Constrained Geometric Parameterization by Mesh Morphing for a Catamaran Foils Optimization Procedure

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[1] **Design Methods** *aerospace consulting*

[2] **University of Rome** "*Tor Vergata*"

[3] **RBF Morph**

[4] **ESTECO**

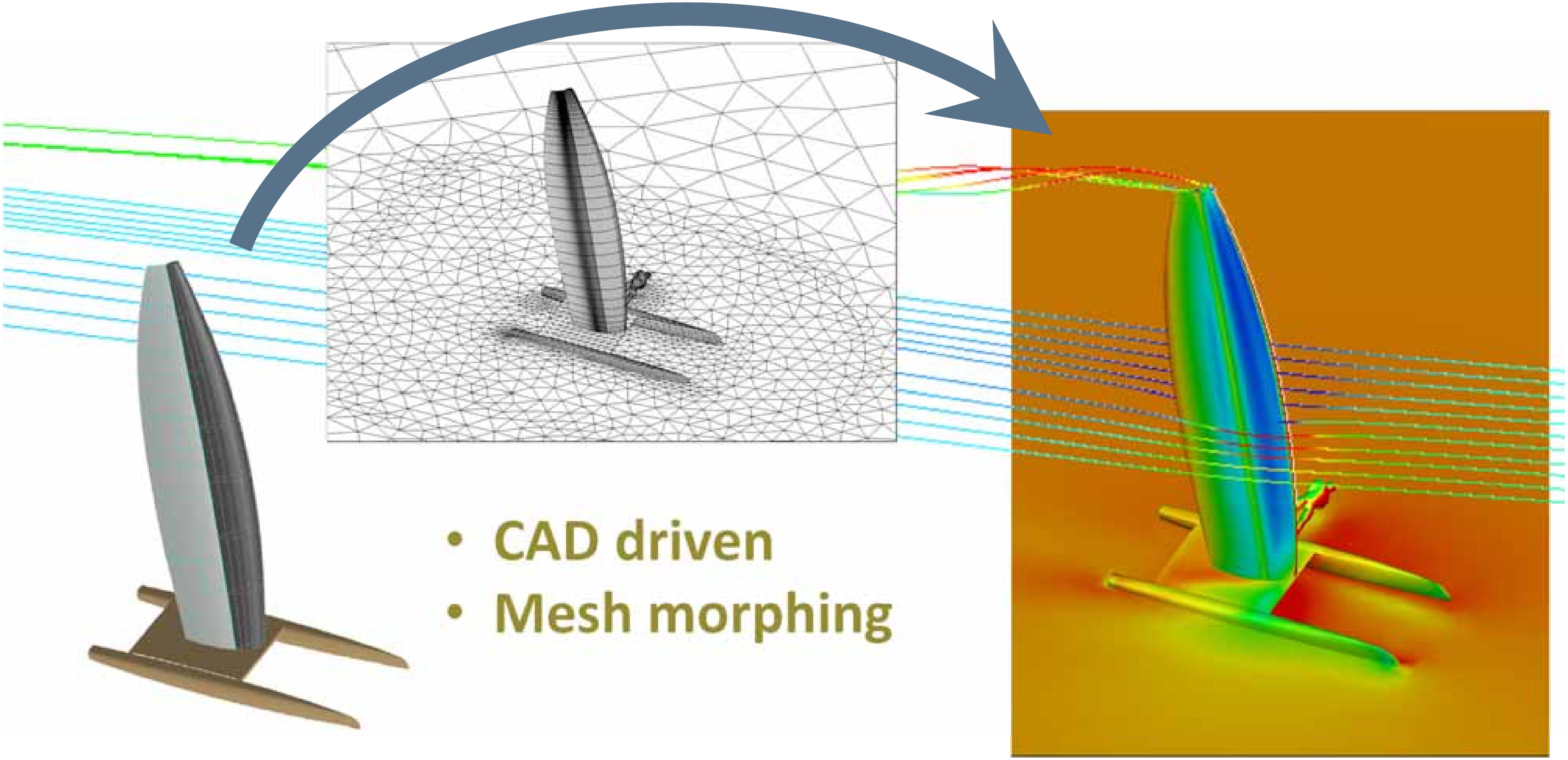
[5] **EnginSoft**

Design by optimization

Optimization environment

Geometric parameterization → **Numerical analysis**

Domain adaptation

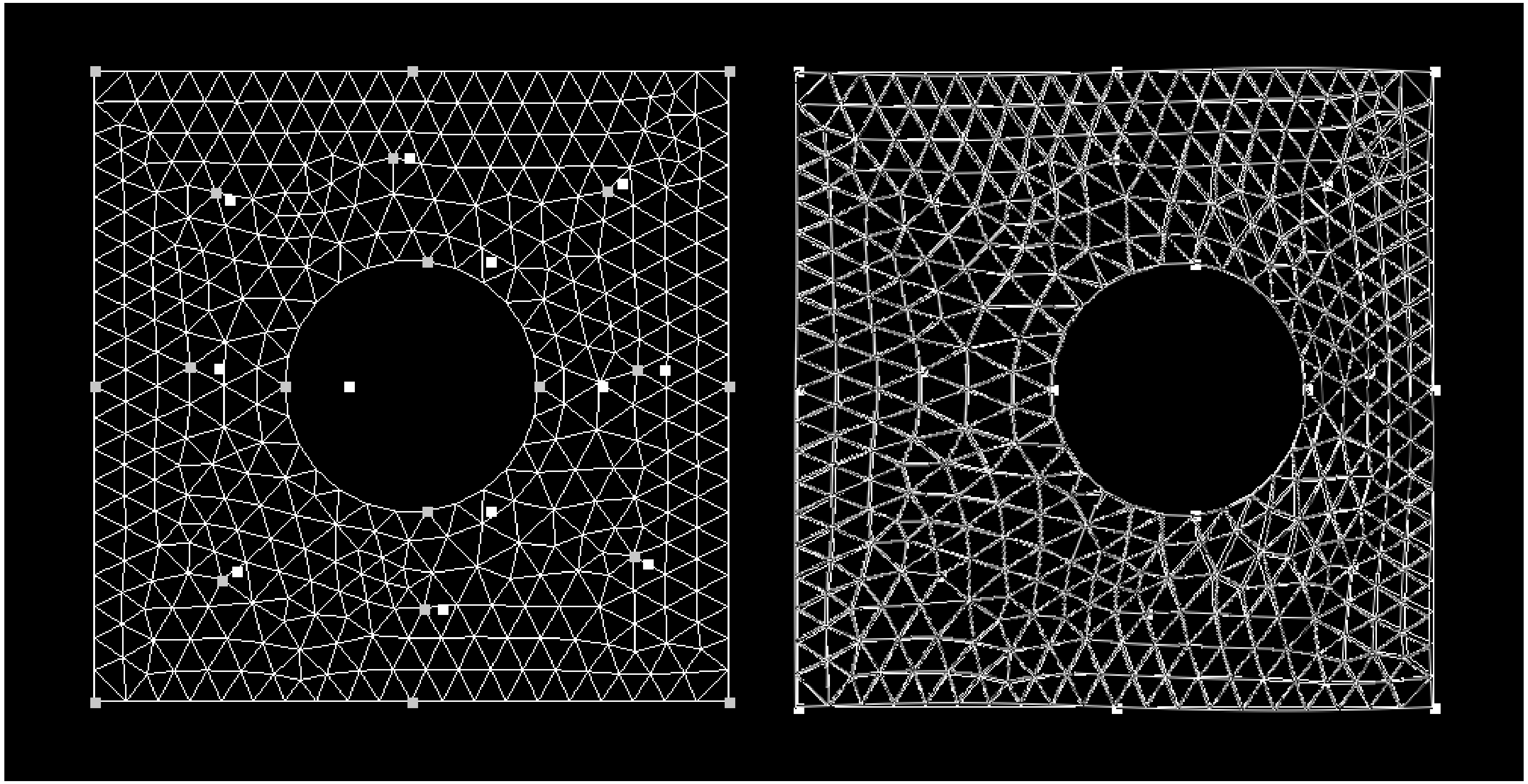


- CAD driven
- Mesh morphing

CAD to mesh

- Main advantages
  - Accurate geometry quality control
  - High constraints setup flexibility
  - No “back to CAD” required
- Main disadvantage
  - Complex and not generalizable setup
  - Highly skilled CAD user required
  - Robustness
  - Remesh required
    - Structured grids
    - Simple geometries

