Simulation Driven Design of an AC 75

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Outline

- Americas Cup and the AC75

- Difficulties
  - Three operational modes
  - Many constraints
  - Dealing with uncertainties of the objective function

- Approach
  - A single model, including many constraints and checks
  - Surrogates for extra constraints and checks
  - Surrogates for individual performance measures
  - Possibility to test different objective functions and thus deal with the uncertainty on the objective function

- Realisation with CAESES

Americas Cup and the AC75

- The Americas Cup
  - The oldest international sports trophy in the world, since 1851
  - Match race, only two boats are in the final competition
  - Racing takes place in purpose-built yachts
  - Short (25 minutes) up/down races close to shore
  - 2 months of racing and 3 to 4 years of development and build
  - A typical AC team consists of 120 to 180 people
  - An AC campaign is always a very tough race against the time

- The AC75
  - A high-performance foiling monohull, very demanding to sail
  - 20.60 x 5.00 m, 7000 kg (with crew), Sails 160 – 215 m^2
  - All controls are electro-hydraulic, power for the sails is manual
  - No autopilots
  - Upwind and downwind boat speed is around 2.5 and 3.5 times the wind speed, respectively

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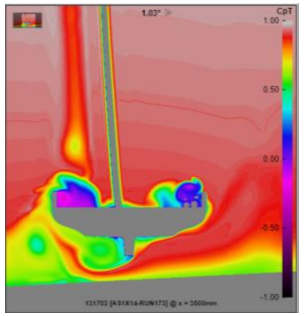
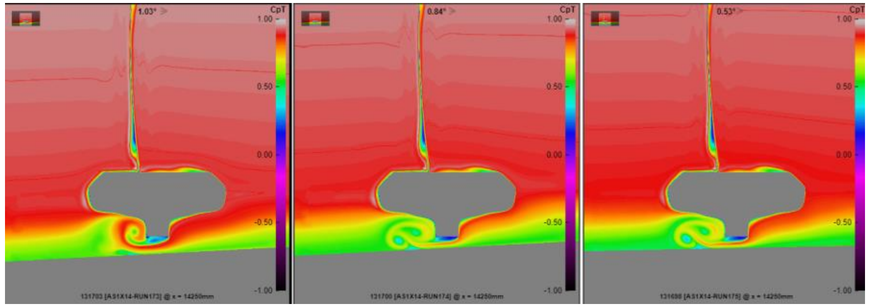
Operational Modes

