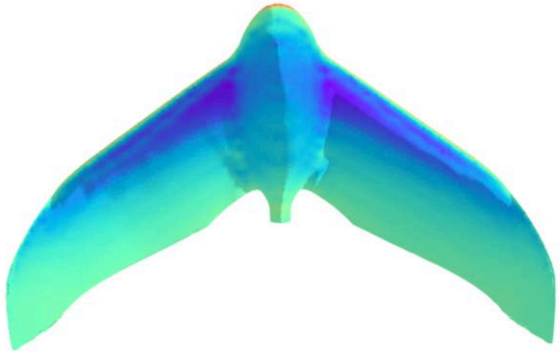
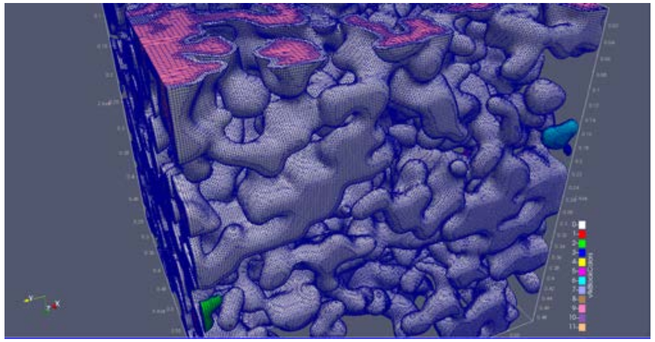
Geodesic Convolutional Shape Optimization





P. BAQUE

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F. FLEURET

P. FUA

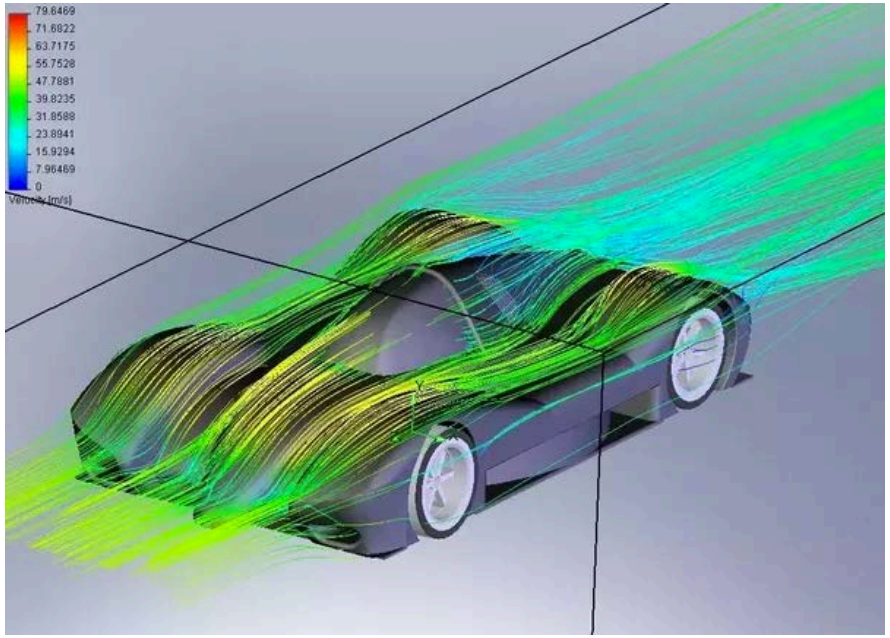
NEURALCONCEPT

IDIAP

EPFL

3D Shape Design

- Design a shape.
- Simulate its performance.
- Redesign.



It works but:

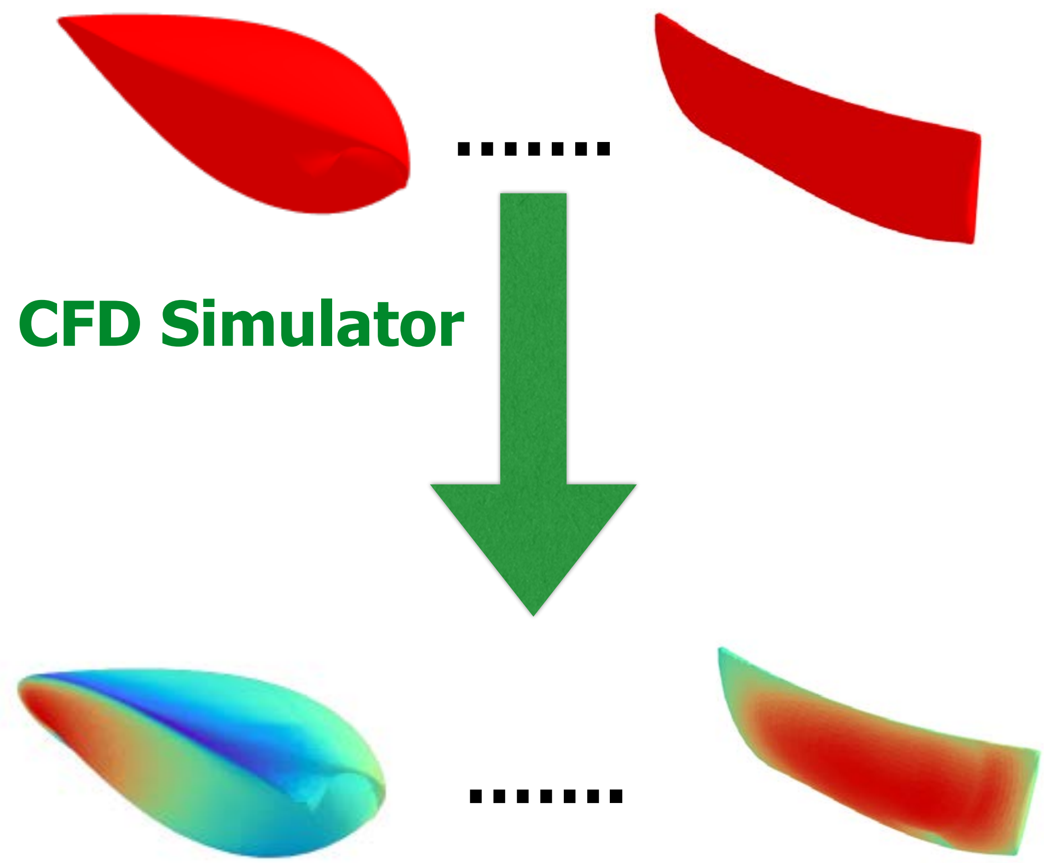
It takes hours or days to produce a single simulation.

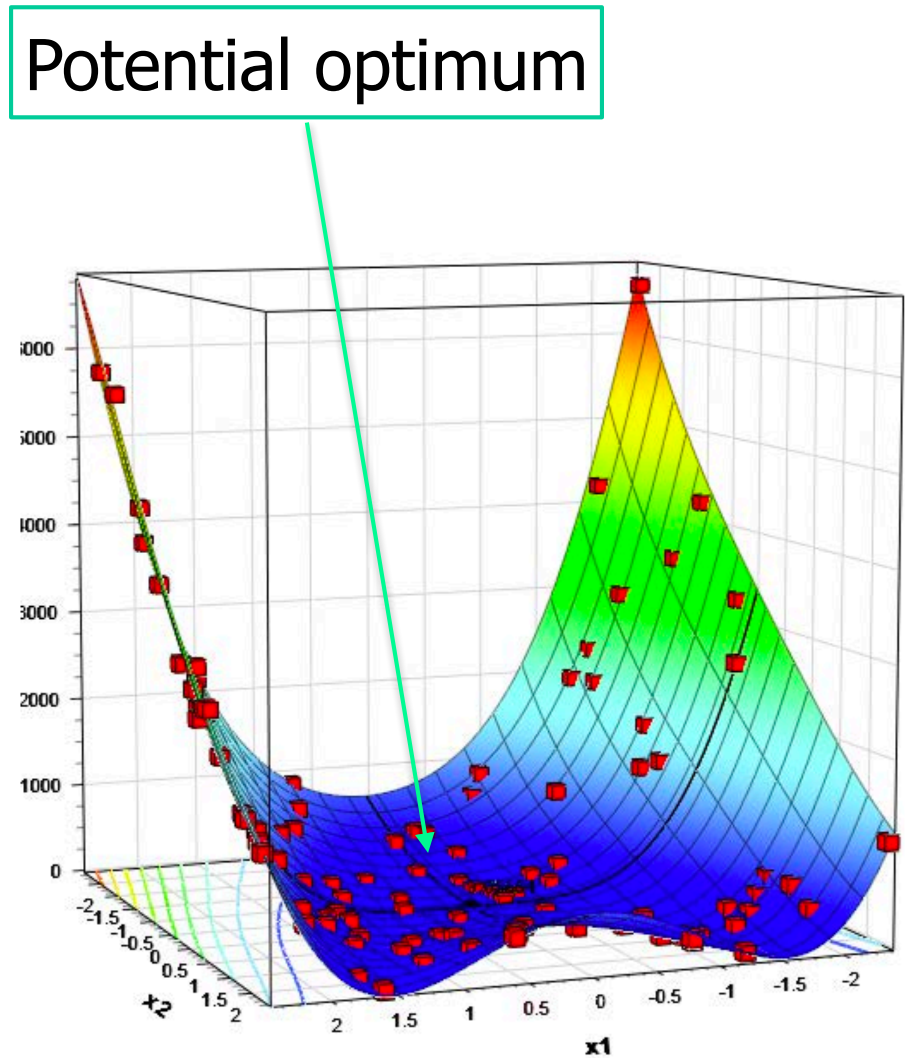
This constitutes a serious bottleneck in the exploration of the design space.

