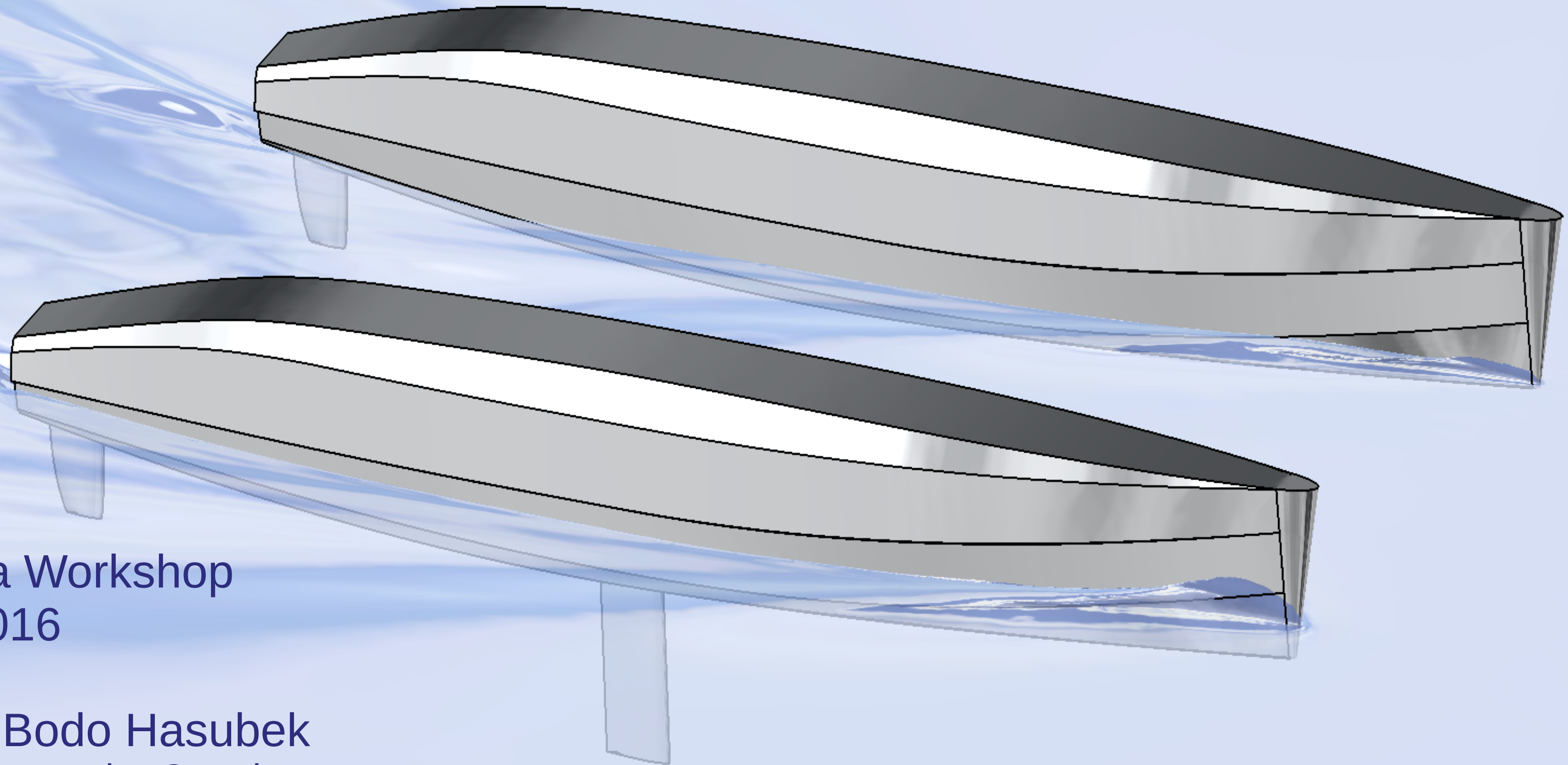
Virtual tank testing for a VPP

of a sailing catamaran



Numeca Workshop
SMM 2016

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www.DreamcatcherOne.de

The Project: Dreamcatcher One

A cruising catamaran for worldwide travel

Key properties

• Length	20.57m
• Max. width	10.67m
• BCB	4.25m
• Mast height	30.0m
• Sail area	$270m^2$
• Weight	36.0t
• Material	Aluminium
• Other	Daggerboards

Motivation

Why going through the effort of using a CFD in a yacht design?