Mesh morphing



RBF for mesh morphing

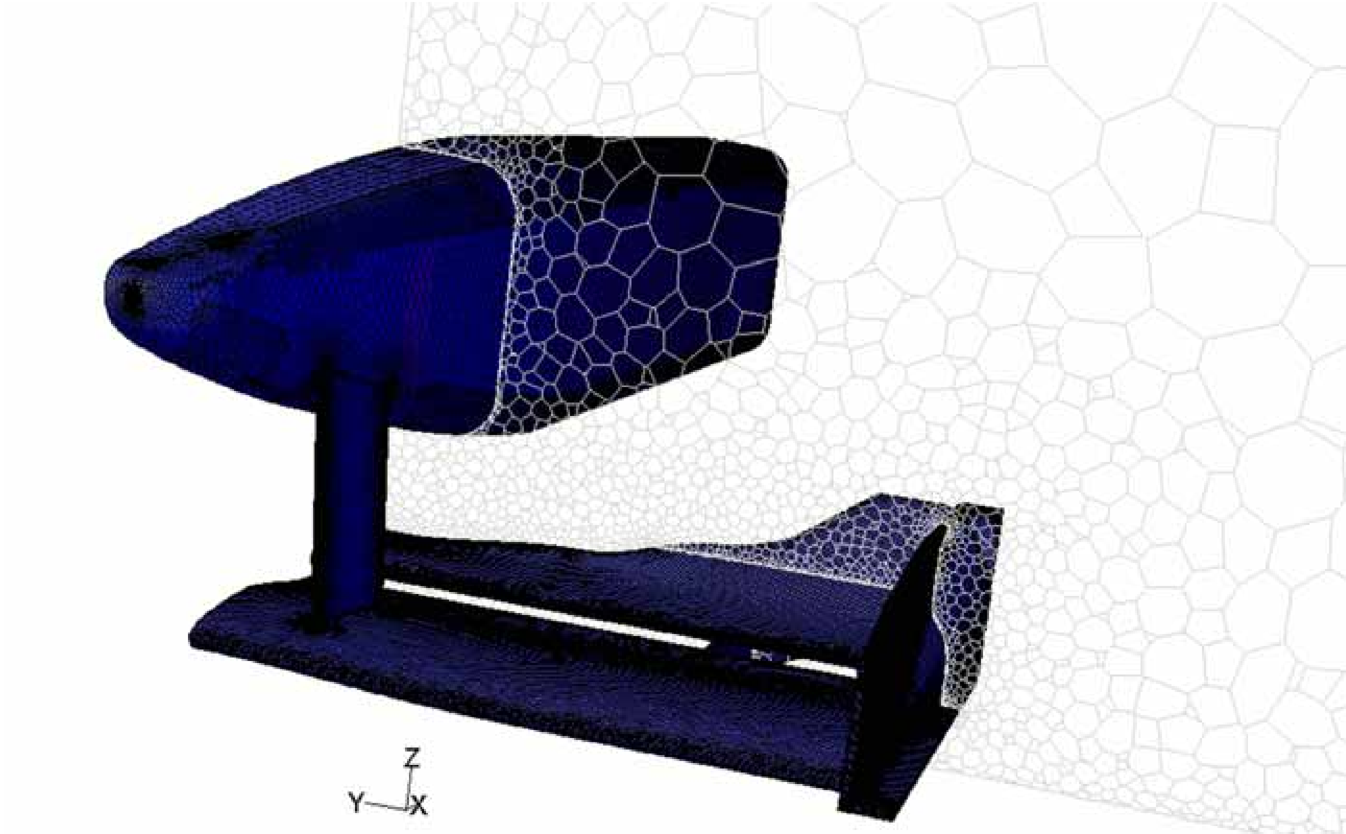
- **Radial Basis Functions** (RBF) can be used to drive mesh morphing (smoothing) from a list of source points and their displacements.
  - Surface shape changes (exact nodes control)
  - Volume mesh smoothing.
- RBF are recognized to be one of the **best mathematical tool** for mesh morphing.

RBF mesh morphing

- Main advantages
  - No re-meshing
  - Can handle any kind of mesh
  - Can be integrated in the CFD solver
  - Highly parallelizable
  - Robust process
- Main disadvantage
  - Computationally expensive (HPC for large grids)
  - Back to CAD procedure required
  - Uncertainness in setting up complex constrained geometric problems

(rbf-morph)™

Welcome to the World of Fast Morphing!

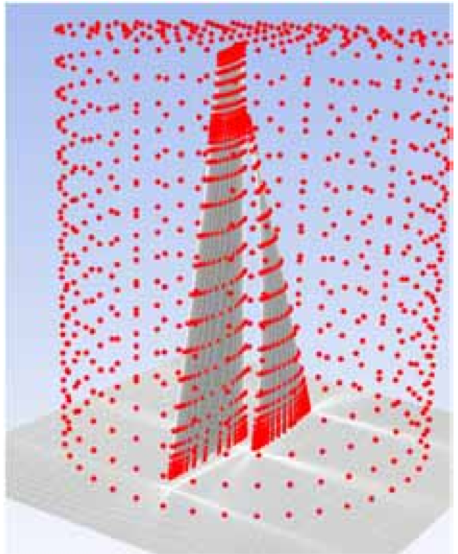


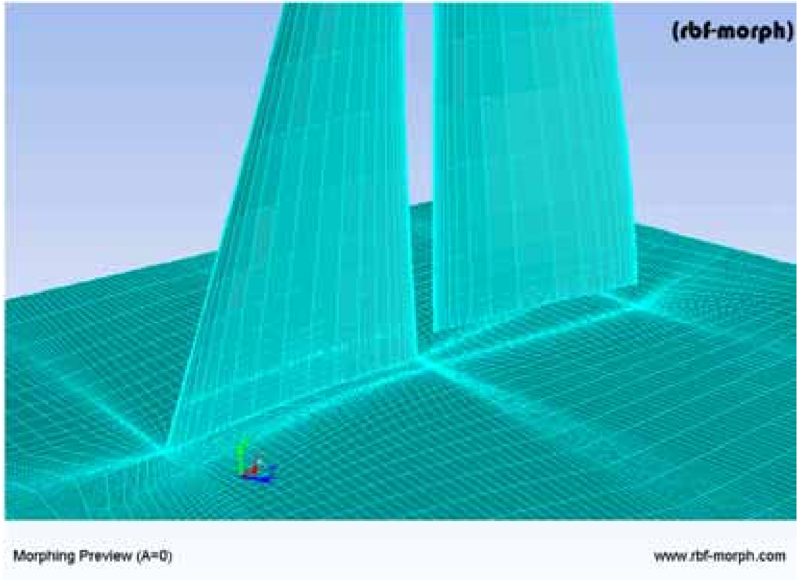
RBF Morph software line

- add-on for ANSYS **Fluent** CFD solver
- Stand alone (GUI+TUI)
  - OpenFOAM, Nastran, elsA, CFD++, StarCCM+, CGNS, NASTRAN
- ANSYS Mechanical ACT module
- HPC RBF general purposes library
  - It is the kernel of RBF Morph (parallel, GPU)

How it works

- Setup
  - Select fixed and moving walls by source points
  - Prescribe the displacements (or a combination of)
- Fitting
  - Solution and storing of the RBF system
- Smoothing
  - Application of the computed morphing actions on surfaces and volume