Designs are limited by humans' cognitive biases.

EPFL

Non Linear Regression



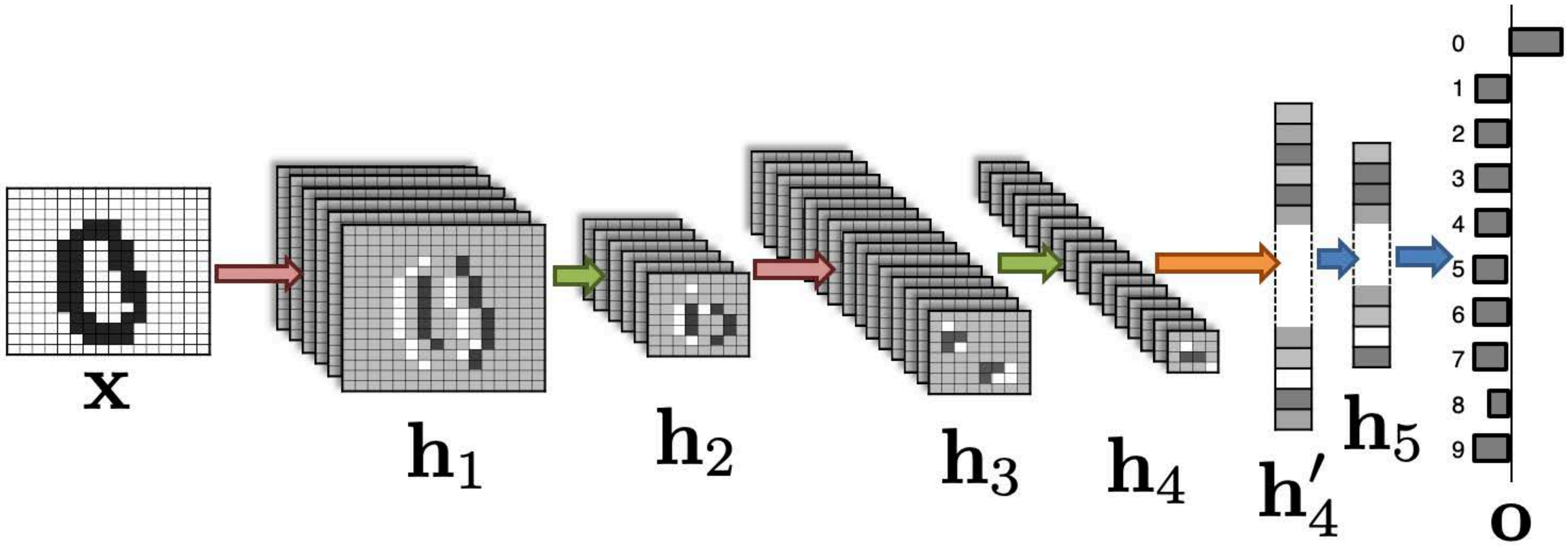


- Drag
- Pressure Coefficients
- Boundary Layer Velocities
- …

The response surface can be approximated by a CNN.

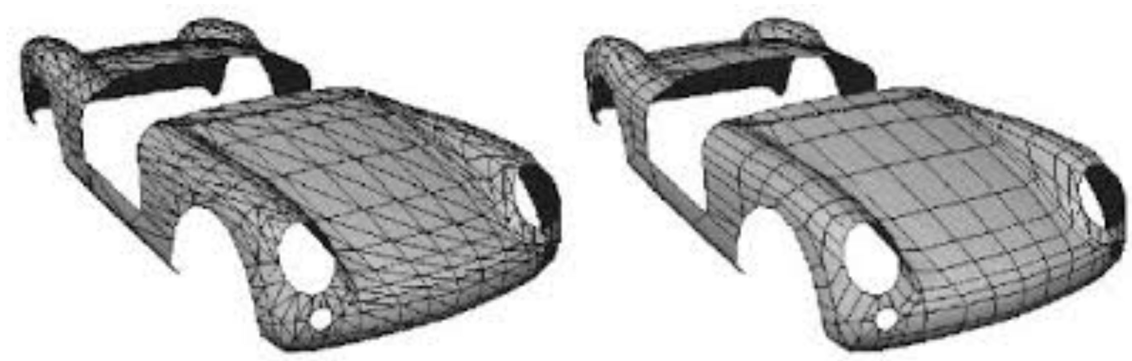
EPFL —> The model can have any number of parameters.

Reminder: Conventional CNN



- Perform convolutions on rectangular grids.
- Implicitly depends on their Euclidean structure.

Object Representations



- 3D objects are often represented as triangulations or quadrangulations.
- The individual facets are not always regular.

—> Need convnets that can operate on those.

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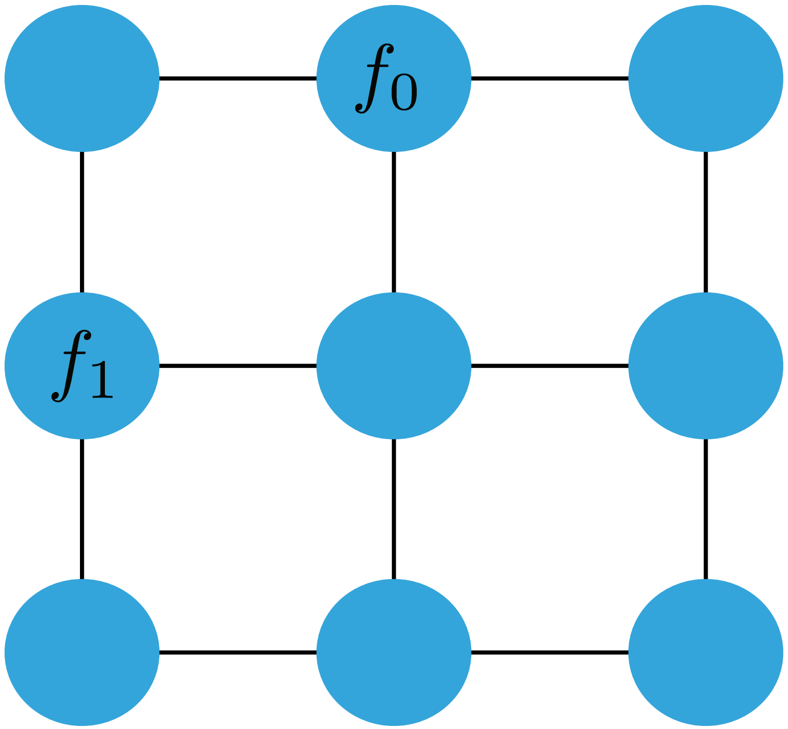
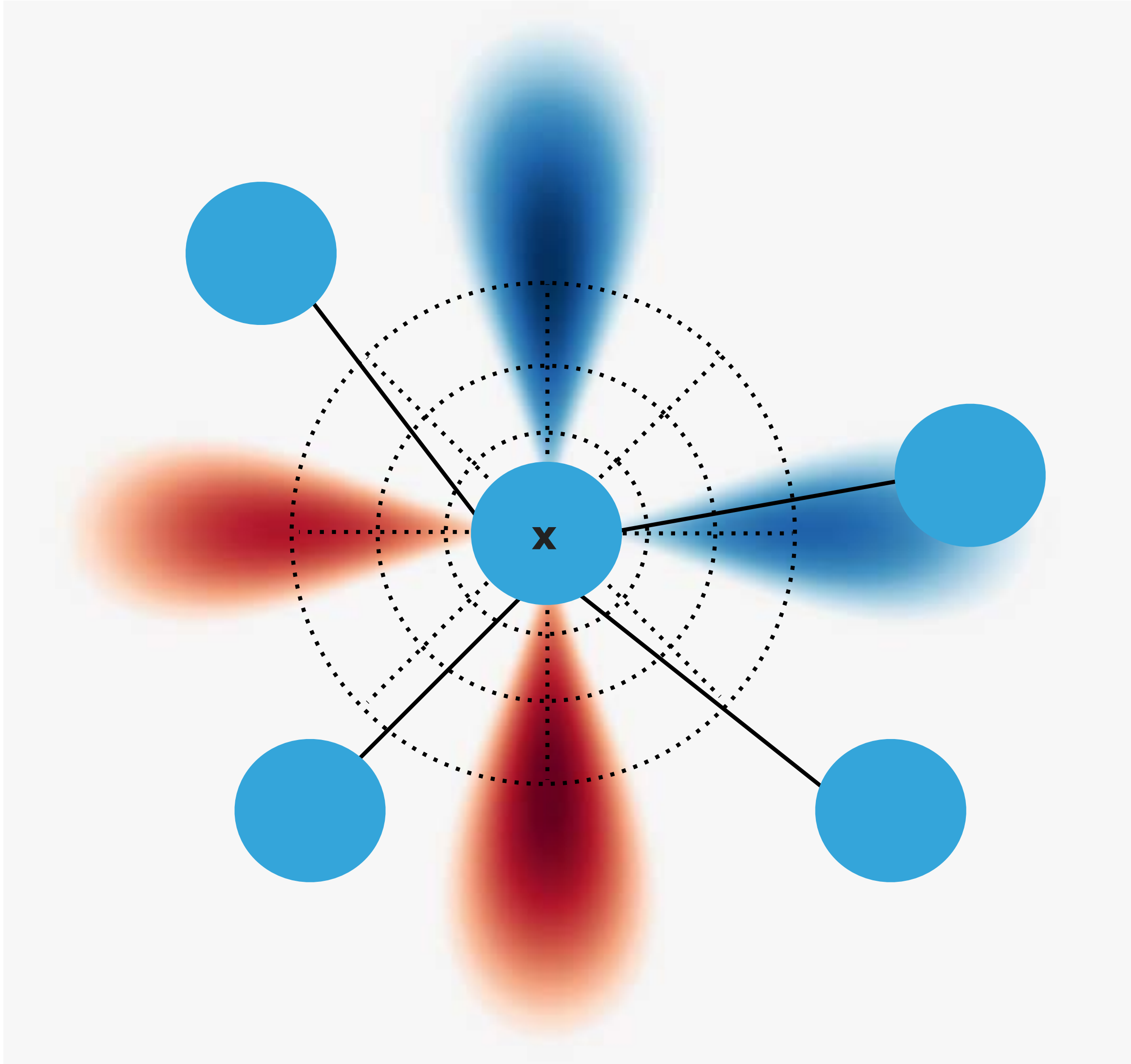
From Grid to Meshes