- More realistic force calculations for optimized hull geometries
- Catamaran designs
  - Interaction between hulls can be captured (in leeway conditions as well)
  - Lift/Sinkage of hulls in heeled conditions
  - Very limited catamaran designs in Delft series
- Appendages and their interaction can be properly described

→ More realistic performance estimate

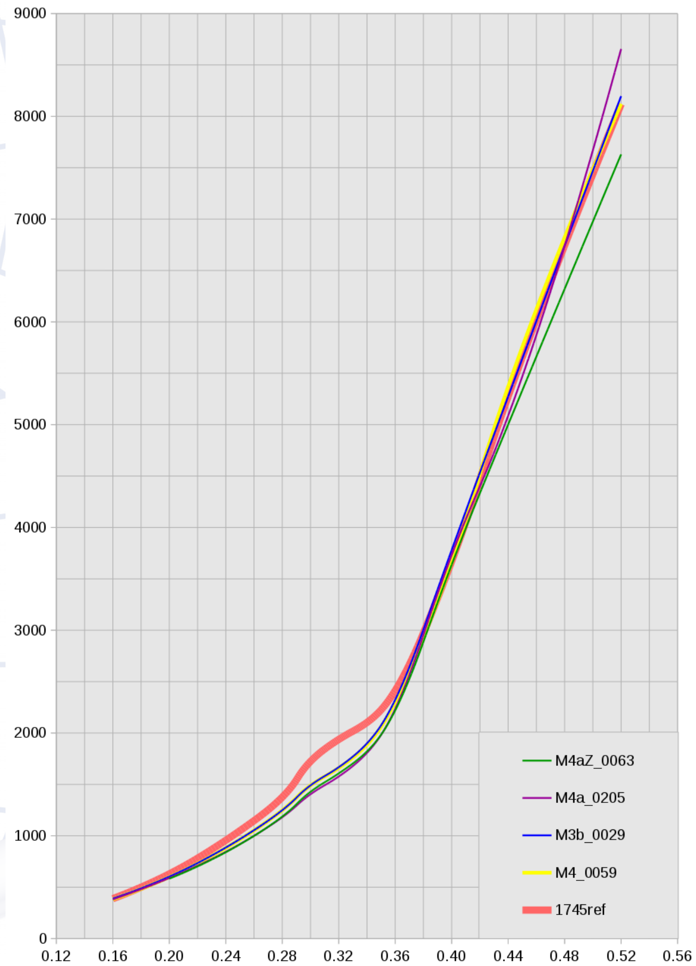
Systematic Hull Variation

Optimization goal:

Best performance at 8-10 kts (Fn=0.3...0.36)