- Take-off
- Aerodynamics
- Touch down hydrodynamics

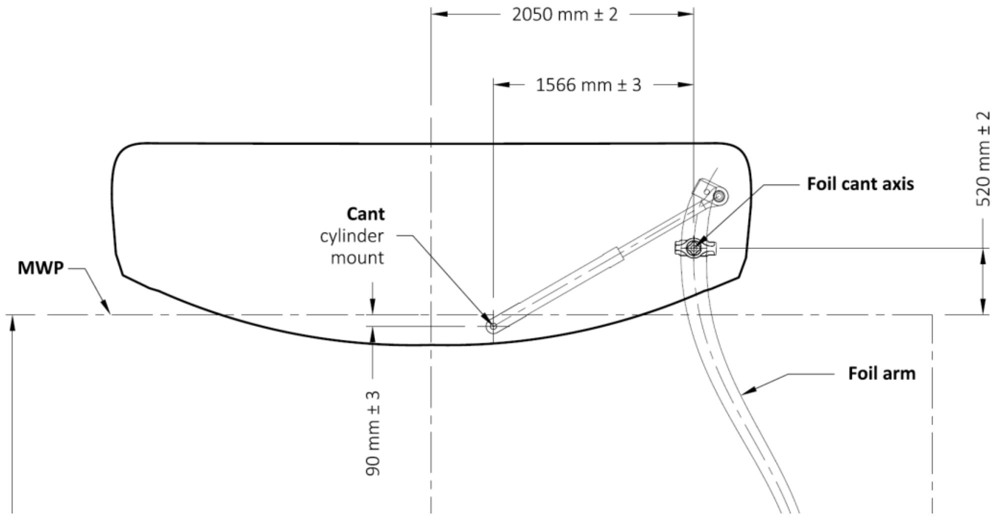




Constraints and Checks

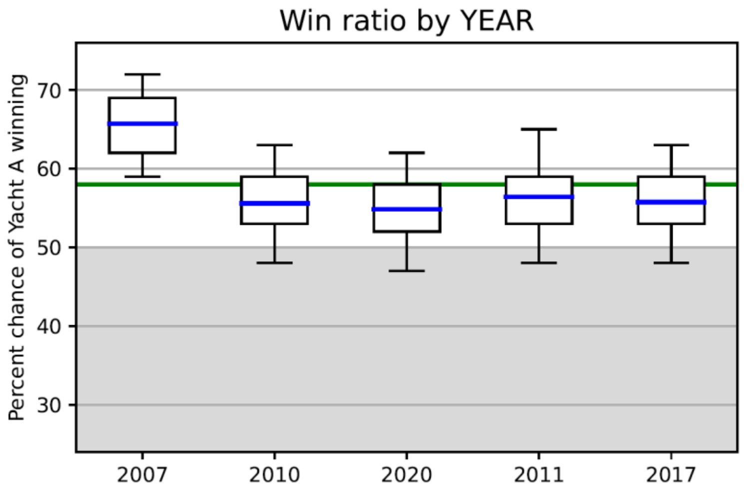
- Class rules: In total 140 pages
  - Main dimensions and some specific hull dimensions
  - Constraints on enclosed hull volume
  - Floating conditions
  - Hydrostatic constraints on righting moment
  - No multihull / no hollows
  - Space for the foil cant system

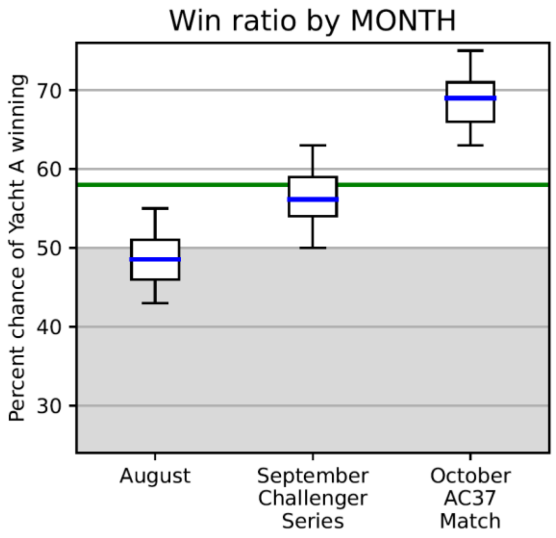
- Take-off
  - Simplified checks

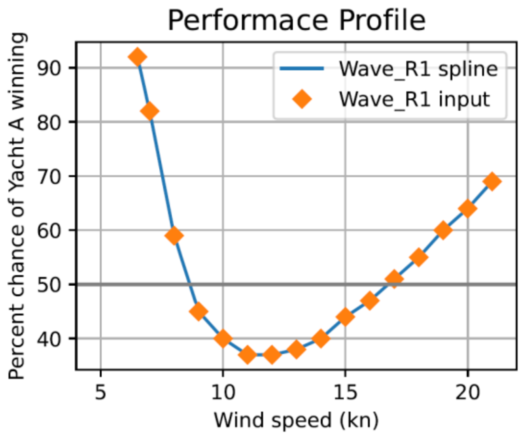


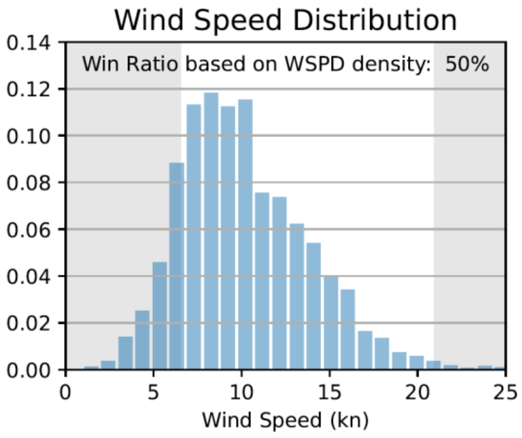
Objective Function - Uncertainties

- Take-off, hydrodynamics, aerodynamics
- Upwind / downwind
- Wind speed
- Sea state
- Non-linearities due to race format
- Positioning vs competitors