$$w_0 f_0 + w_1 f_1 + \ldots$$



- Perform convolutions on irregular meshes.
- Estimate geodesic distances.

Mesh Convolutions

Let $f = (f^1, \ldots, f^N)$ be defined at each vertex ${\mathbf{X}^i}_{1 \leq i \leq N}$ of mesh $\mathbf{M}$.

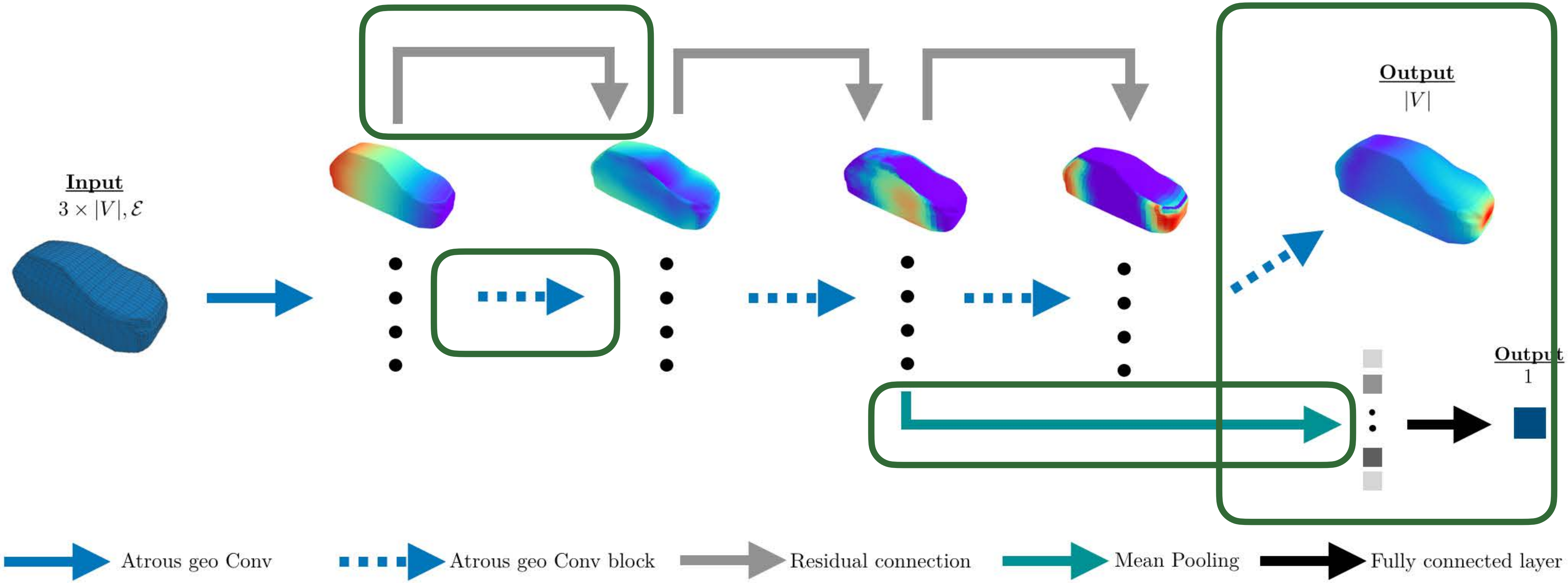
$$
\begin{aligned}
f \star g &= \sum_{k \in 1, \ldots, K} g_k D_k f \ , \\
(D_k f)^i &= \sum_{j \in \mathcal{N}^i} f^j \exp\left(\frac{-(\rho(\mathbf{X}^i, \mathbf{X}^j) - \alpha_{k\,\rho})^2}{\Sigma_{k\,\rho}} \right) \exp\left(\frac{-(\theta(\mathbf{X}^i, \mathbf{X}^j) - \alpha_{k\,\theta})^2}{\Sigma_{k\,\theta}} \right),
\end{aligned}
$$

where $\rho(\cdot)$ and $\theta(\cdot)$ are relative geodesic coordinates.

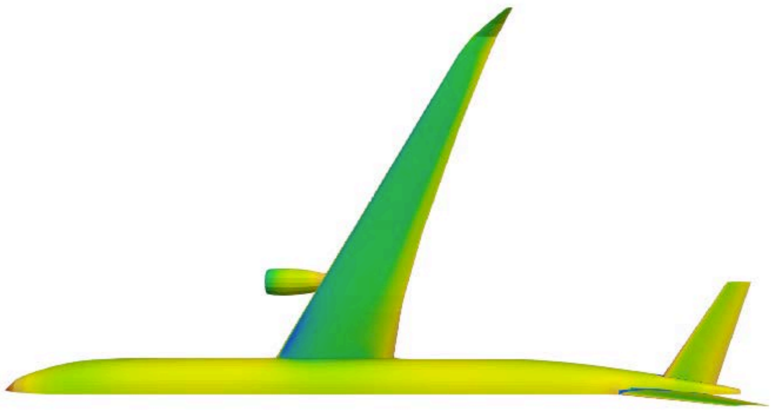
—> Slower convolutions because using the GPUs effectively is more difficult.

—> But can be optimized to make the cost tolerable.

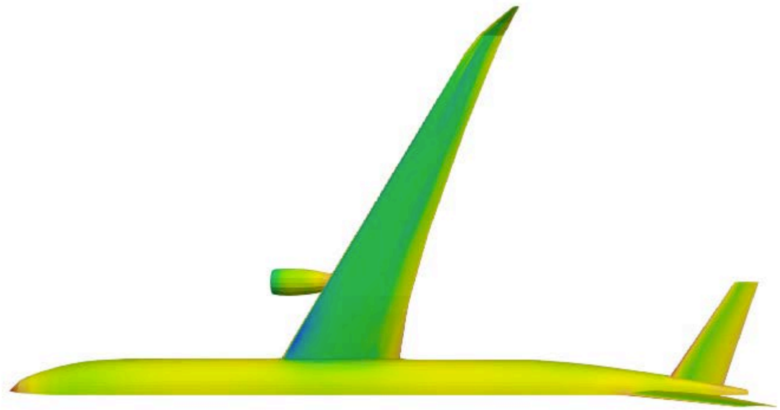
Geodesic CNN



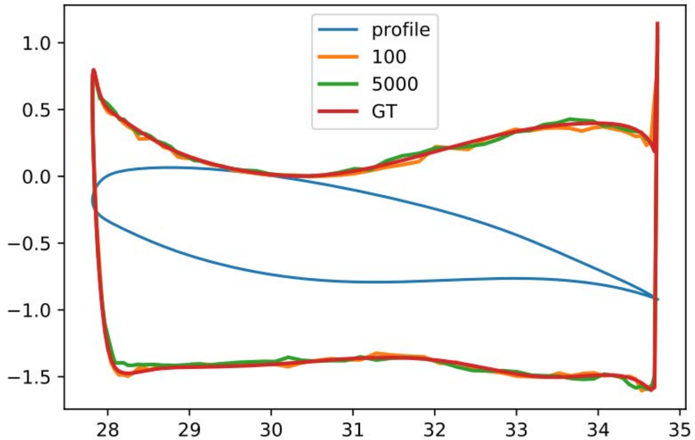
Aerodynamics Simulation



Full Simulation (1 h)

