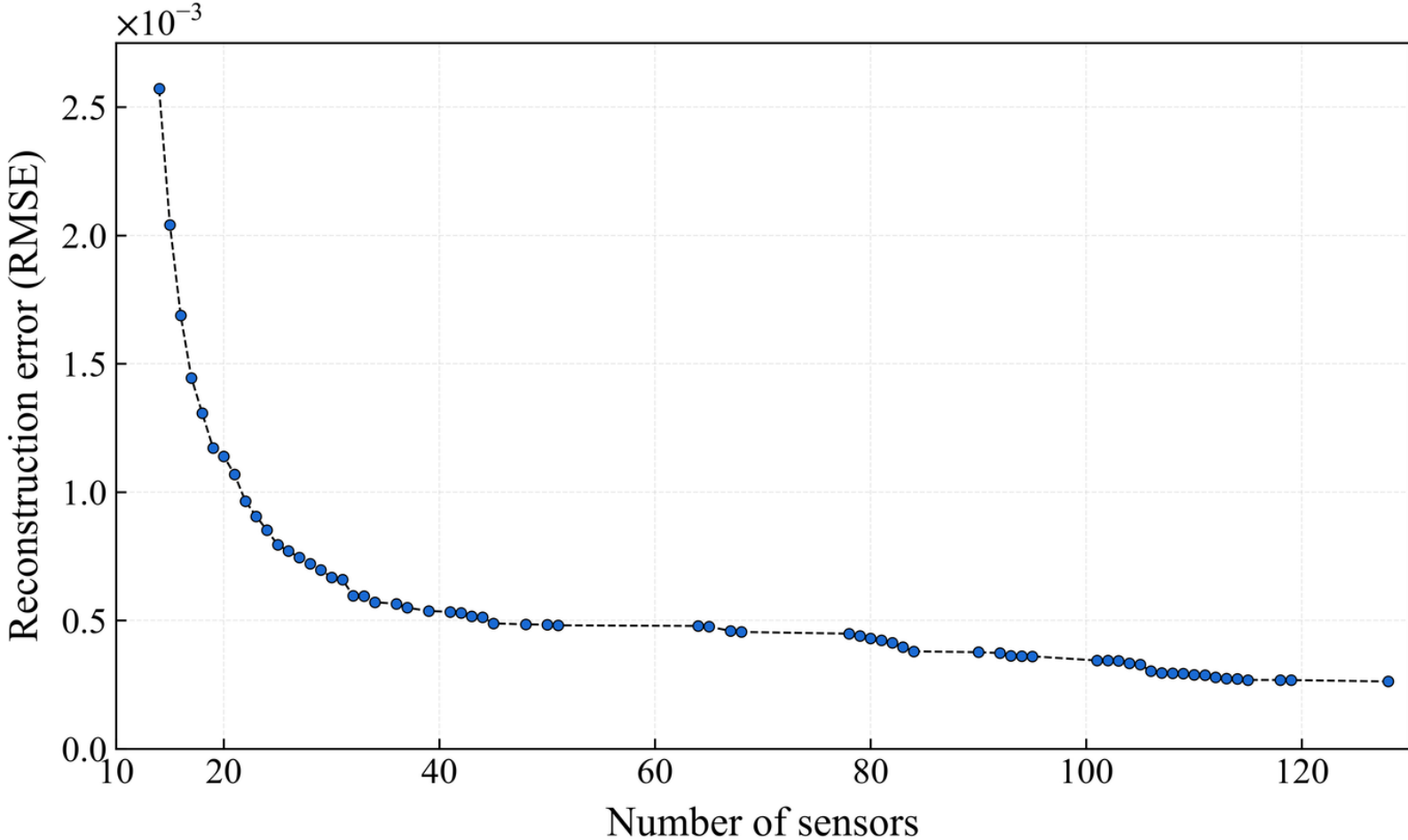
Trapezoidal half-model wing – C_p distribution.