WIN RATIO A: 58%

Profile: WIDE_FOIL
Points required: 7
Passes: 500
Whiskers: [5, 95]
Met Source: Airport

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Approach

- A single model
  - Parametric model to generate very complex geometries
  - Ensuring that all candidates
    - Are smooth
    - Have closed surfaces
  - Integration of a complex set of rules constraints
  - Integration of checks

- Surrogates for the constraints (that are not automatically satisfied)
  - Run very fast checks whether a candidate is suitable
  - Checking the “real” constraints on the fly would be too expensive

- Uncertainties on the objective function
  - Upwind/downwind, 2 wind speed, flat water/waves
  - Surrogates for the individual performance measures
  - Possibility to combine the individual measures in different ways
  - Optimise for different objective functions
  - Compare only designs that are optimal according to some objective function

A Single Model in CAESES

- Shape complexity
  - Capturing all variations with a single model
  - Bustle + flat plate bustle extension
  - Cockpits
  - Transition from bustle to rudder

- Constraints and checks
  - Integration of rules to ensure rule compliance as much as possible through the model
  - Additional checks on feasibility

- Model quality
  - Very high requirements on smoothness due to high resolution CFD runs
  - Ensuring closed surfaces

Realisation with CAESES

1) Parametric hull model (Meta Surface)
   - 200 parameters (Meta Surface) + local features and morphing
   - 50 free parameters for the optimisation
   - 37 constraints (rules, hydrostatics, foil cant system)

2) DOE (400 cases)
   - 14 CFD runs per candidate (3 x take-off, 3 x touch down, 8 x aerodynamics)

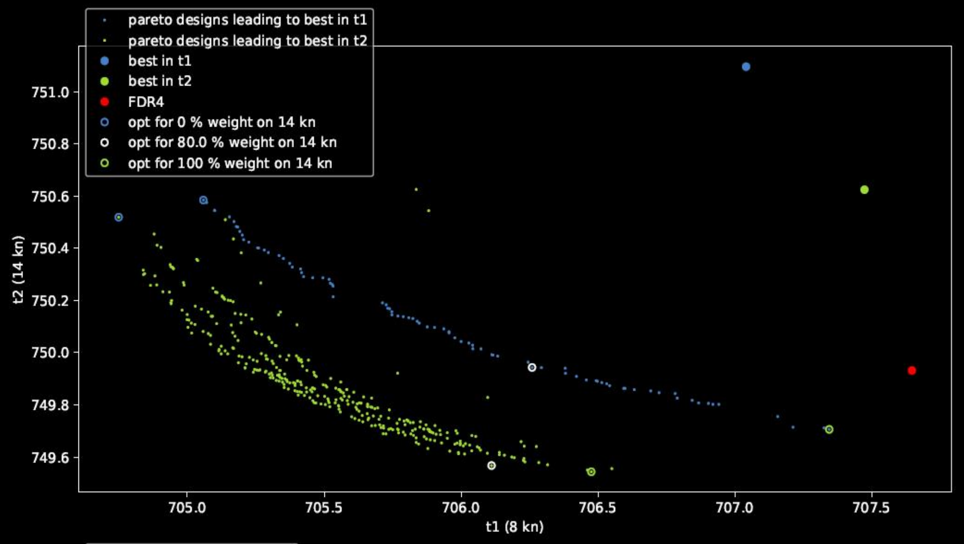
3) Surrogates
   - CFD results
   - Constraints (geometric and hydrostatic)