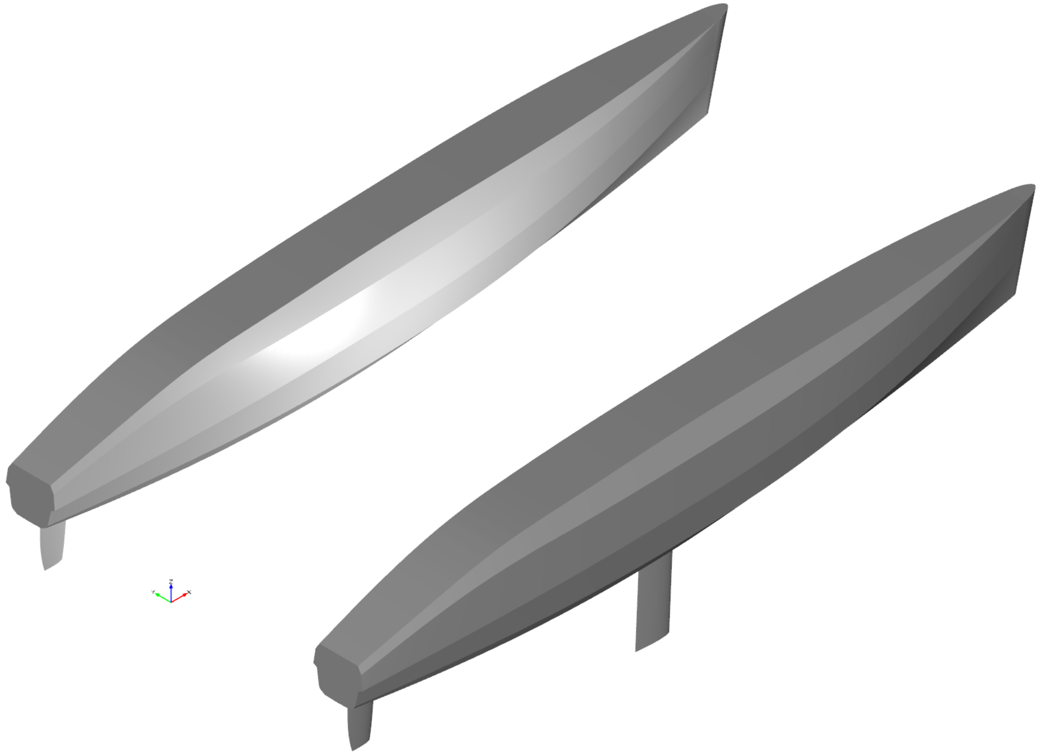
Setup using CAESES

- **Unappended, single hull**
- 4508 models in total
- 3987 wave resistance analysed (potential flow)
- 521 combined potential flow and Navier-Stokes (VOF) analysis
- Reduced total resistance at 8kts by 15% compared to best analytical design using “good” design criteria



Model for Fine/Marine

Appended hull



- Standard profiles
  Daggerboard NACA0012
  Rudders NACA0015

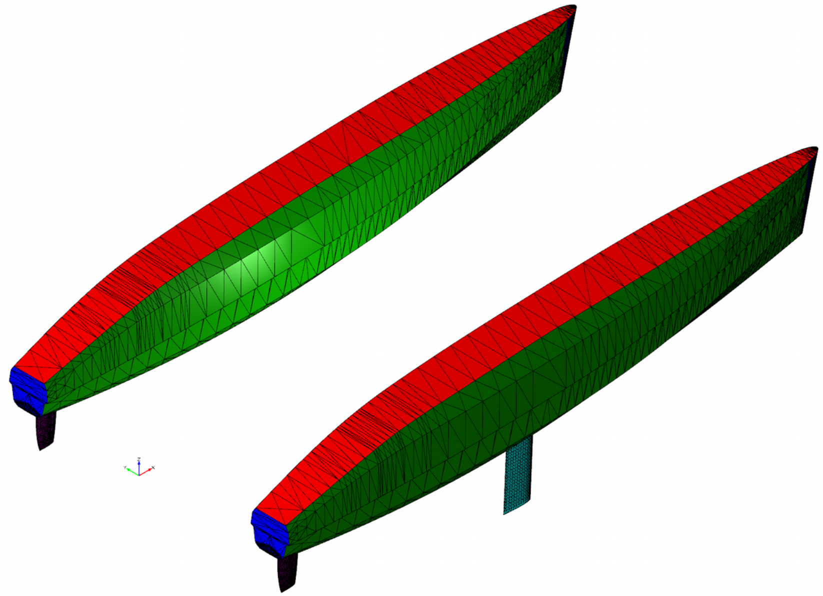
- Projected areas
  Daggerboard $2.6m^2$
  Rudders (each) $1.06m^2$

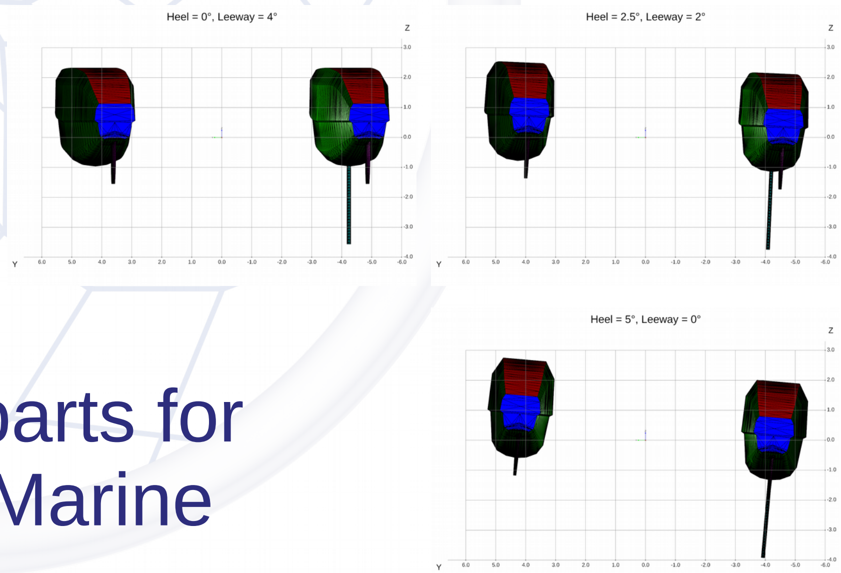
- Asymmetric set-up with leeward board down
- Rudders are attached to hull (no gap for easier meshing)
- Rudder angle is 0°