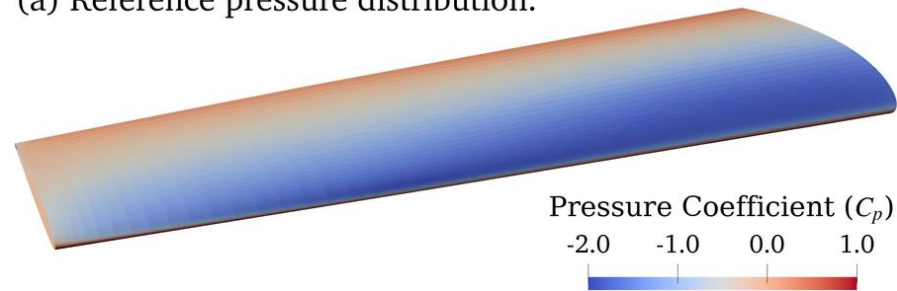
DUST validation against LLT.

Tapered half-model wing

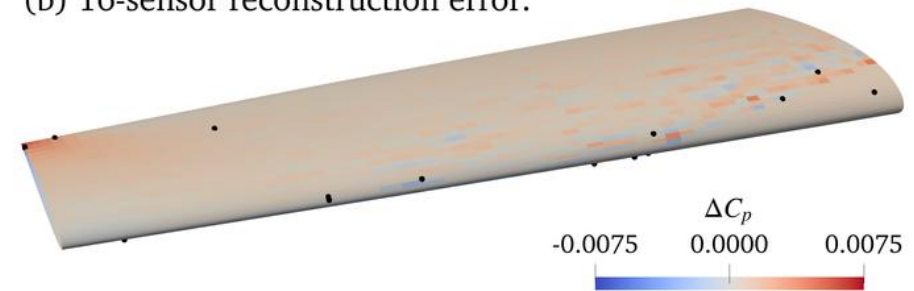
- **17 AoA** generated with DUST.
- Verified against **LLT predictions** from XFLR5.



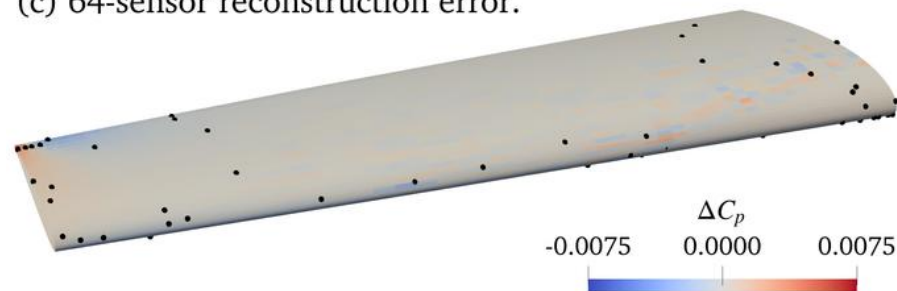
(a) Reference pressure distribution.



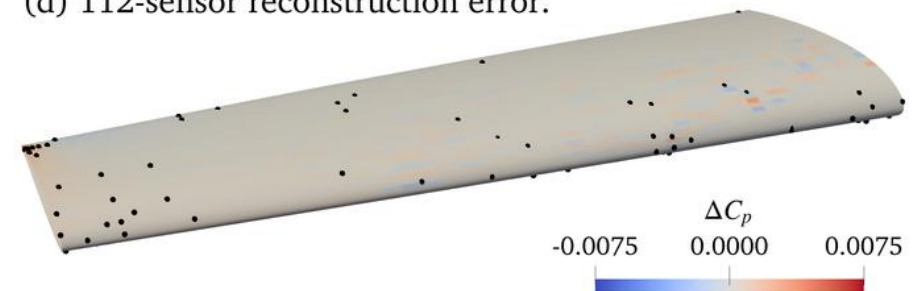
(b) 16-sensor reconstruction error.