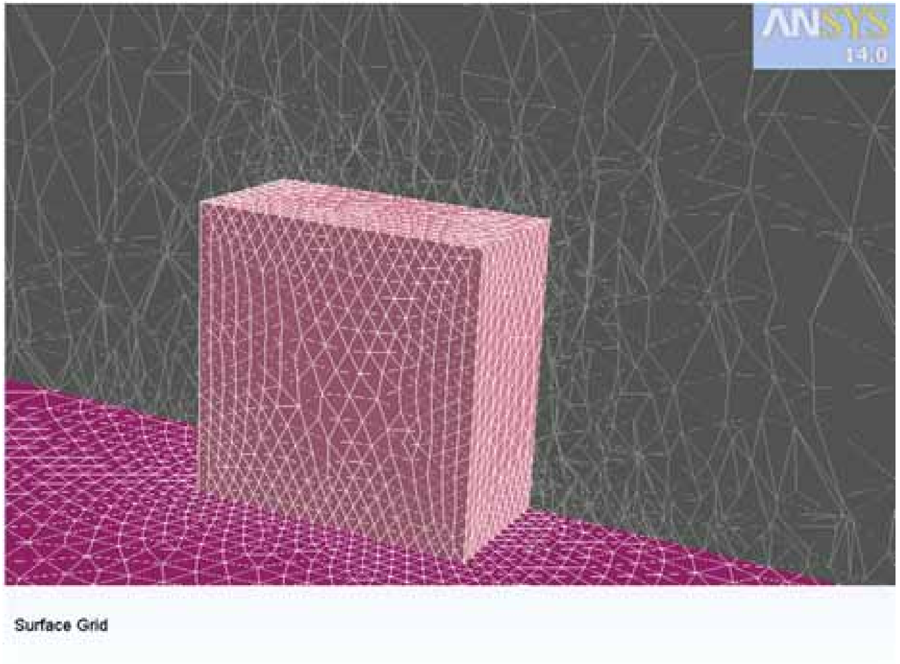


Solver performance samples

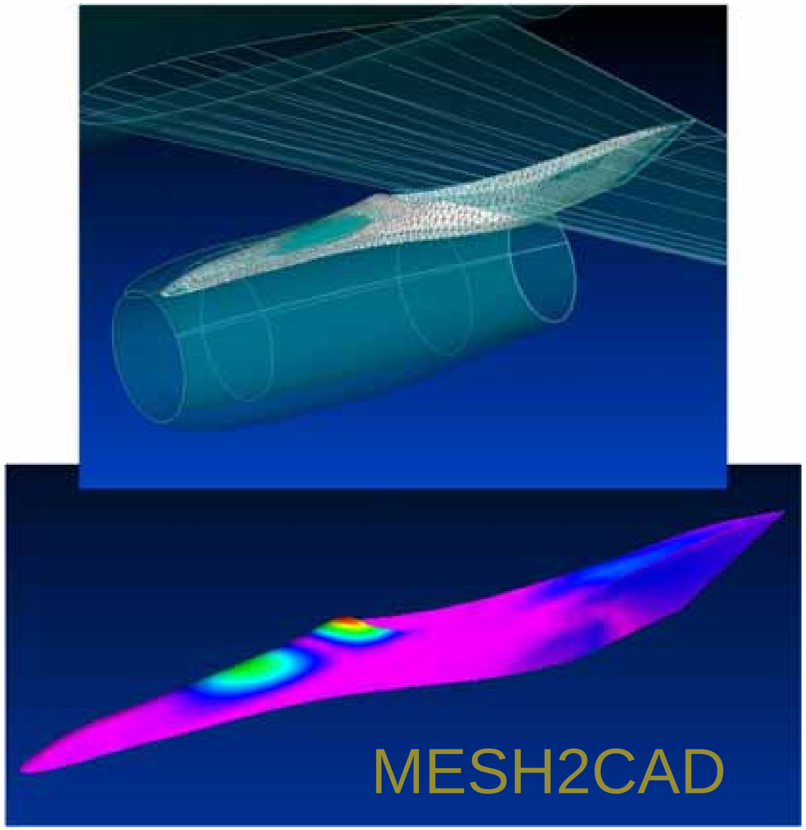
- **14 mill.** cells, 60.000 points, PC **4 cpu** 2.67 GHz
  - fitting time: **53 sec.** (serial)
  - smoothing: **3.5 min.**
- **50 mill.** cells, 30.000 points, HPC **140 cpu**
  - fitting time: **25 sec**. (serial)
  - smoothing: **1.5 min.**
- **100 mill.** cells, 200.000 points, HPC **256 cpu**
  - fitting time: **25 min.**
  - smoothing: **5 min.**

- Largest fitted cloud **2 mill.** points on **32 cpu** in **3 hours**.
- Largest model morphed (in our knowledge) **700 mill.** cells on **768 cpu** in **45 min.**

CAD input and output



STL target



Objectives of this work

- Test the capability of mesh morphing approach to manage **complex constrained shape parameterization**
- Verify its efficiency when coupled with leading technologies in an **optimization environment**
- Develop a **challenging test pilot problem** to demonstrate the capability of the proposed approach

Partners

A-Class cat foils design

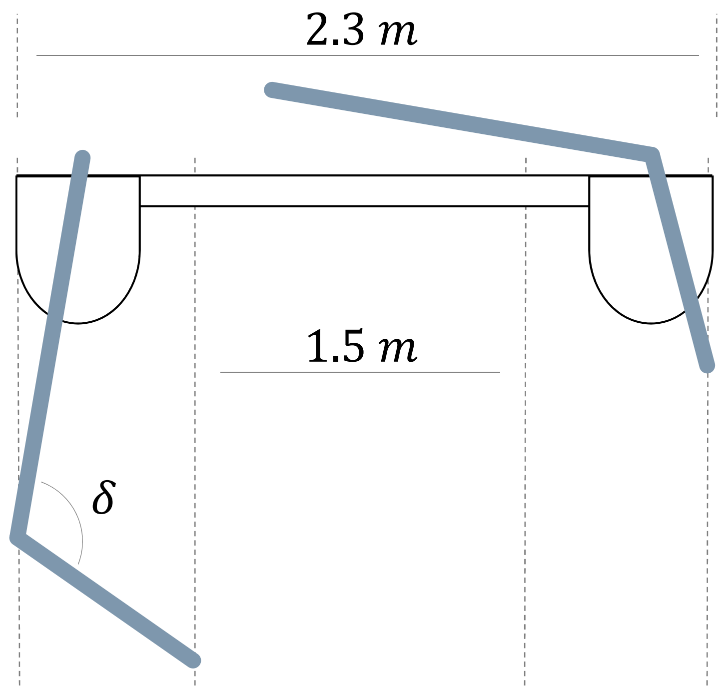
The fastest single handed racing boats

Geometric constraints

A-Class Rules

8.1 - No part of each hull or hull appendages below the waterline shall be less than 0.75 meters from the centre line

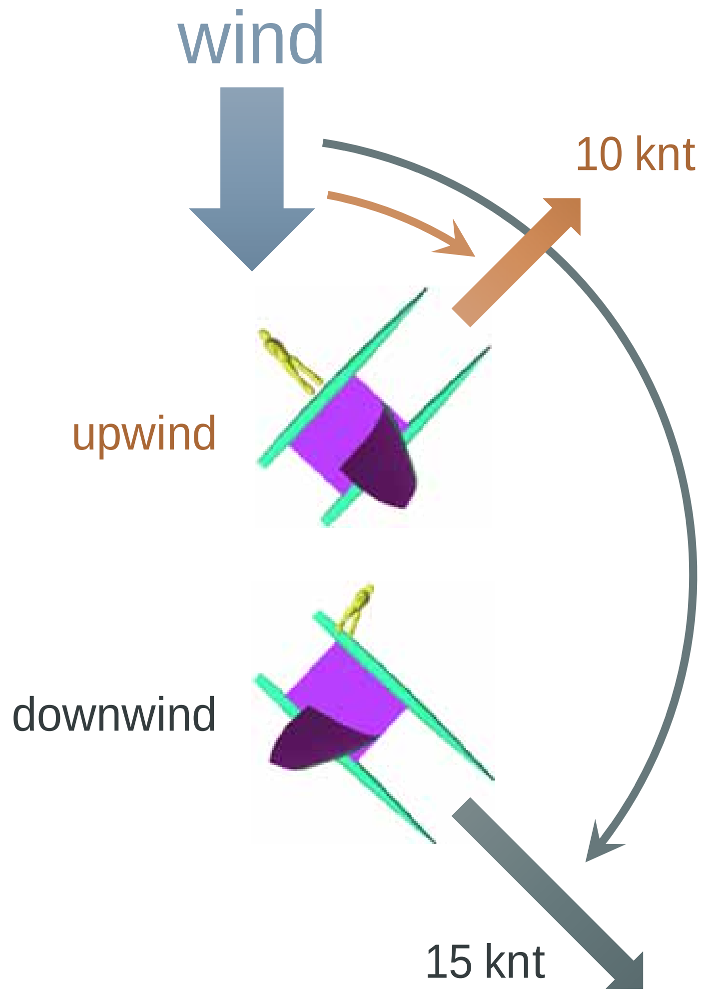
8.2 - Movable and retractable hull appendages shall be inserted from the top or be capable of being fully retractable into the hull.