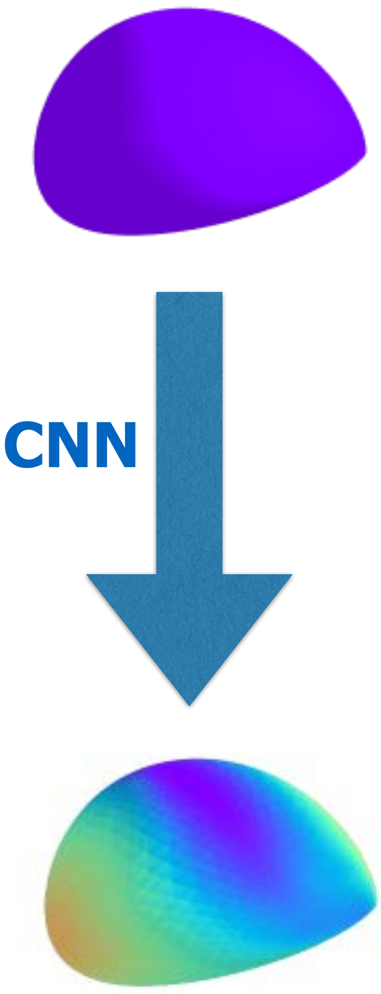


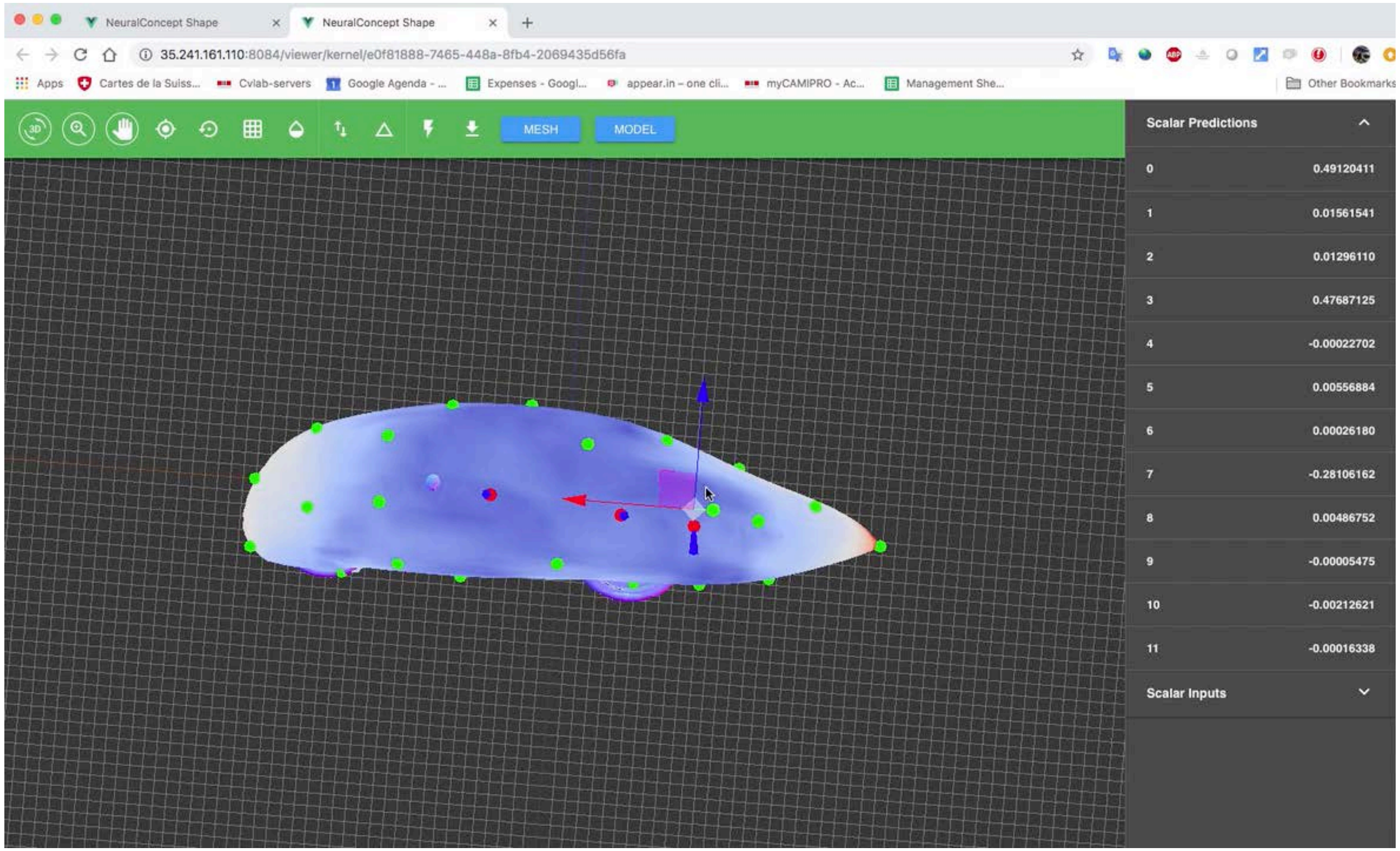
Deep Network (30 ms)