Model setup for Fine/Marine

Model setup workflow

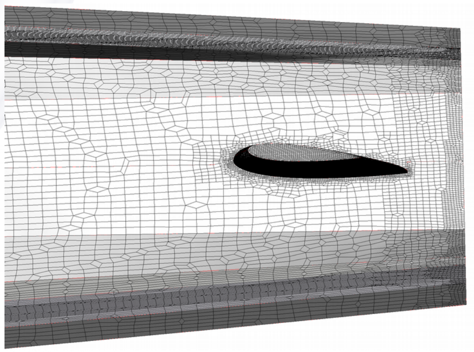
- Parametric model in CAESES
  - Heel / Leeway transformations
  - Fixed displacement
  - Variable rudder angles and daggerboard sweep angles
- Triangulation in CAESES
  - Water-tight STL body
  - STL-triangulation exported (multibody STL)
- Different colours for different parts for automatic recognition in Fine/Marine





Meshing in Fine/Marine

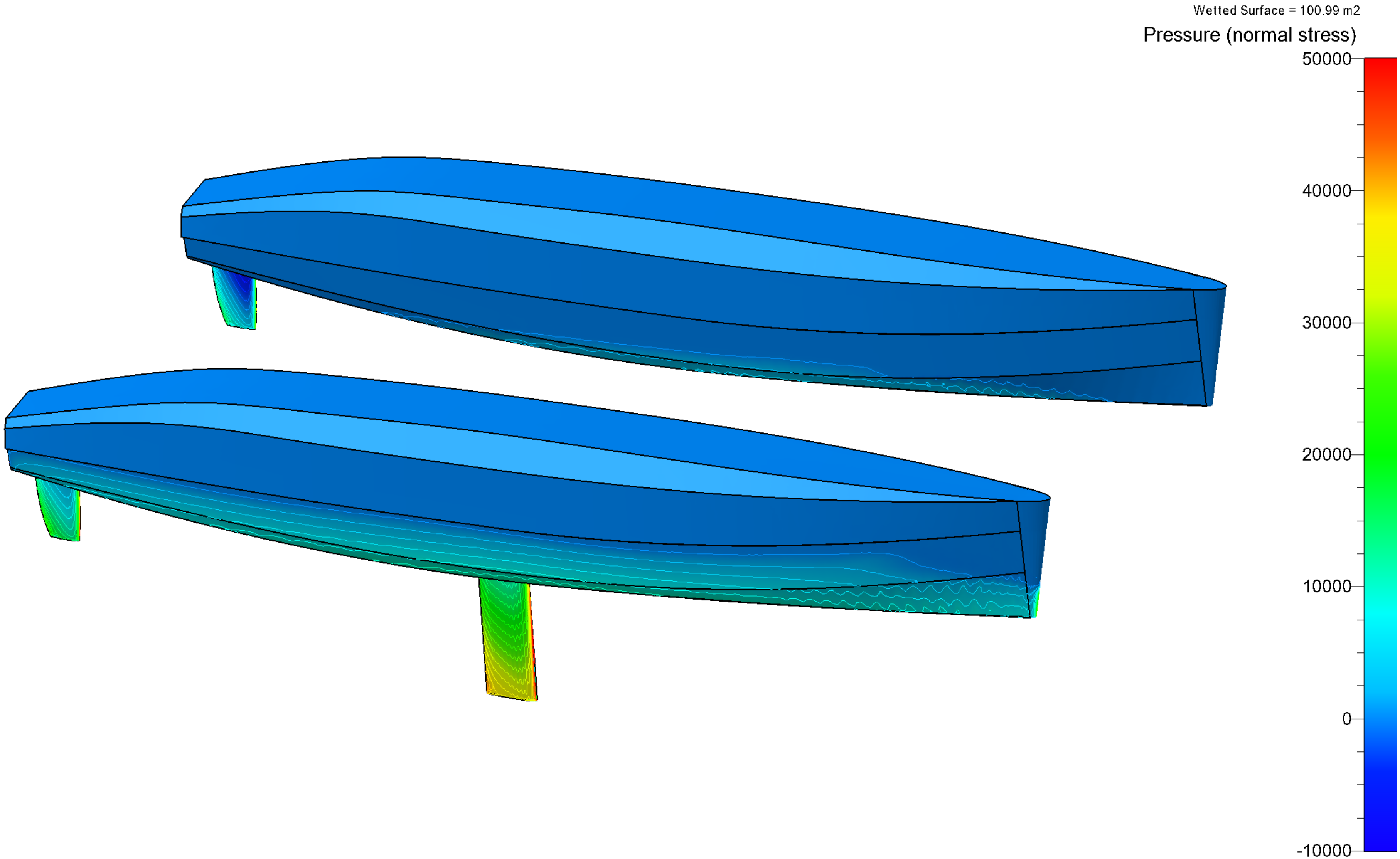
- Fine/Marine Wizard for base set-up
- Manual Mesh refinement of bow and daggerboard an rudders to properly capture sharp discontinuities in curvature
- Between 5 and 7 mio. cells (Larger number for larger heel/leeway angles)
- Grid quality measures were ruined by edge above the waterline
- Grid sensitivity analysis showed little influence on results for increased number of cells