Design conditions

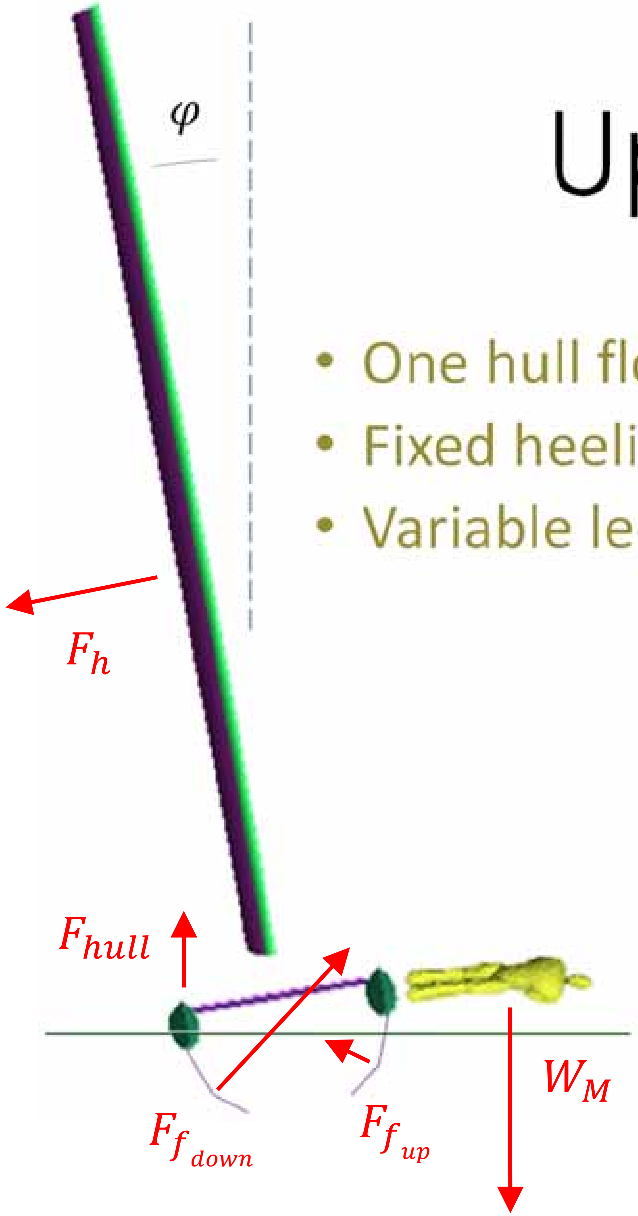
Total displacement = 170 Kg
heeling angle = 5 deg

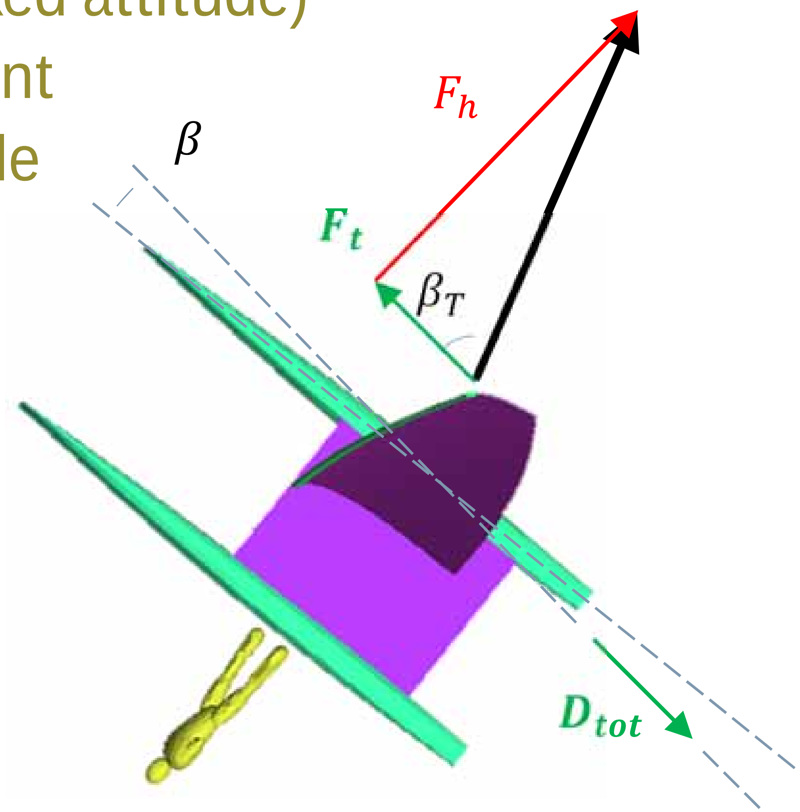
- Upwind sailing
  - "traditional" sailing
    - Boat speed = **10** knots
    - fixed sinkage
    - free leeway angle
- Downwind sailing
  - "foiling" sailing
    - Boat speed = **15** knots
    - leeway angle = 3 deg
    - free sinkage