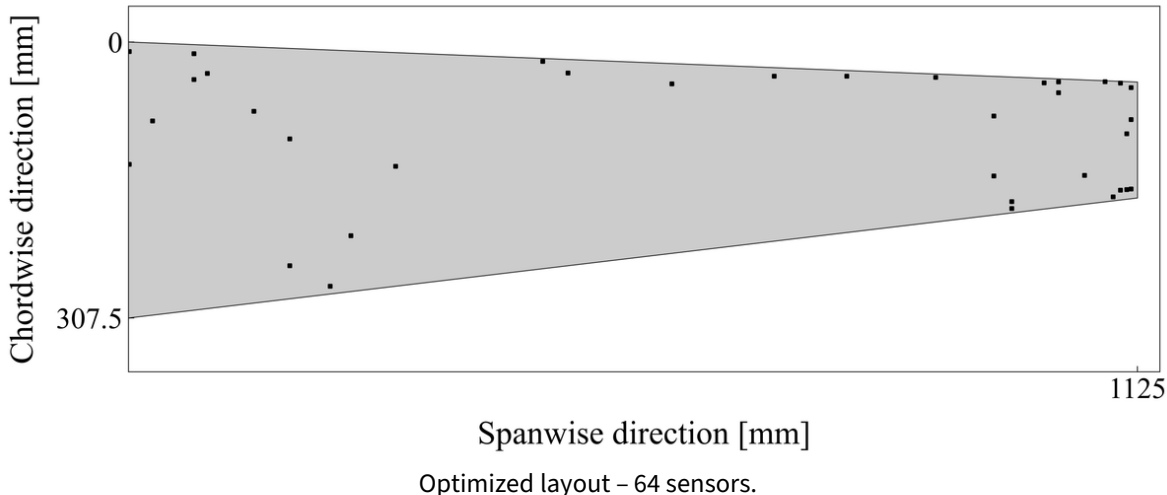
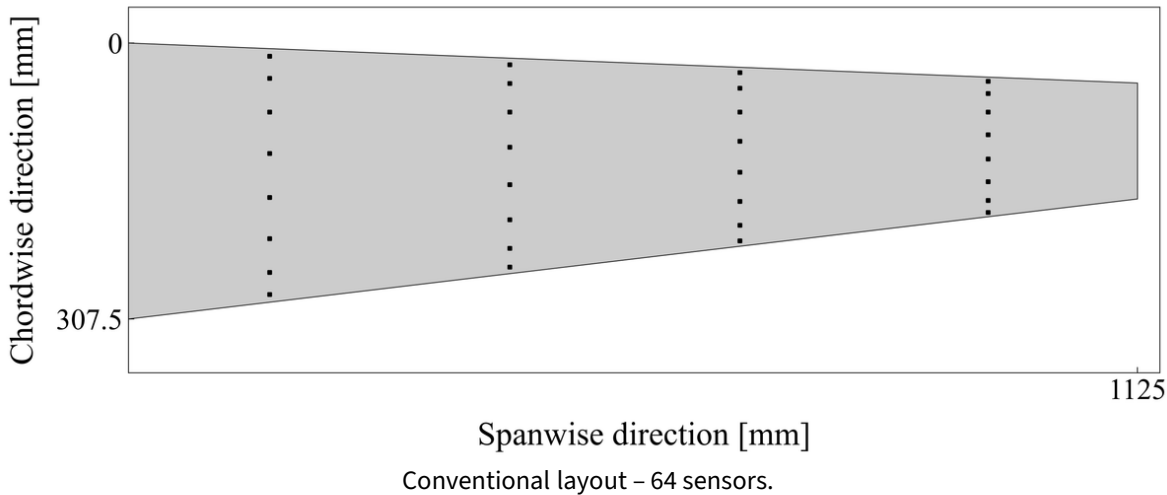
(c) 64-sensor reconstruction error.



(d) 112-sensor reconstruction error.



- Beyond the **Pareto knee**, additional sensors yield **diminishing returns**.
- Optimal layouts concentrate near the **suction peak**, **suction surface** and **wingtip**.



Sensor Count	Conventional RMSE	Optimized RMSE
64	1.2×10^{-2}	4.8×10^{-4}
112	5.6×10^{-3}	2.8×10^{-4}

Conventional vs. Optimal

- **At least one order of magnitude improvement in reconstruction error.**
- Fewer sensors – **better accuracy.**

OPSET demonstrates optimal sensor placement for pressure reconstruction

- **DUST** provides a computationally efficient training dataset.
- **NSGA-II** effectively navigates the trade-off between **sensor count** and **reconstruction error**.
- Formulation compatible with **Gappy POD** and **alternative reconstruction techniques**.

Current limitations and next steps

- **Panel centroids** introduce spatial bias – **physical pressure tap locations** are preferred as sensor candidates.
- **Gappy POD** is mode-limited – **nonlinear ROMs** could improve reconstruction with fewer sensors.
- Validate against **actual experimental measurements**.
- Extend to eVTOL configurations with wing-propeller interaction.

Thank you! Questions?



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