Virtual tank tests

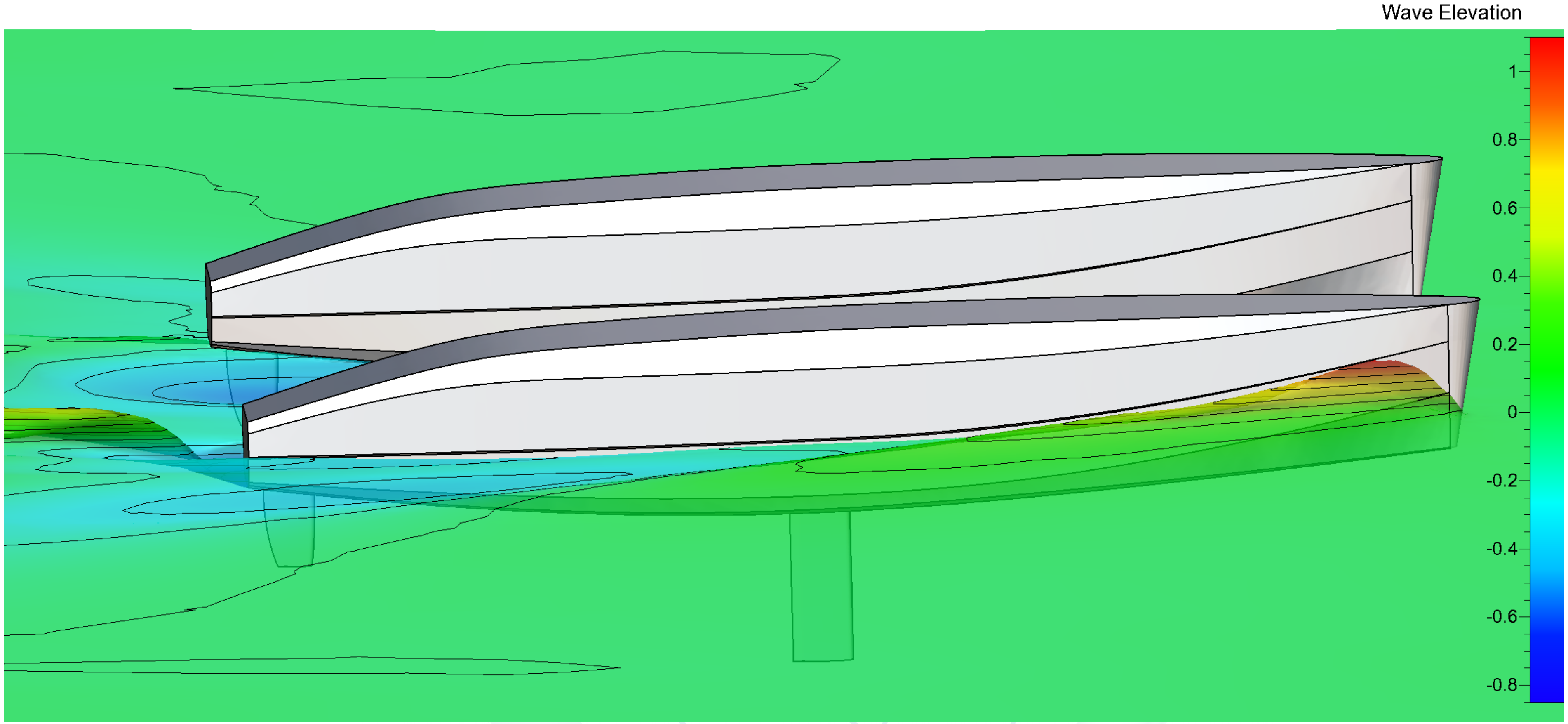
- Test range
  - Velocities — 4-14kts (Fn=0.15-0.52)
  - Heel — 0.0° – 5.0°
  - Leeway — 0.0° – 4.0°
  - Total — 4 velocities each
16 models at different angle combinations
64 calculations
- Calculation effort
  - Hardware — 8-core Hashwell running at 3.0/3.5 GHz
64 GB RAM (no swapping)
  - Average calc. time — 29.1 hours (per calculation)
  - Total calc. time — 77 days