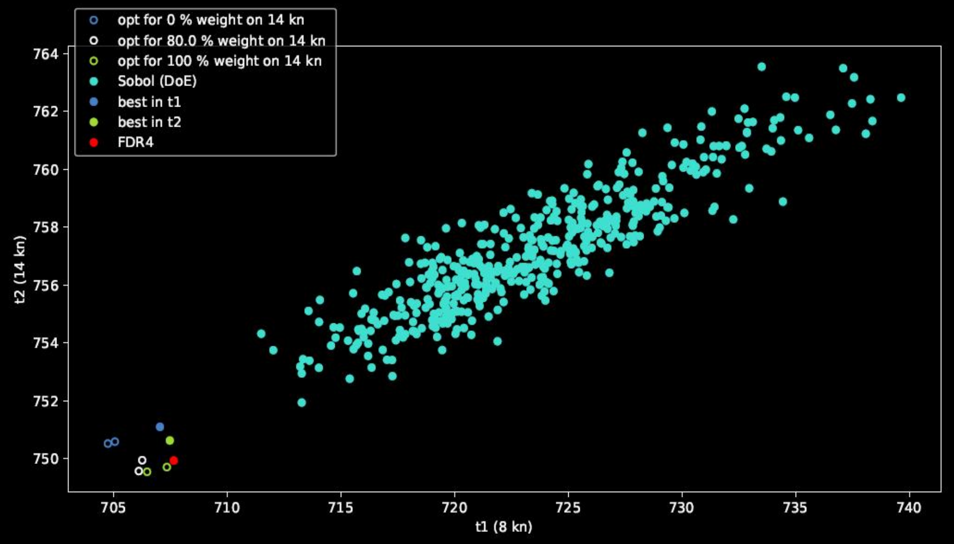
4) Optimisation with a genetic algorithm on the surrogates
   - 50 generations with 20000 candidates allowed to get a good approximation of the Pareto frontier
   - After checking the constraints, a few Pareto optimal designs that respect all constraints remain
   - Refit of the surrogates around the optimum

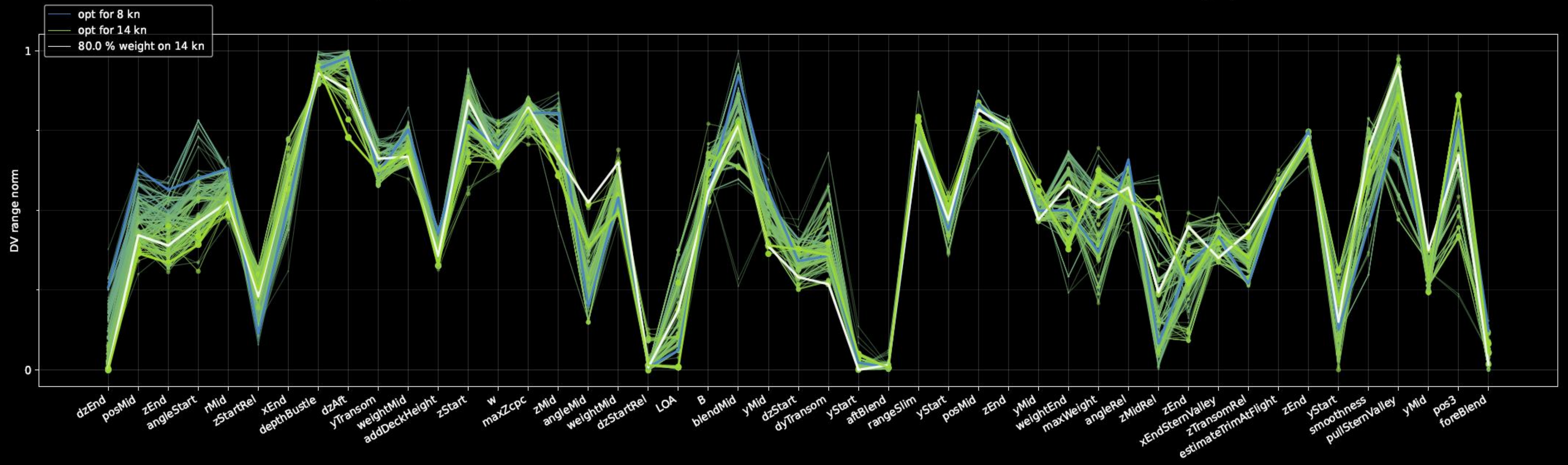
5) Additional CFD runs for selected candidates along the Pareto frontier