Physics Type	External Aerodynamics
Dataset size	~1000 shapes
R2-accuracy	95 %

Real Time Prediction

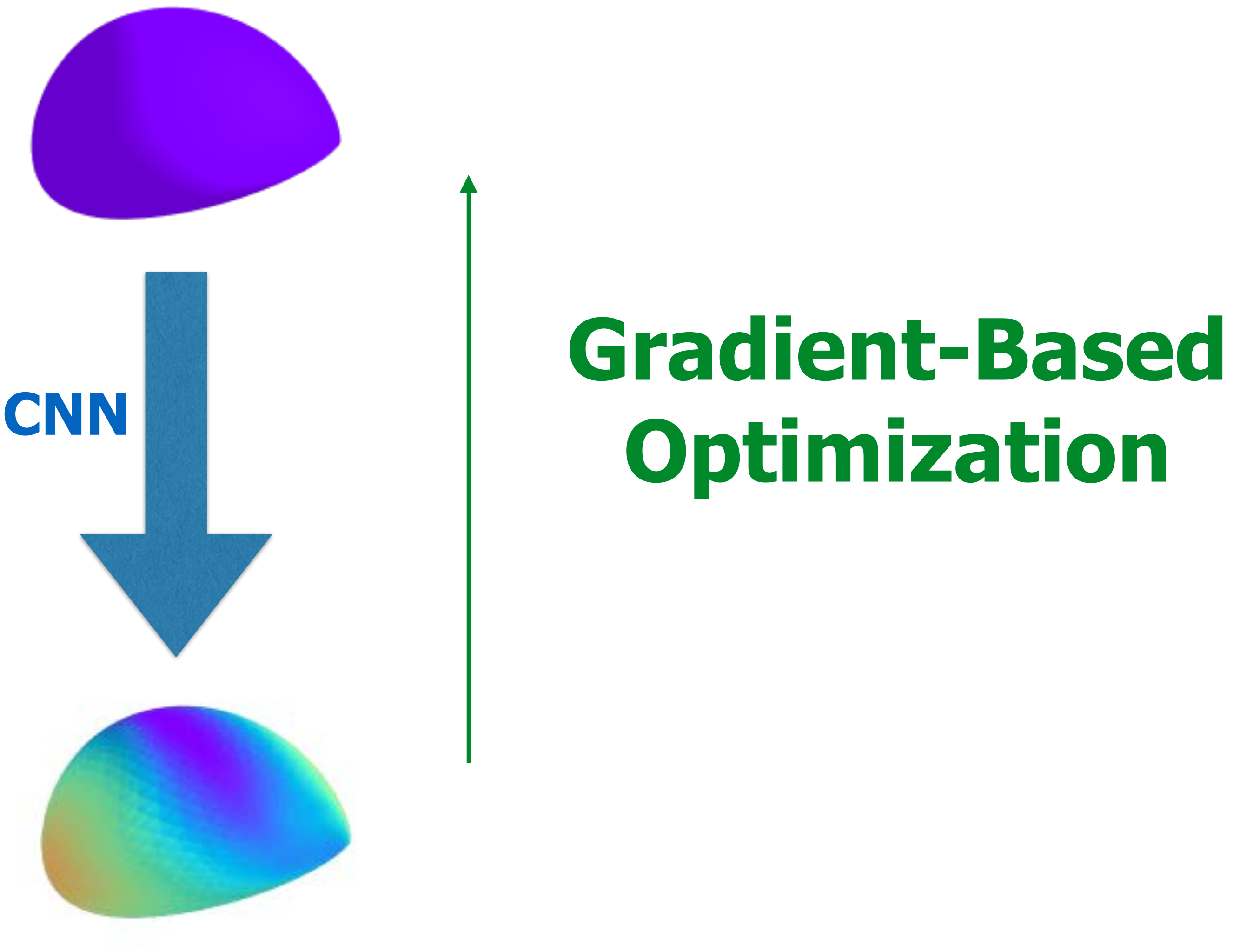




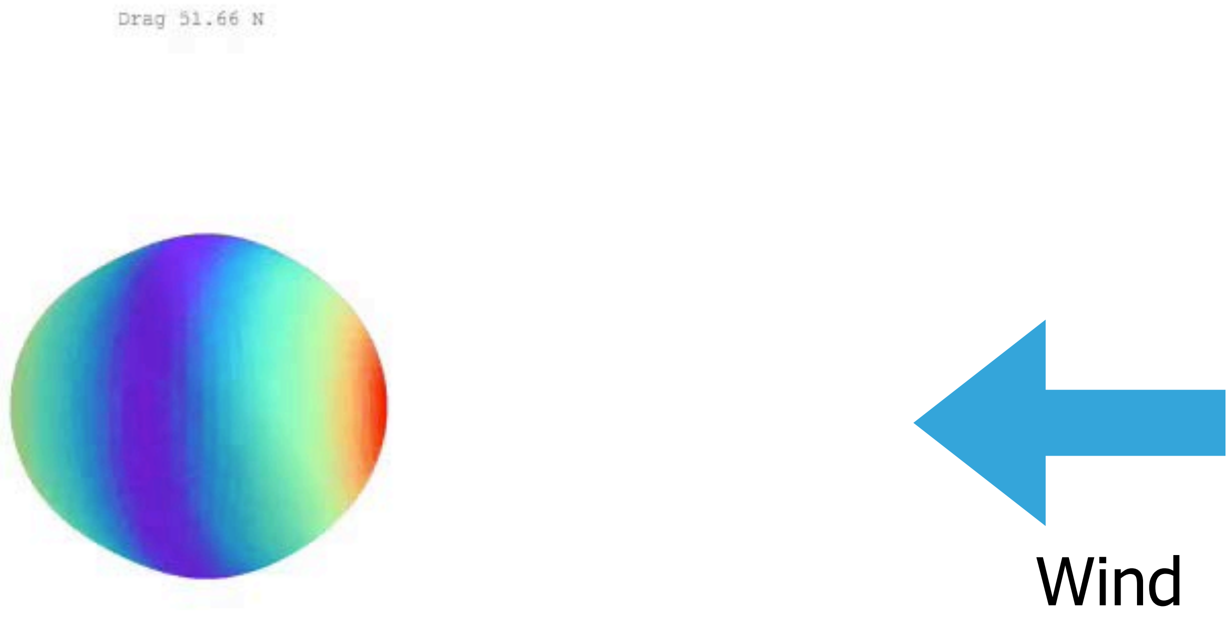
We can now operate on individual vertices.

—> Interactive shape exploration

Differentiable Prediction

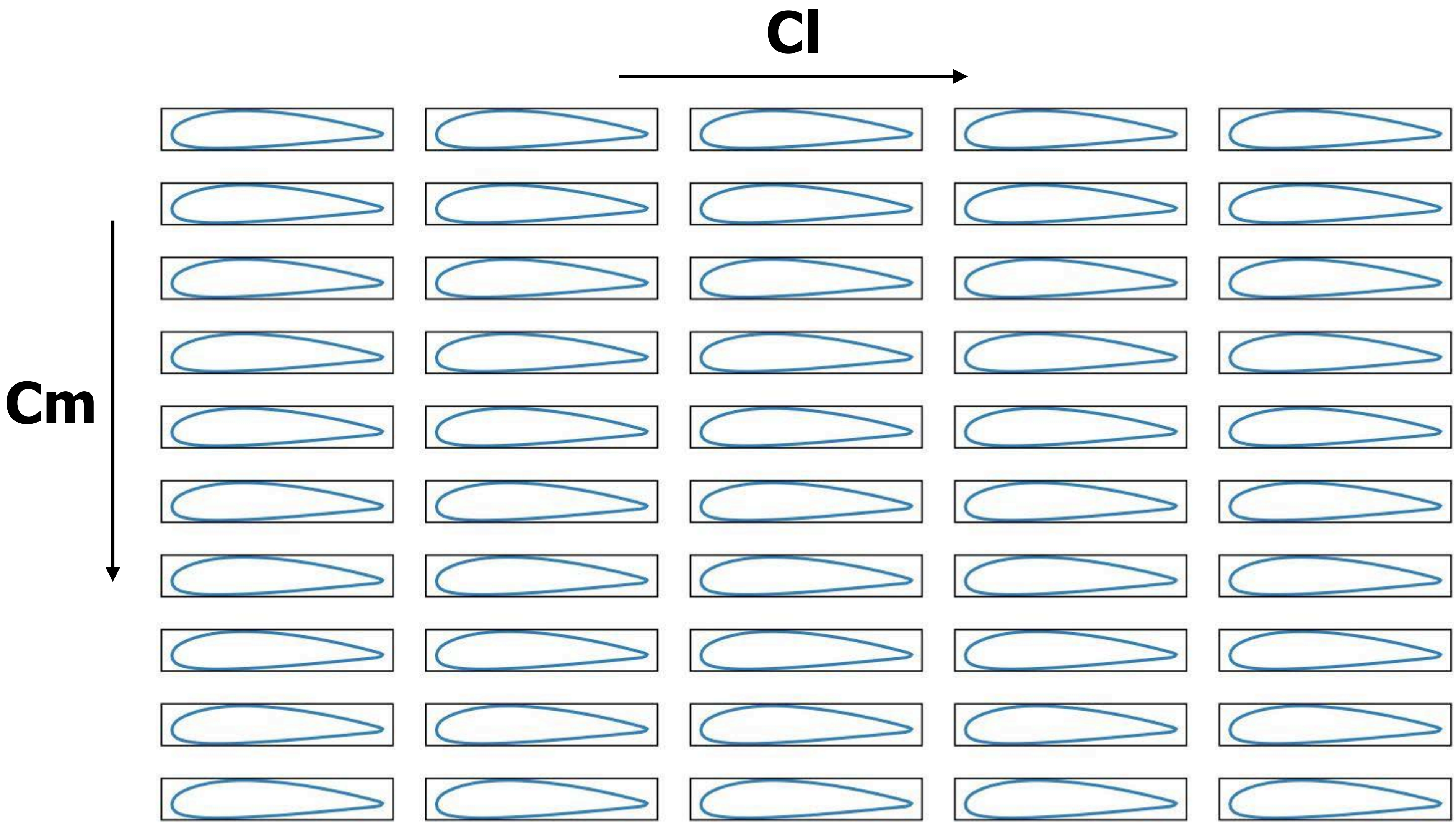


Minimize Drag Under Constraints



Minimizing drag while enclosing a sphere

Naca Profiles

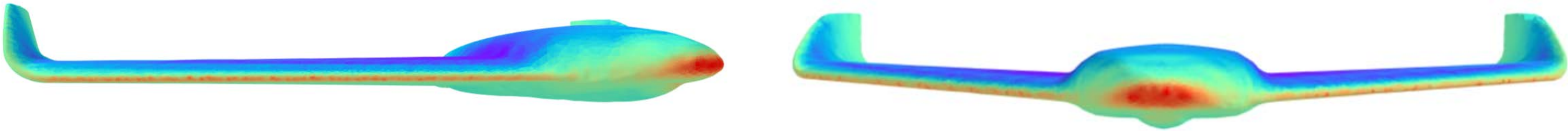


Lift, Drag, Momentum, ….