Results: Visual inspection 1



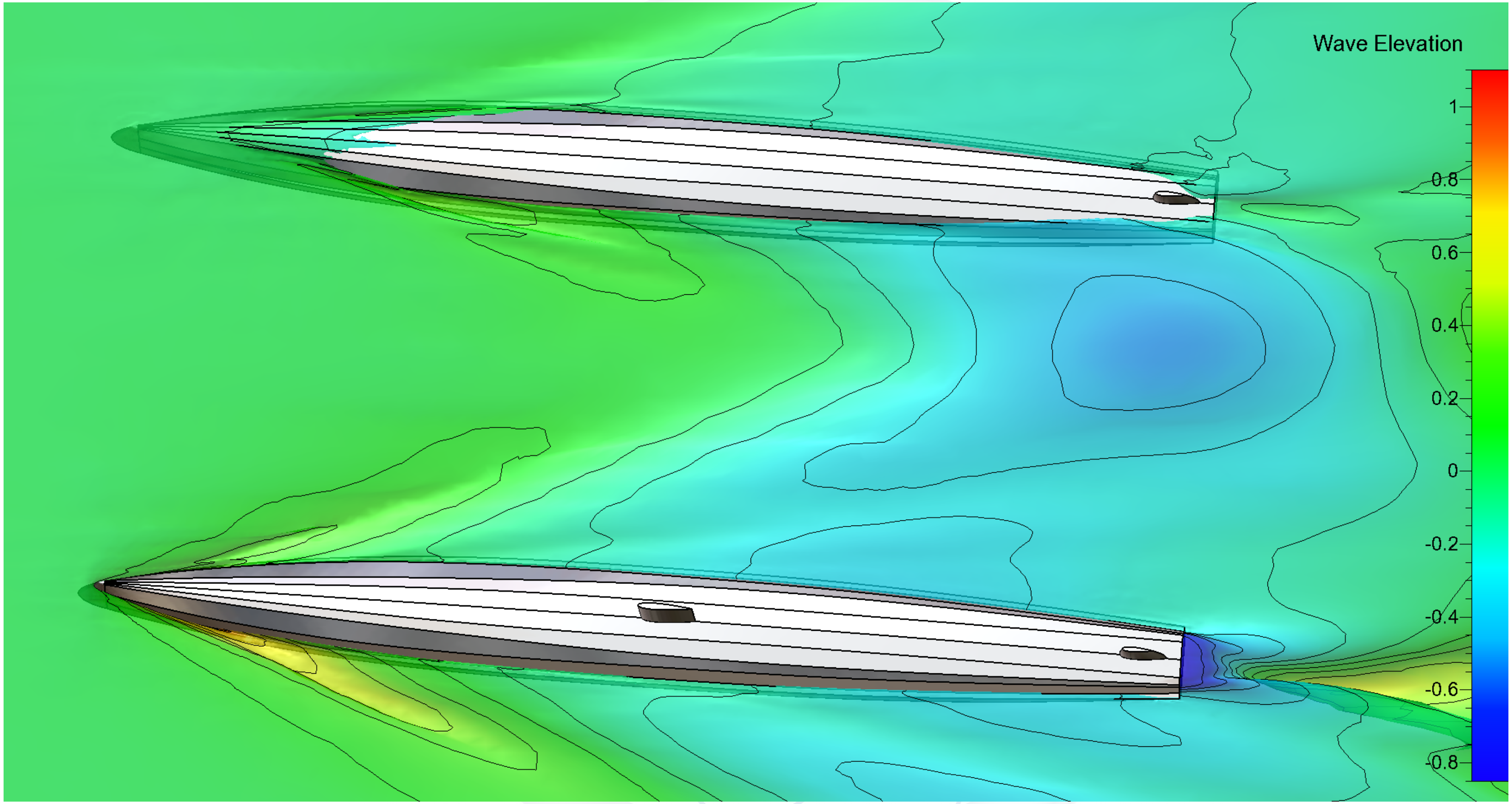
Pressure distribution: rectangular shape vs. elliptical appendage shapes