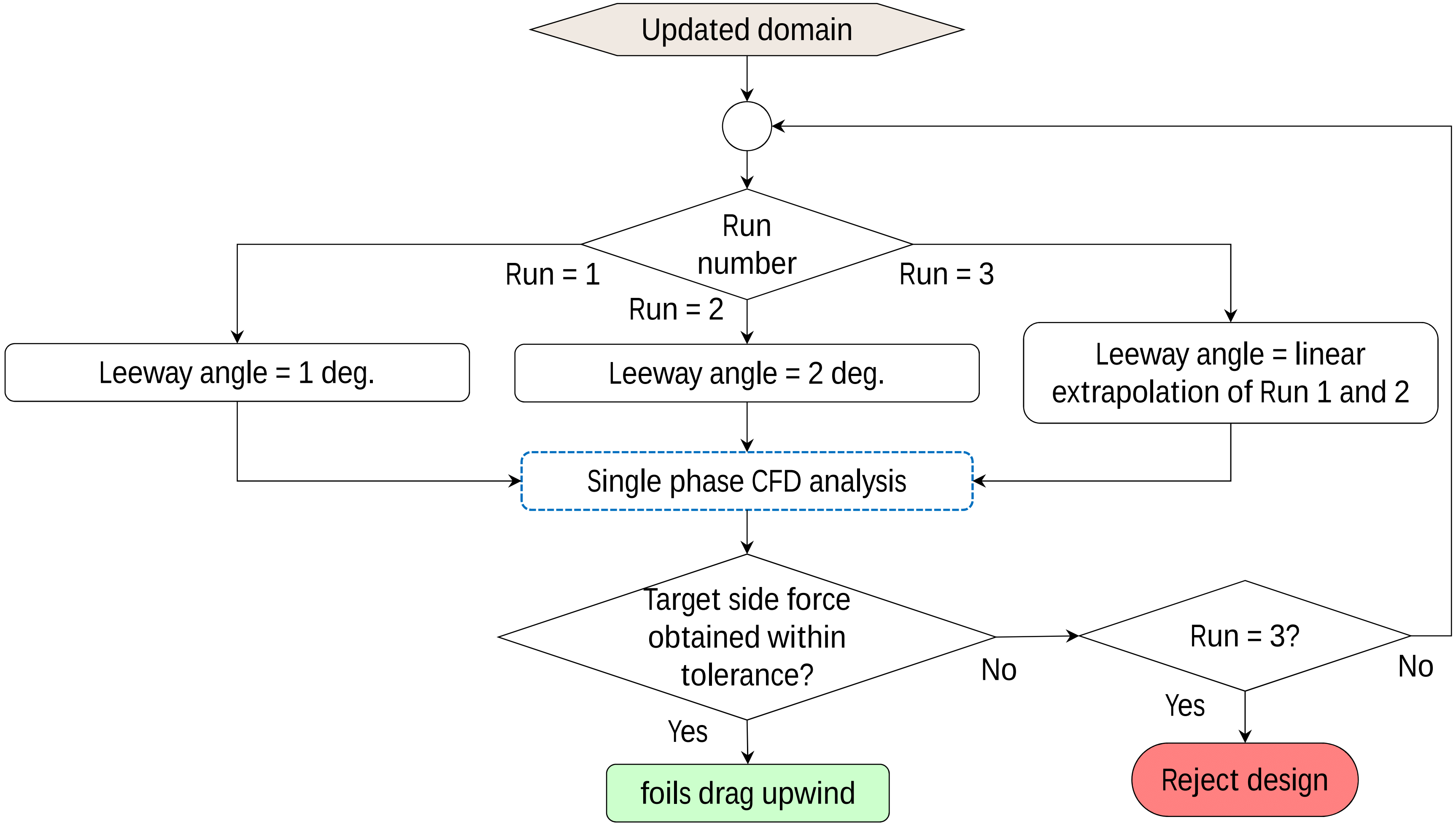
Upwind equilibrium

- One hull floating (fixed attitude)
- Fixed heeling moment
- Variable leeway angle