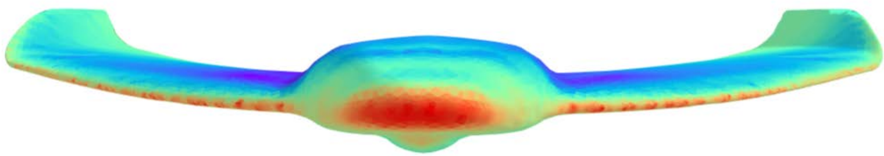
UAV Design

https://www.sensefly.com/

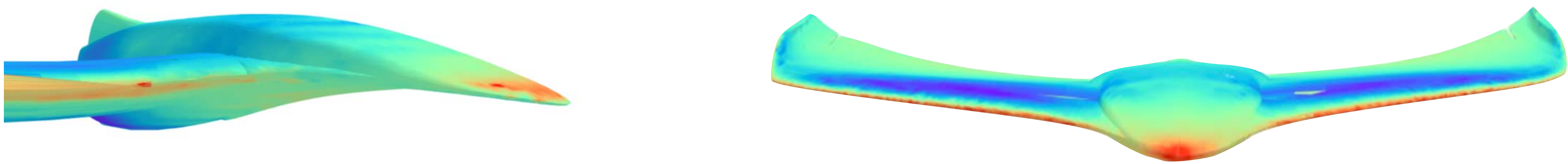
From UAV To Lifting Body



Sensefly drone (L/D 11.9)

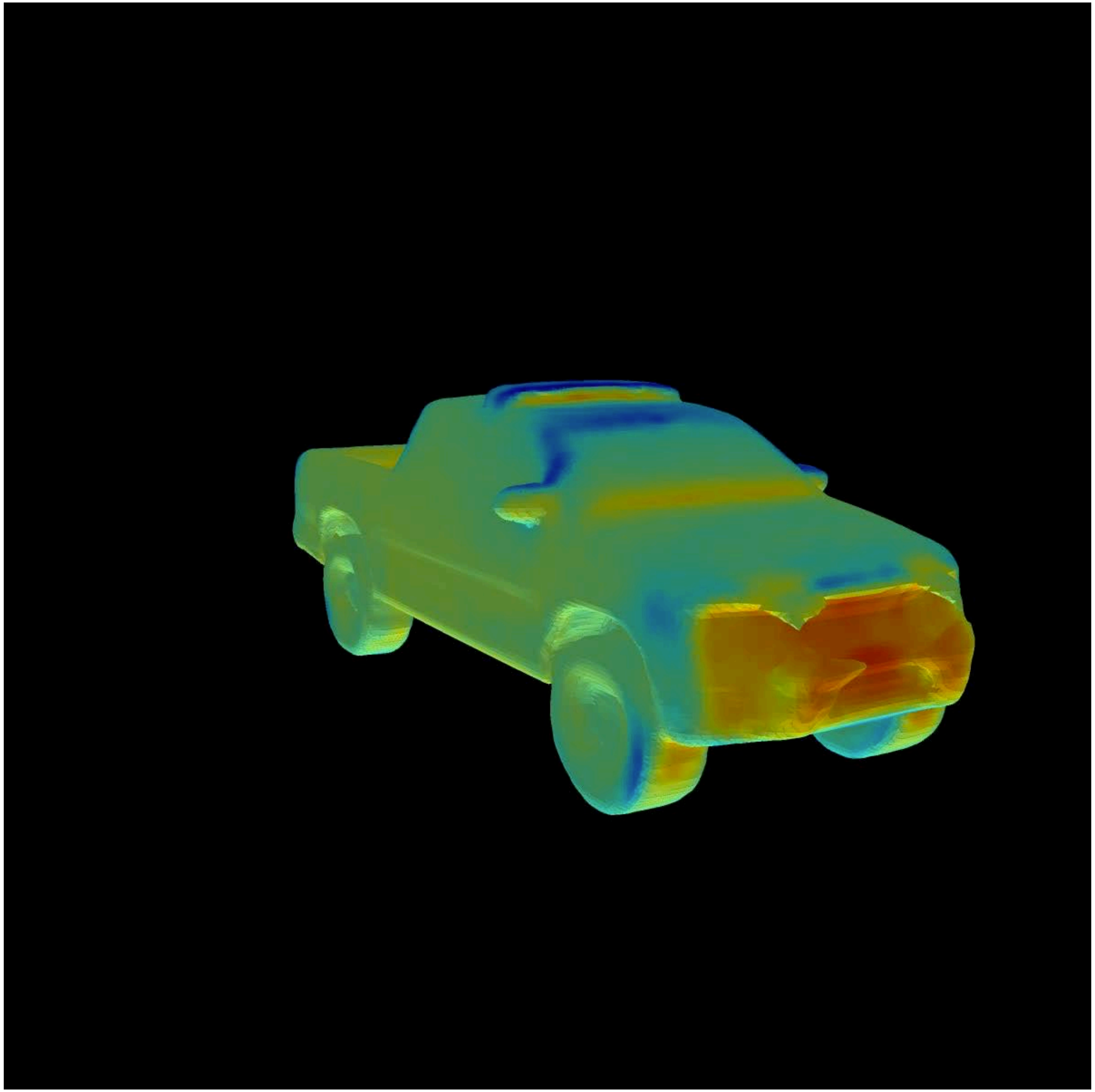


Optimize the wings (L/D 13.7)

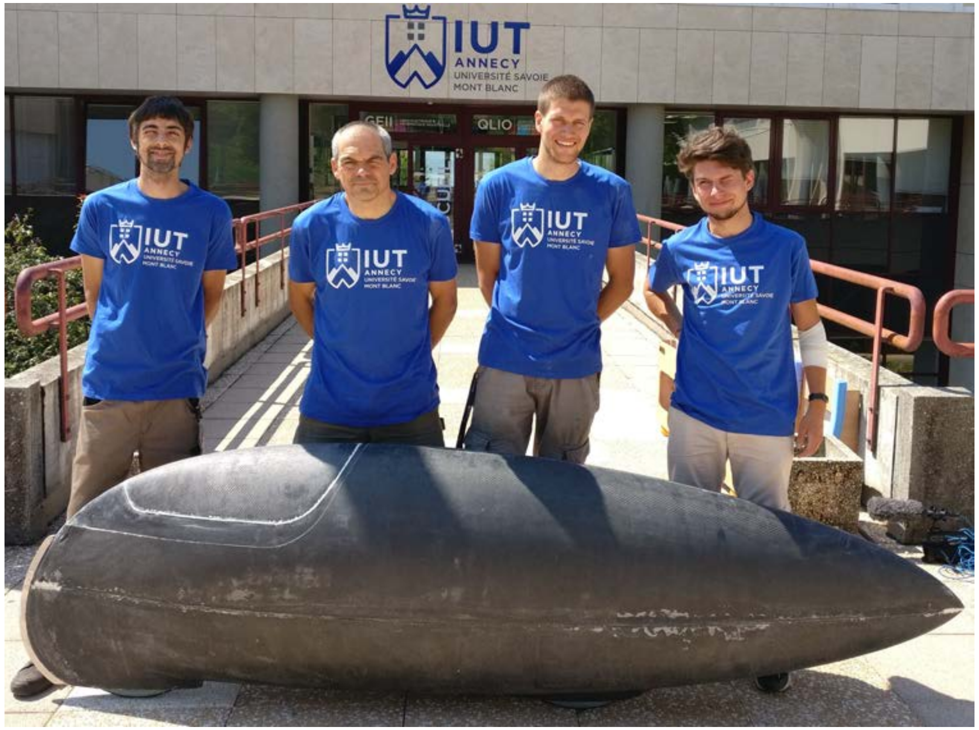


Optimize the fuselage as well

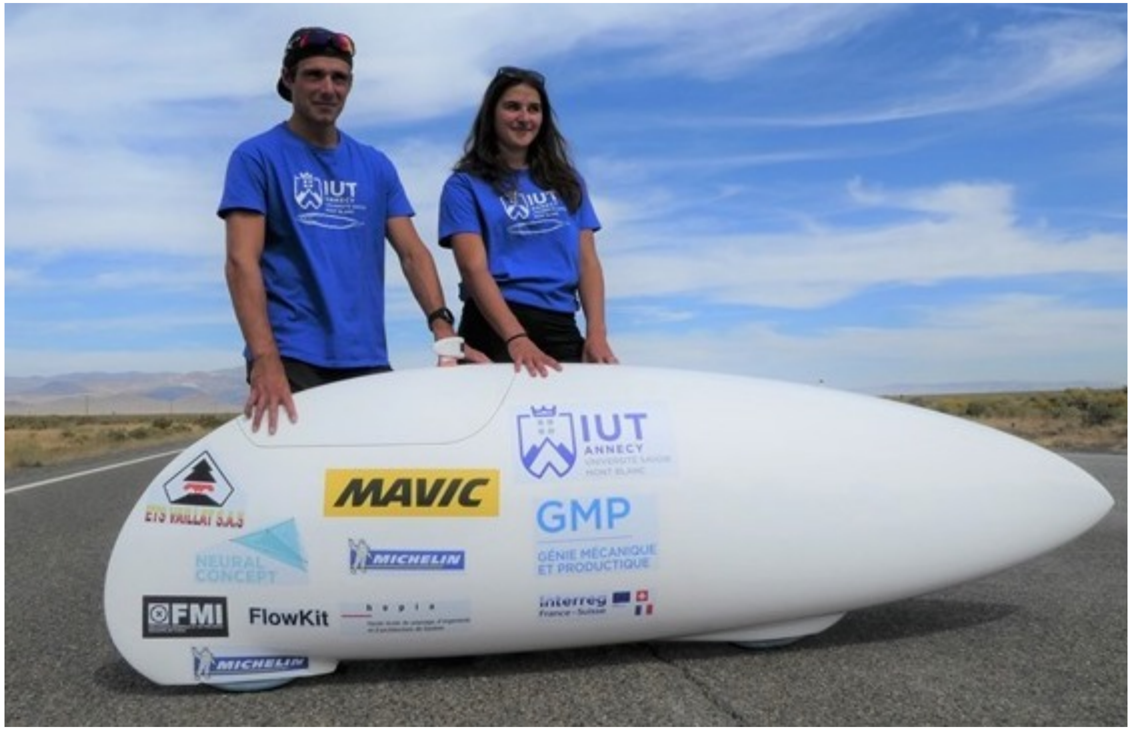
From Pickup-Truck to Sports Car



Bicycle Shell



Altair 6, IUT Annecy, 2018



World Human Powered Speed Challenge
Battle Mountain Nevada, 2019

Women world record: 126,48 km/h
Men student world record: 136.74 km/h

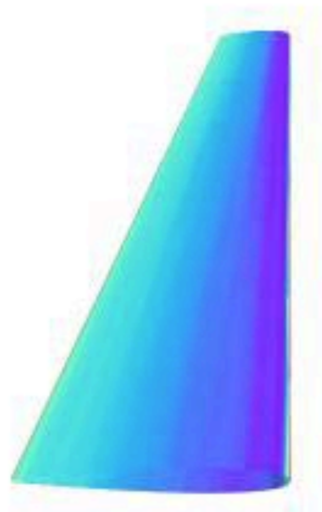
Hydrocontest Boat

Goal:

- **Reduce drag.**
- **Increase stability.**

Hydrofoil

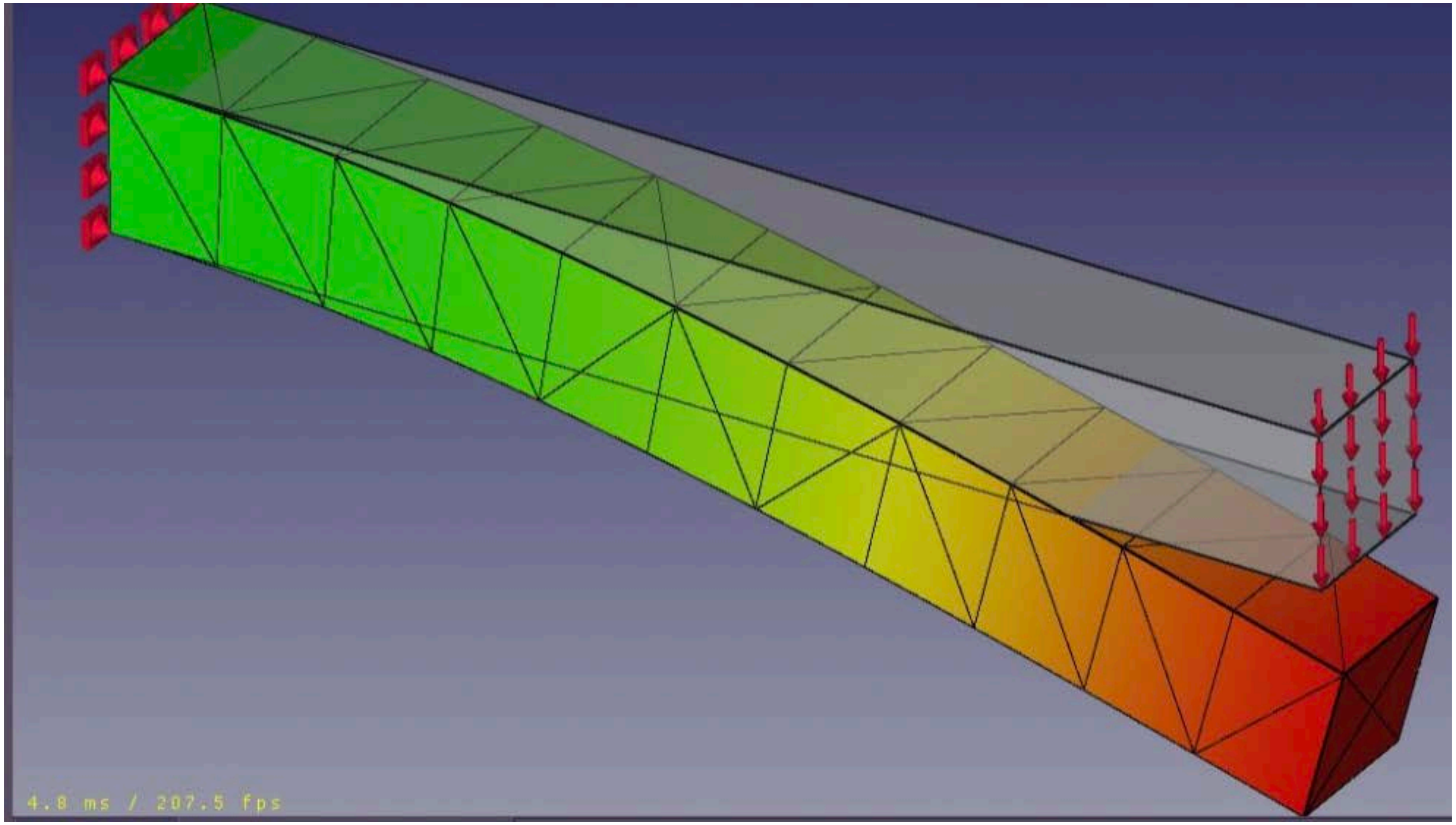
Lift: -0.01 / (target = 0.5) Drag: 0.42, Pitch momentum : -0.01, Roll momentum : -0.51 / (target = 0.5)



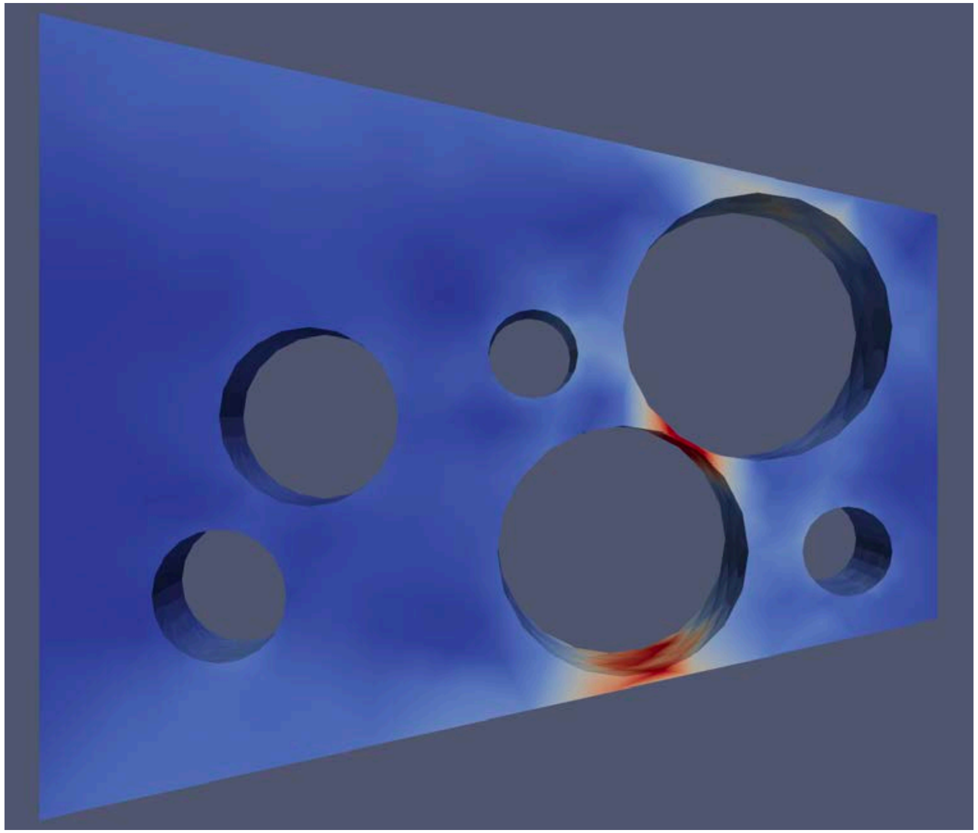
Minimize drag while reaching a target lift and stability.

—>A slightly unexpected shape.