Results: Visual inspection 2



Wave elevation: Clean run-off at the submerged hull

Results: Visual inspection 3

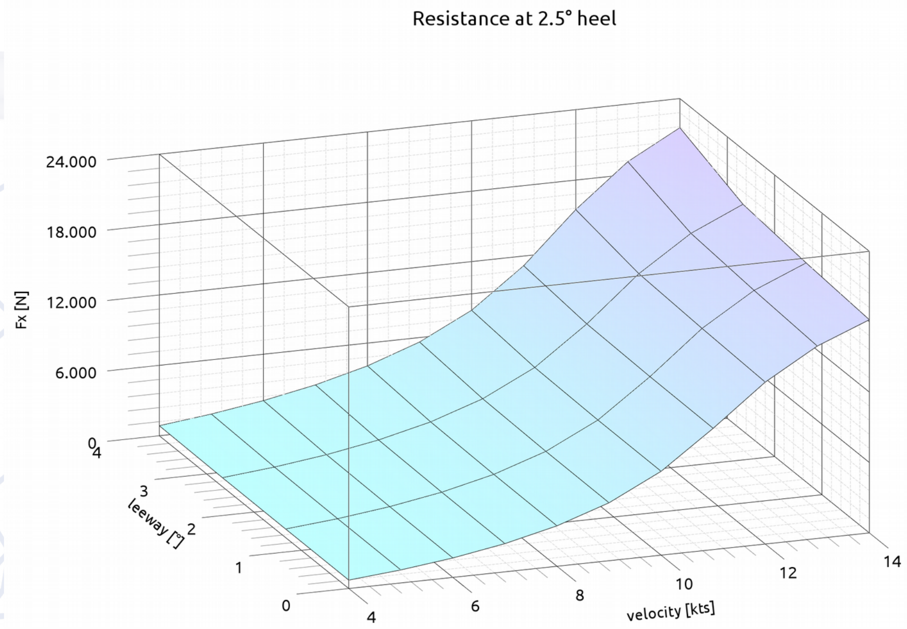


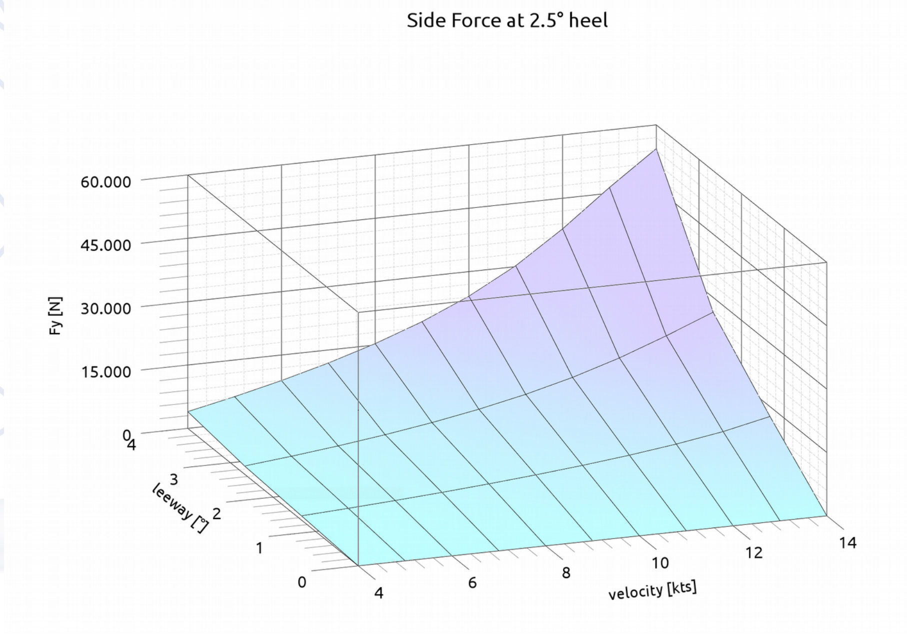
Wave elevation: Bottom view, no rudder ventilation

Results: Resistance and side forces

Numerical results

- Resistance forces in global x direction
  - Confirms results from systematic hull variation series: No bump at Fn = 0.3 (8kts)
  - Influence of leeway
  - One such surface for each heel angle
- Side forces perpendicular to mid-ship line
  - Highly efficient appendages
  - Side forces of one daggerboard sufficient to balance sail side forces





Velocity Prediction Program (VPP)