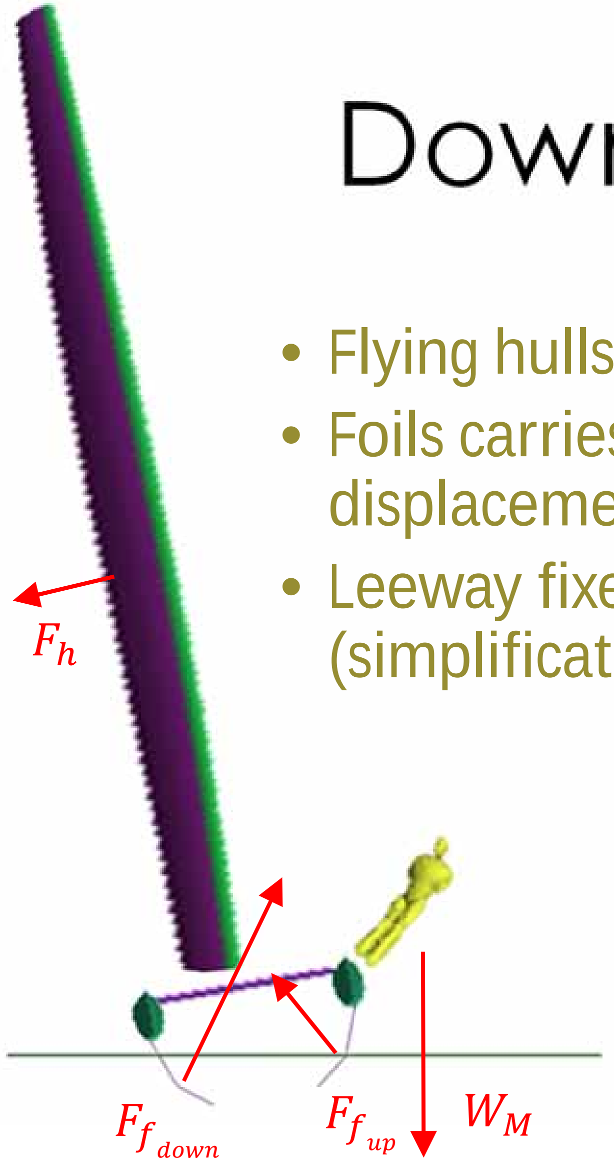




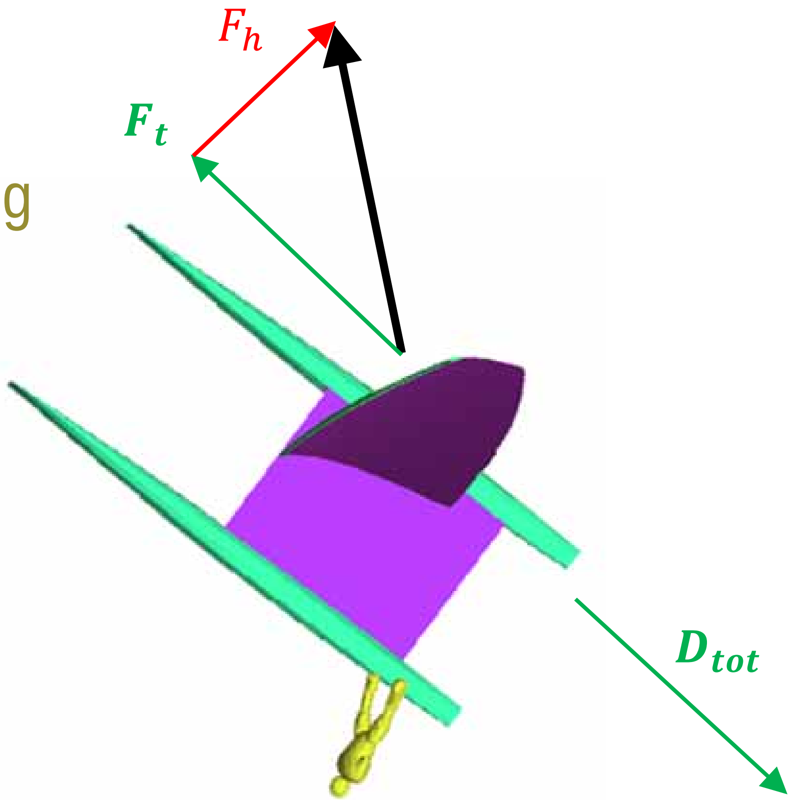
Upwind analysis



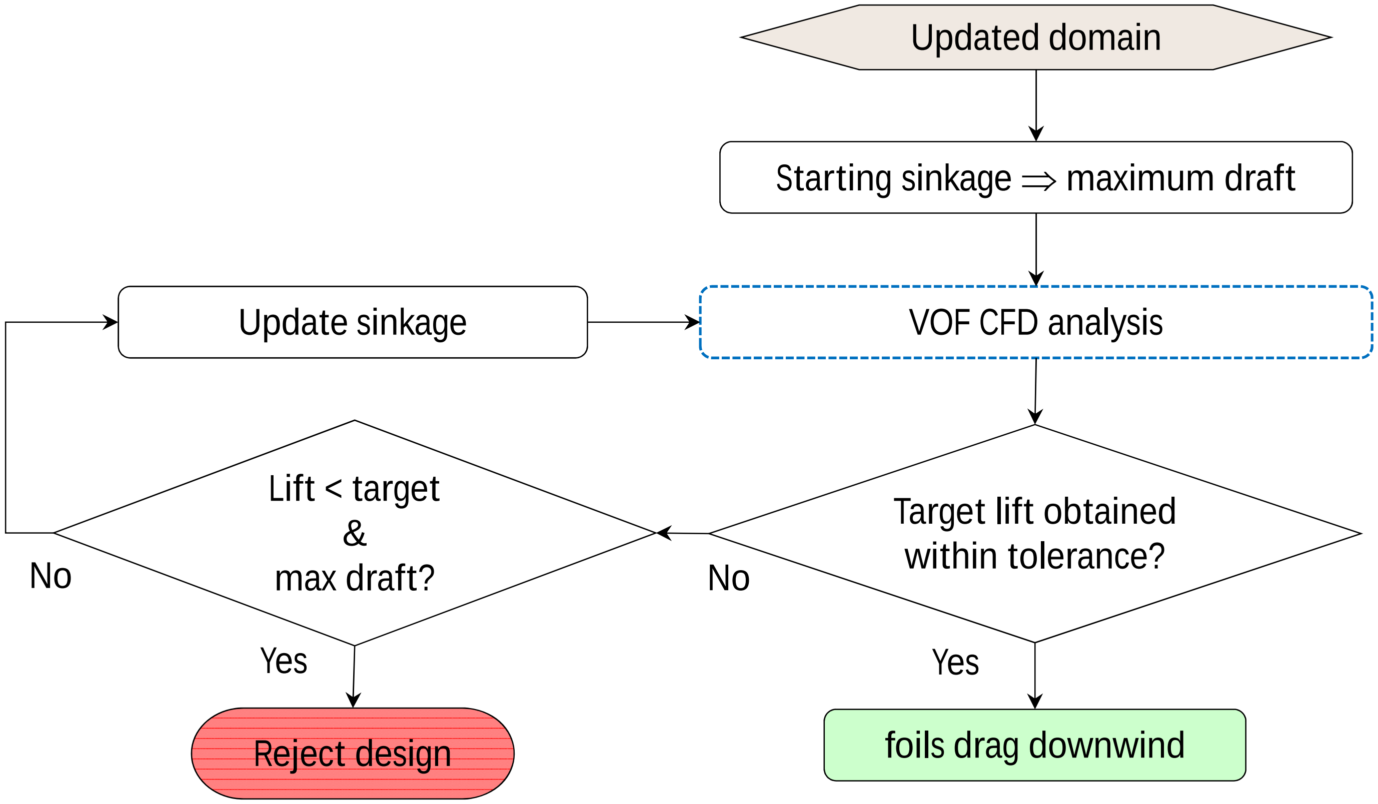
Downwind equilibrium



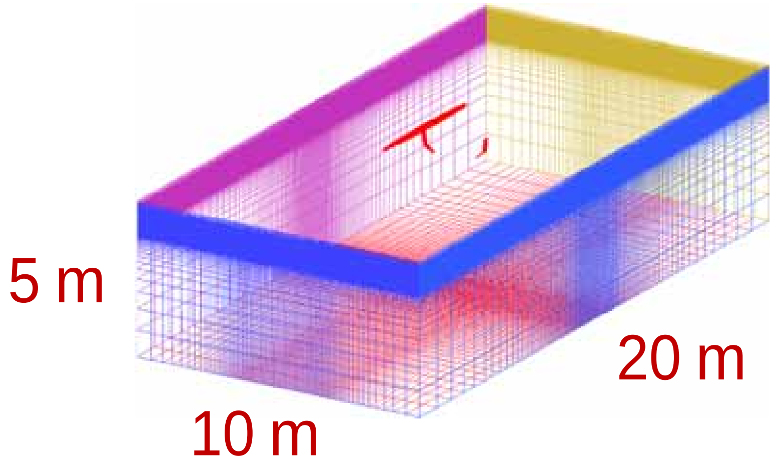
- Flying hulls (foiling)
- Foils carries 70% of displacement
- Leeway fixed to 3 deg (simplification)



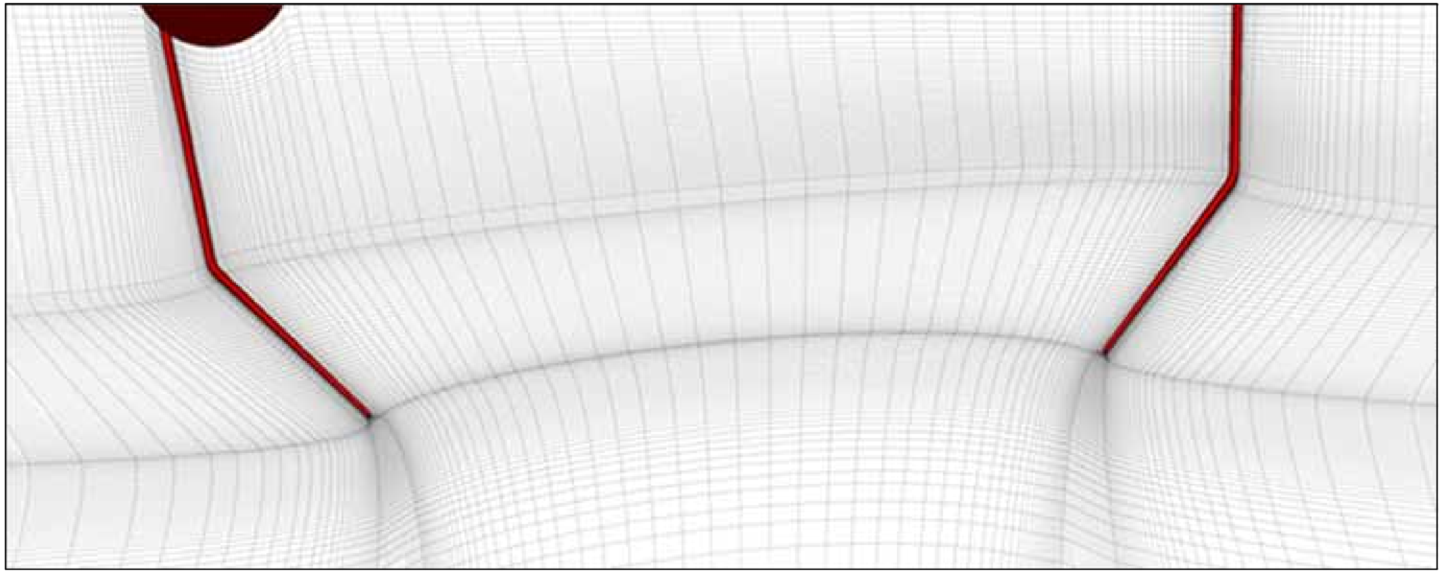
Downwind analysis



Computational domain

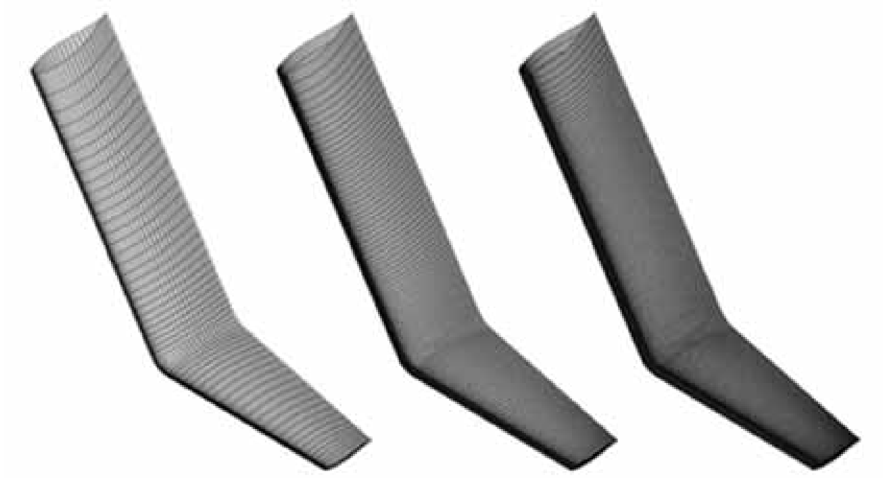


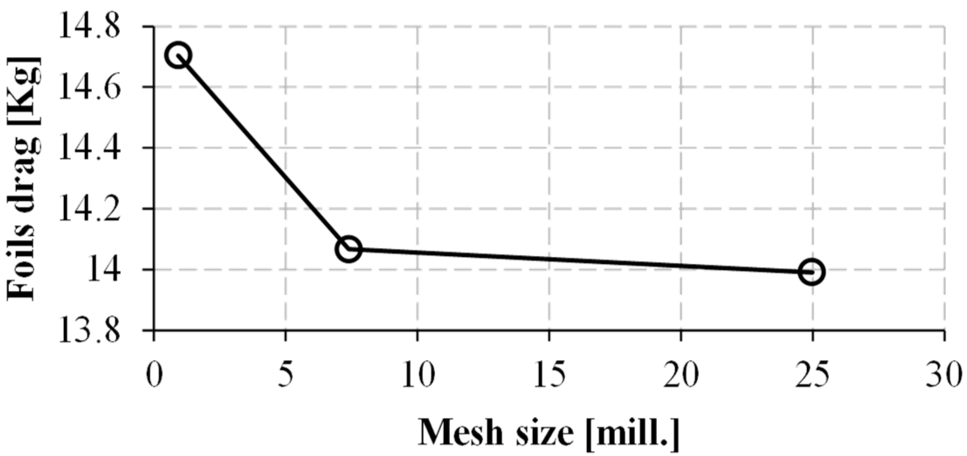
- Structured hexa
  - Inviscid hull
  - Wall functions on foils (fully turbulent BL)