6) Back to step 3, including the new CFD points

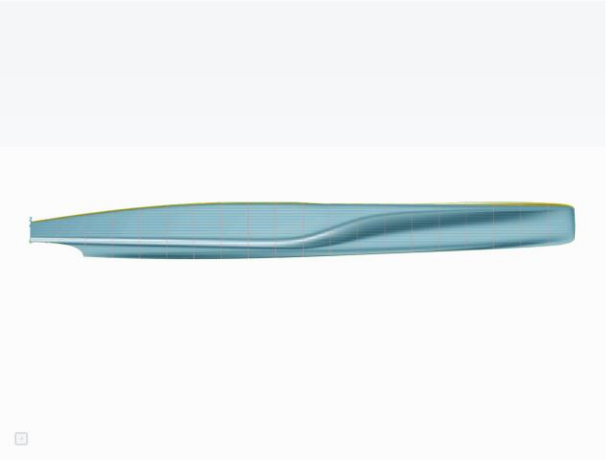
This loop was run 3 times, but during the 3rd iteration no further improvement was found

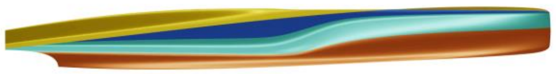

pareto designs leading to best in t1
pareto designs leading to best in t2
best in t1
best in t2
FDR4
opt for 0 % weight on 14 kn
opt for 80.0 % weight on 14 kn
opt for 100 % weight on 14 kn
t2 (14 kn)
751.0
750.8
750.6
750.4
750.2
750.0
749.8
749.6
705.0
705.5
706.0
706.5
707.0
707.5
t1 (8 kn)

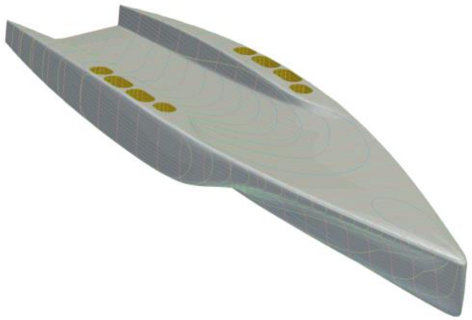

opt for 0 % weight on 14 kn
opt for 80.0 % weight on 14 kn
opt for 100 % weight on 14 kn
Sobol (DoE)
best in t1
best in t2
FDR4
t2 (14 kn)
764
762
760
758
756
754
752
750
705
710
715
720
725
730
735
740
t1 (8 kn)

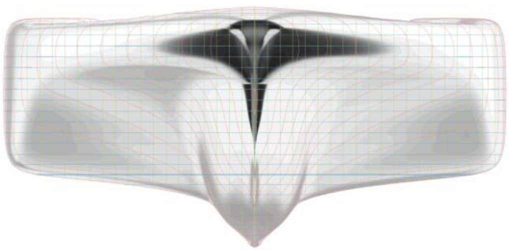

opt for 8 kn
opt for 14 kn
80.0 % weight on 14 kn
DV range norm
1
0
dzEnd
posMid
zEnd
angleStart
rMid
zStartRel
xEnd
depthBustle
dzAft
yTransom
weightMid
addDeckHeight
zStart
w
maxZcpc
zMid
angleMid
weightMid
dzStartRel
LOA
B
blendMid
yMid
dzStart
dyTransom
yStart
aftBlend
rangeSlim
yStart
posMid
zEnd
yMid
weightEnd
maxWeight
angleRel
zMidRel
zEnd
xEndSternValley
zTransomRel
estimateTrimAtFlight
zEnd
yStart
smoothness
pullSternValley
yMid
pos3
foreBlend

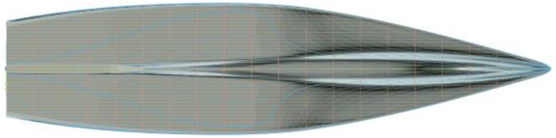
Some Shapes











Summary

- Parametric hull model for a complex geometry subject to complex constraints
- Optimisation with uncertainties on the objective function
- Comparing only optimal designs to each other
- Computation of the objective function is expensive
- Surrogates for flexibility
- Iterative approach to successively improve the accuracy of the surrogates