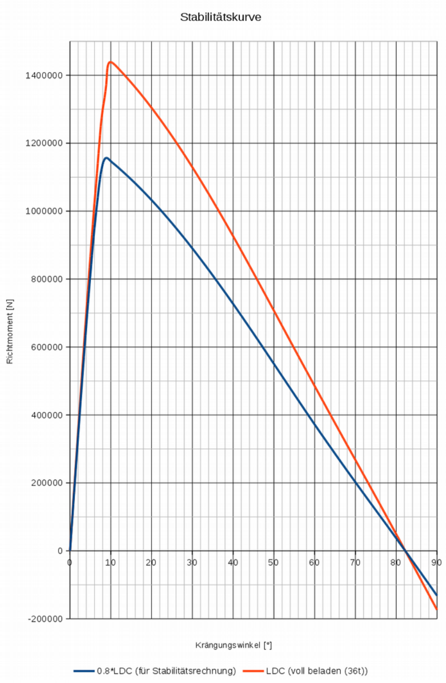
Balancing of hull and sail forces

$$F_x^A = F_x^H \quad (1)$$

$$F_y^A = F_y^H \quad (2)$$

$$M_x^A = M_x^H \quad (3)$$

- ORC only uses two (equations (1) and (3))
- Here Fy-equilibrium (2) is used in addition to determine leeway angle
- CFD calculations deliver Fx and Fy, static stability curve delivers Mx of the hull
- Sailmodel delivers Fx and Fy of the sails, and the heeling arm to determine Mx
- Balancing is done using the Newton-Raphson-Method



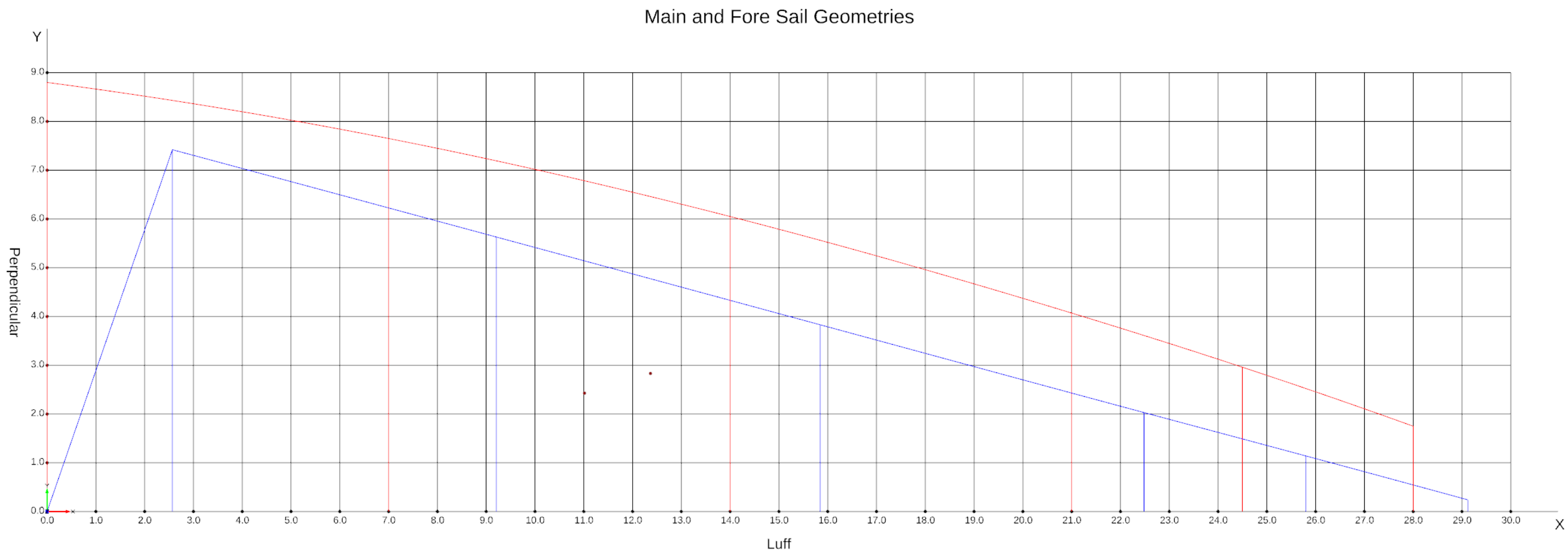
Hull resistance and side force model

3-dimensional B-spline interpolation for scattered data using the simulation data for Fx and Fy

- Uses 4th order B-splines
- Proper non-linear interpolation
- Grid refinement procedure allows for close approximation of calculated data
- Differentiable (important for Newton-Raphson)
- Can be extrapolated

Sail Model

- Uses an adapted ORC model
  - Sail areas and centre of effort are derived from exact geometric representation of the sails including reefing (ORC uses simple trapezoidal rule)
  - Lift and Drag coefficients are taken from the ORC



Advantages/Disadvantages

Advantages

- Arbitrary hull shapes
  - Multihulls
  - Hard chines
- Independent of systematic series
- Unusual appendage configurations
- Bonus: Moments around vertical axis for boat balance considerations

Disadvantages

- Only flat water simulation (no waves)
- Calculation effort

Thank you

Questions?

More information on my project:

www.dreamcatcherone.de (German only)