Grid sensitivity analysis

- Level 1 = **1** millions
- Level 2 = **7.5** millions
- Level 3 = **25** millions

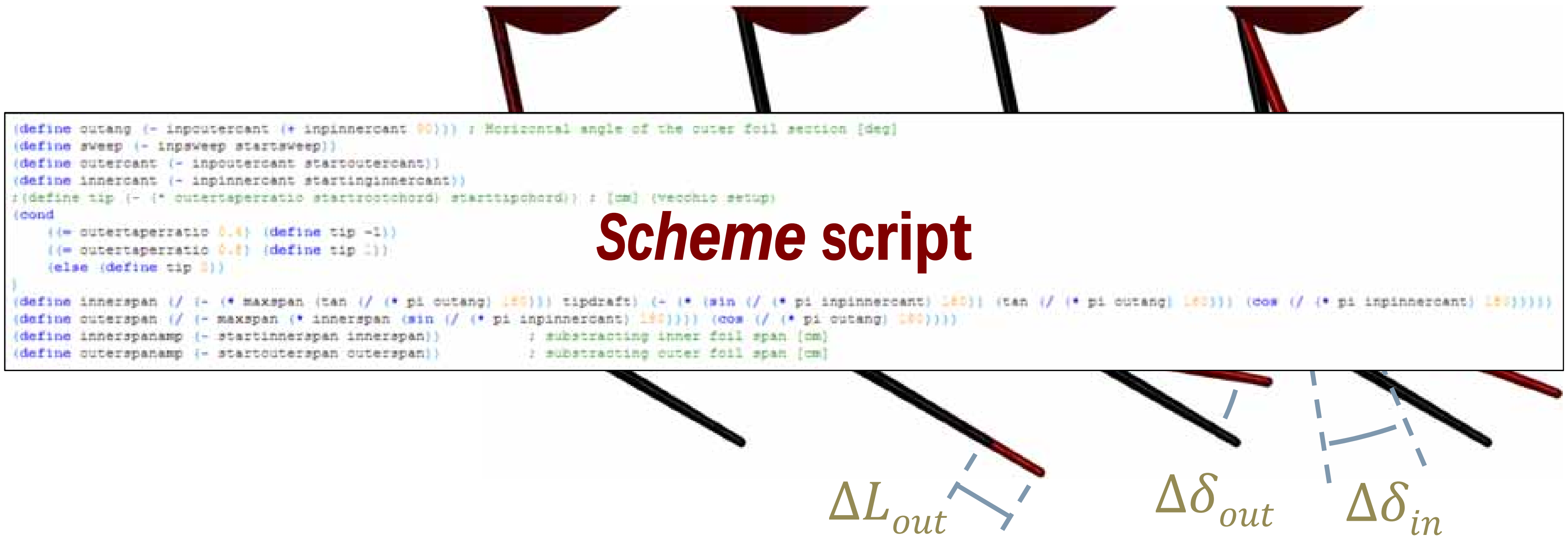




order of 5 %
(downwind analysis)

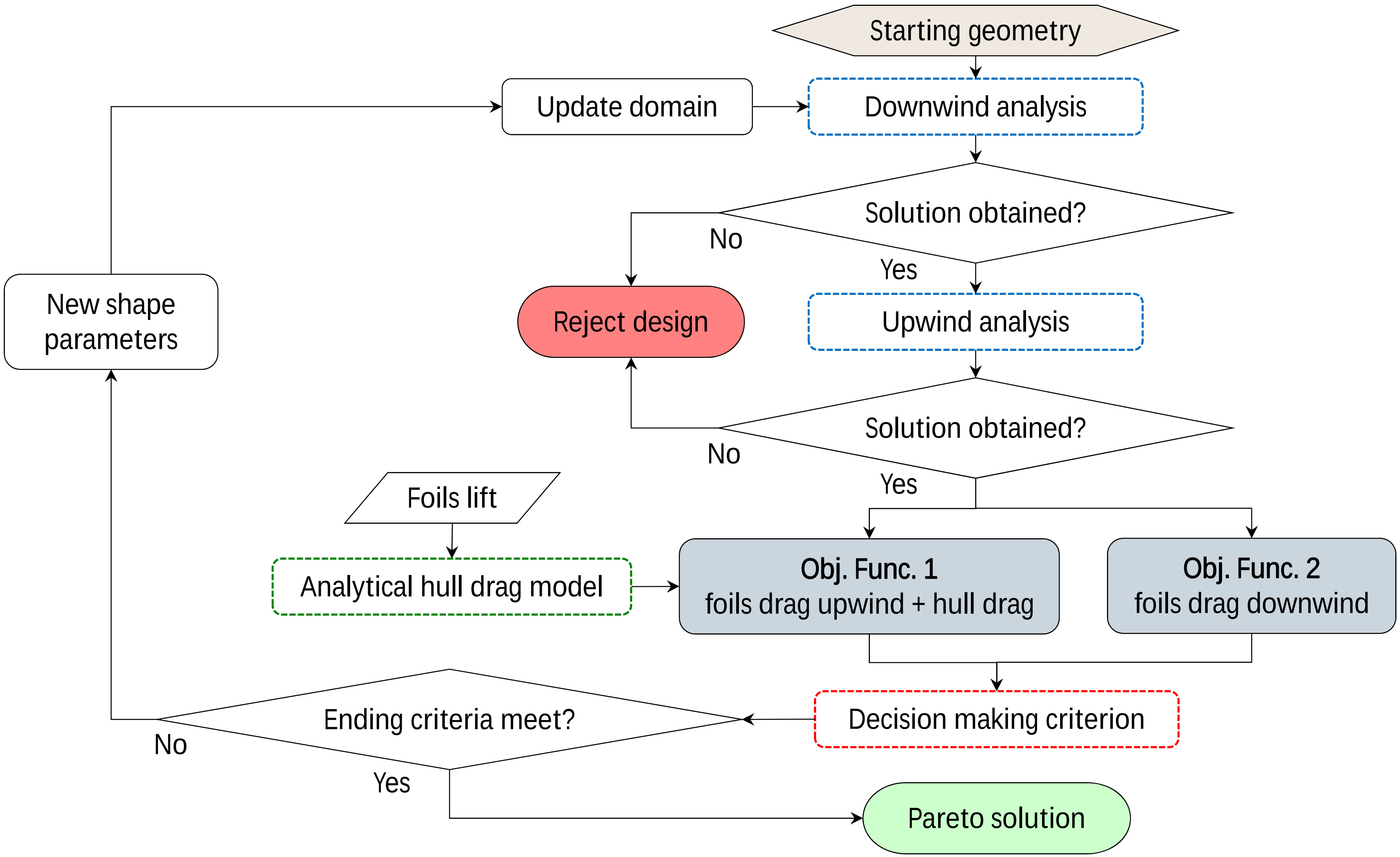
Front shape parameters

- Front shape variables of design
  1. total foil draft
  2. outer segment cant angle
  3. inner segment angle respect to vertical