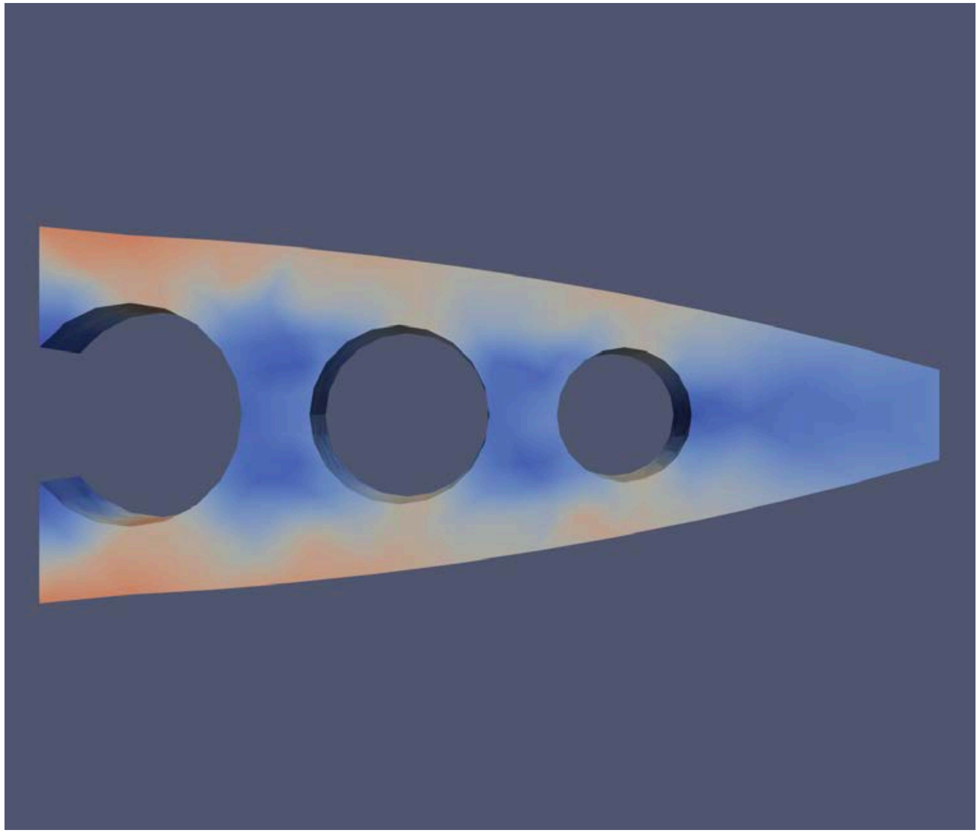
Cantilever Beam



Structural Design



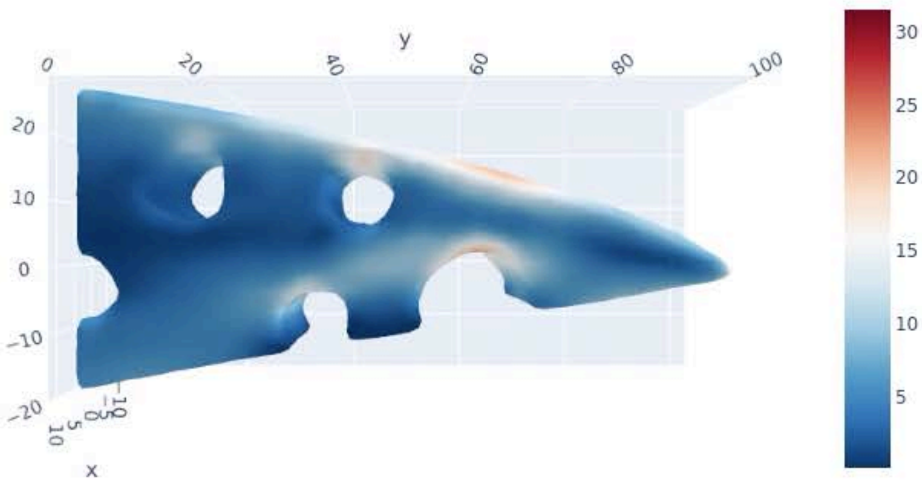
Poor design: Heavy, high stresses

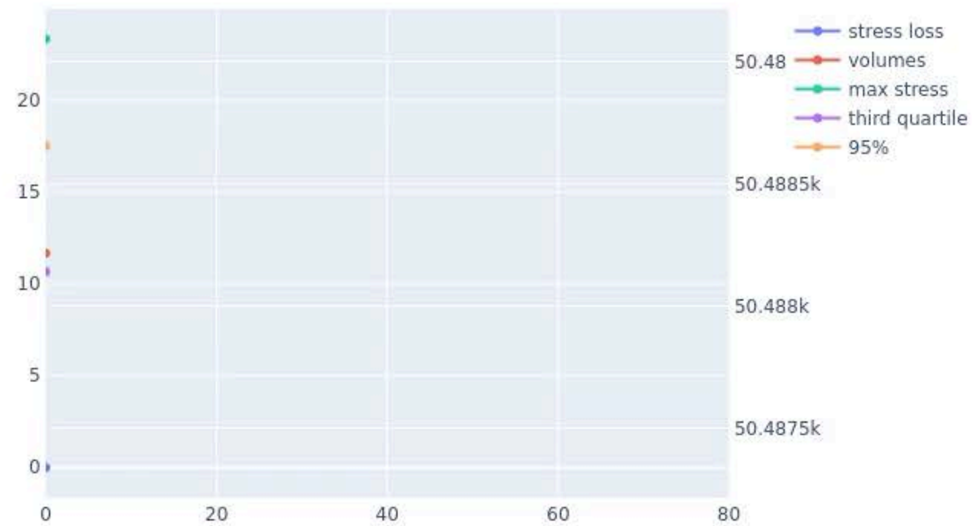


Better design

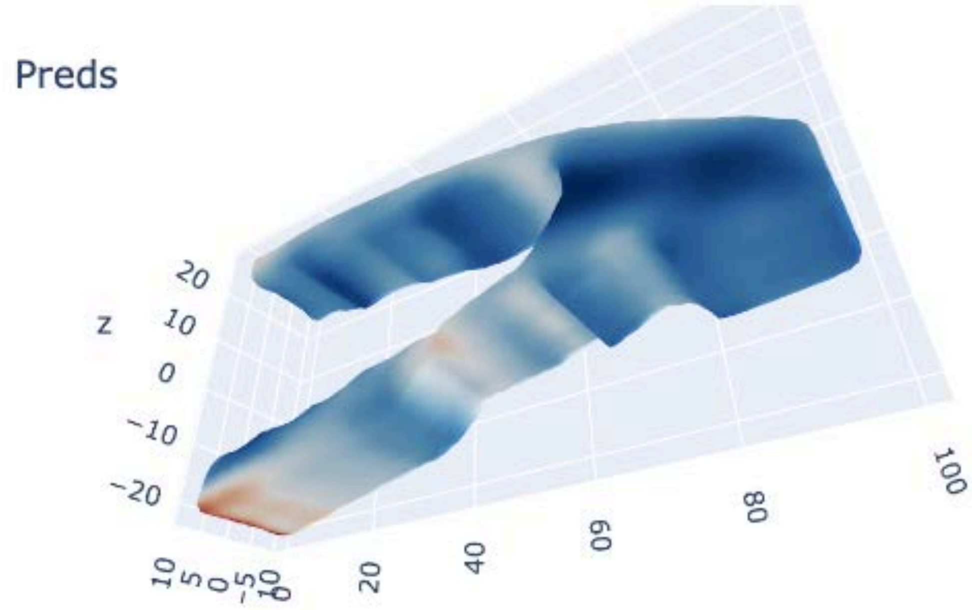
Structural Design

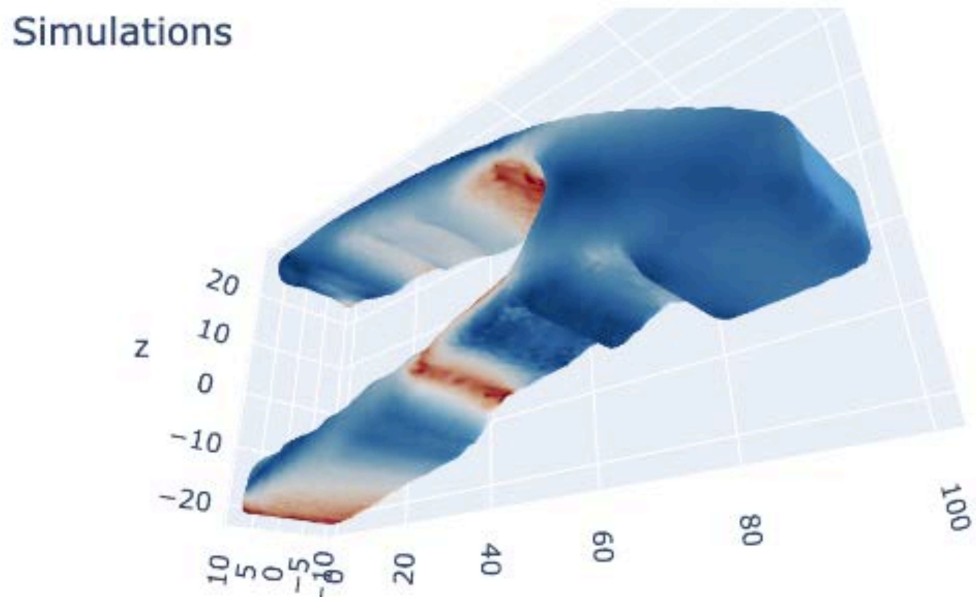
Preds sigma





Structural Design





Conclusion

Geodesic CNNs can be used to:

- Reliably emulate a simulator.
- Optimize the aerodynamic performance of a shape.

Future work will focus on:

- Exploring the shape-space more thoroughly.
- Allowing the topology to evolve as needed.
- Build training databases from real data.
- Tech Transfer.

EPFL NEURAL CONCEPT