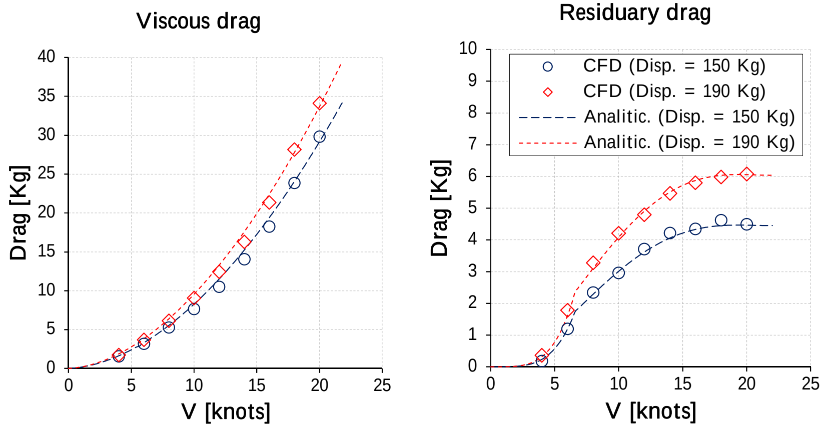
Planform parameterization

Optimization workflow

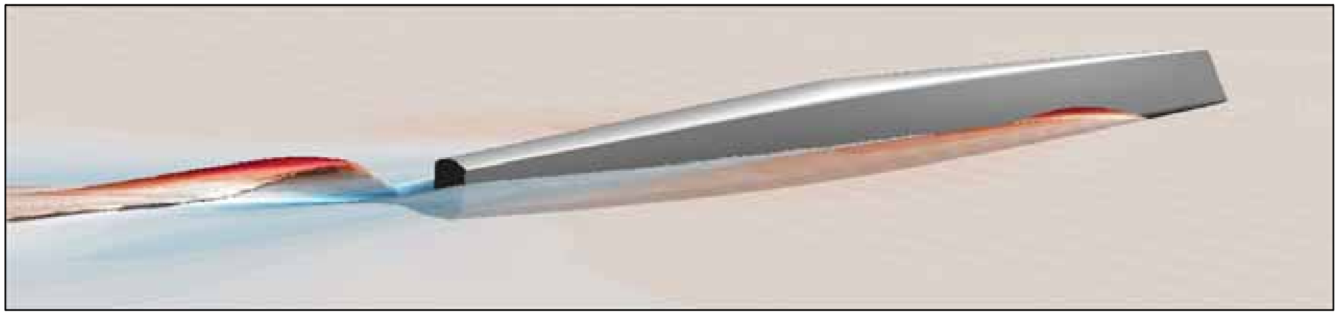


Analytical hull drag model

Analytical models tuned against a database of CFD solutions on the isolated demihull [1]

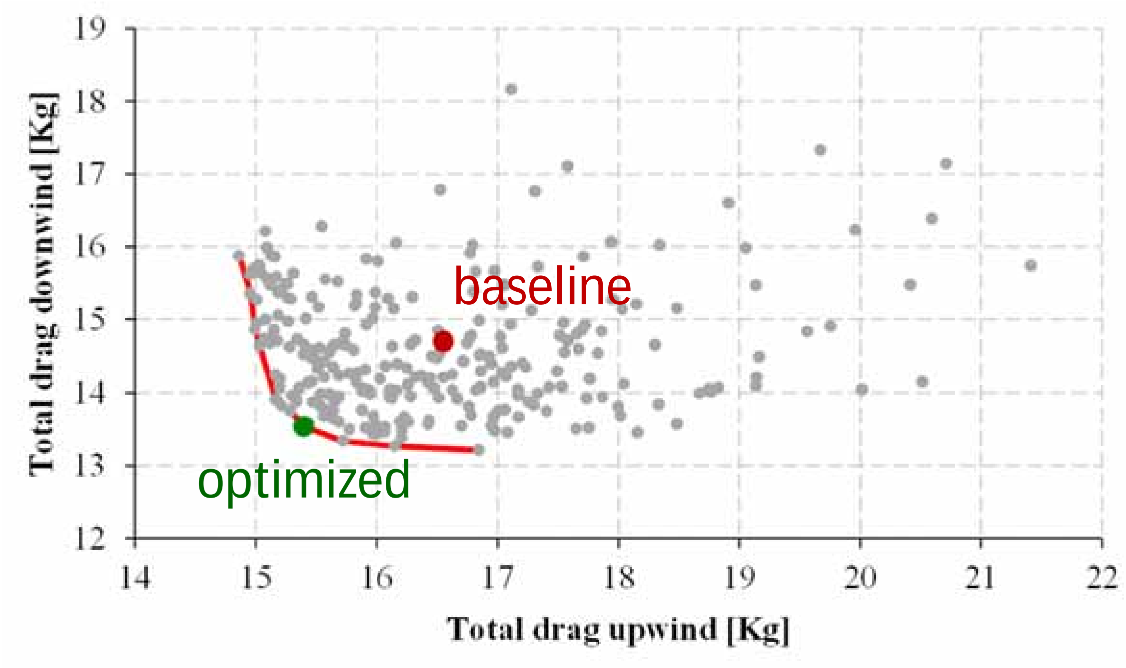


$$D_H = \frac{1}{2}\rho_w V^2 S_{wet}(W_{BO})\left[(1+k)C_f + C_w\right]\left[1 + k_\beta V^{\tau_\beta}\left(W_{BO} + w_\beta\right)\beta^2\right]$$



[1] Ubaldo Cella, Francesco Salvadore, Raffaele Ponzini, “*Coupled Sail and Appendage Design Method for Multihull Based on Numerical Optimisation*”, PRACE – EU SHAPE Project final report, 5th July 2016, available online at www.prace-ri.eu

Pareto solution



2 objectives optimization using GAs

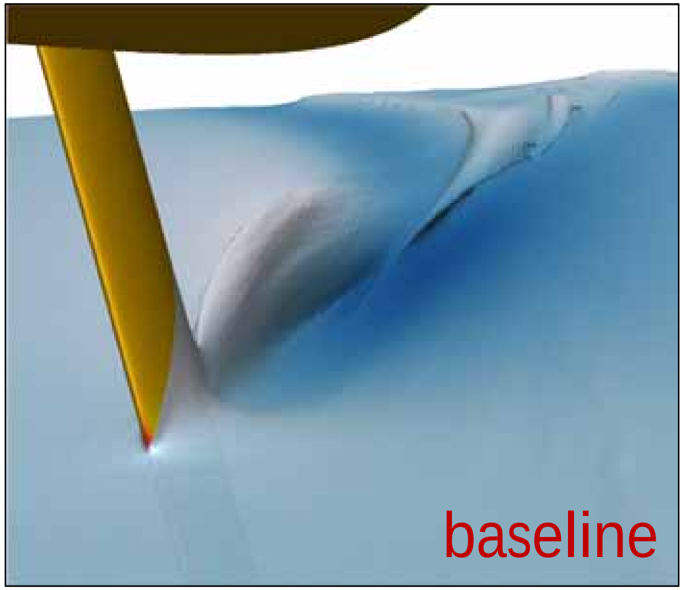
Around 400 eval.
Around 40% rejected

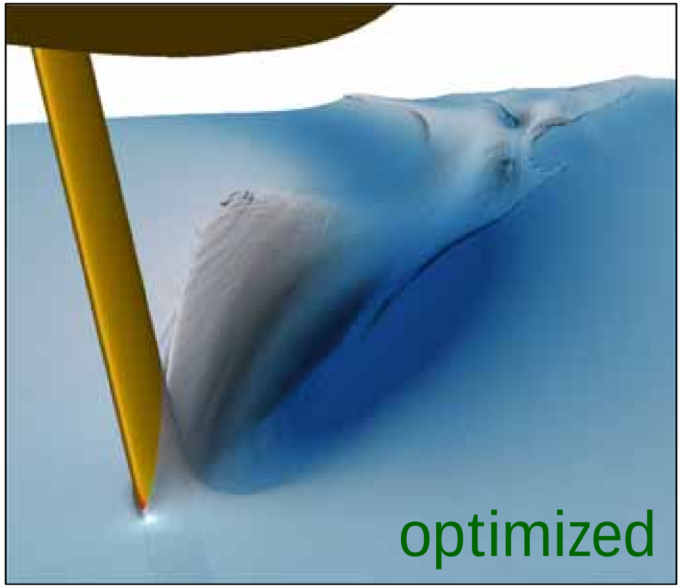
Total drag reduction:

Upwind = **- 7** %.
Downwind = **- 7.9** %

Post design verification

Mesh	Baseline Kg	Optimized Kg	Drag reduction %
Coarse (1 mill.)	14.7	13.54	**7.89**
Fine (25 mill.)	13.99	12.92	**7.65**





Conclusions

- Strongly constrained parameterization problem **successfully faced** by RBF mesh morphing.
- A complex workflow of a test pilot problem was **setup and efficiently integrated** in an optimization environment.
- **Improvement larger than 7%** was obtained starting from a geometry roughly replicating existing designs.

Thank you for your Attention

Ubaldo Cella

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