Seakeeping Analysis of Sailing Yacht Hulls and Centerboard Effect: Comparison between Different Computational Methods

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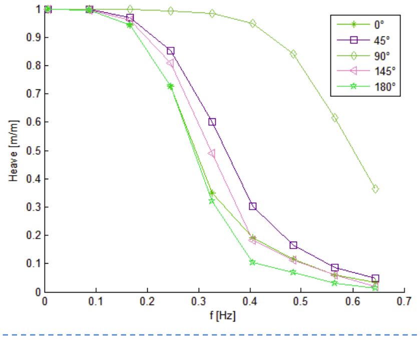
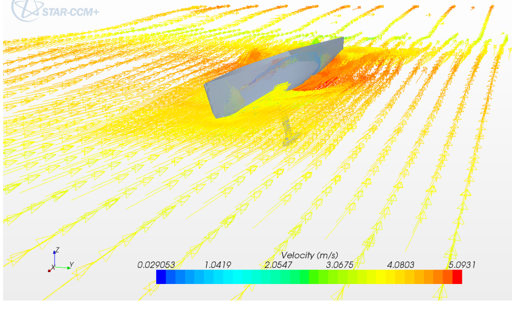
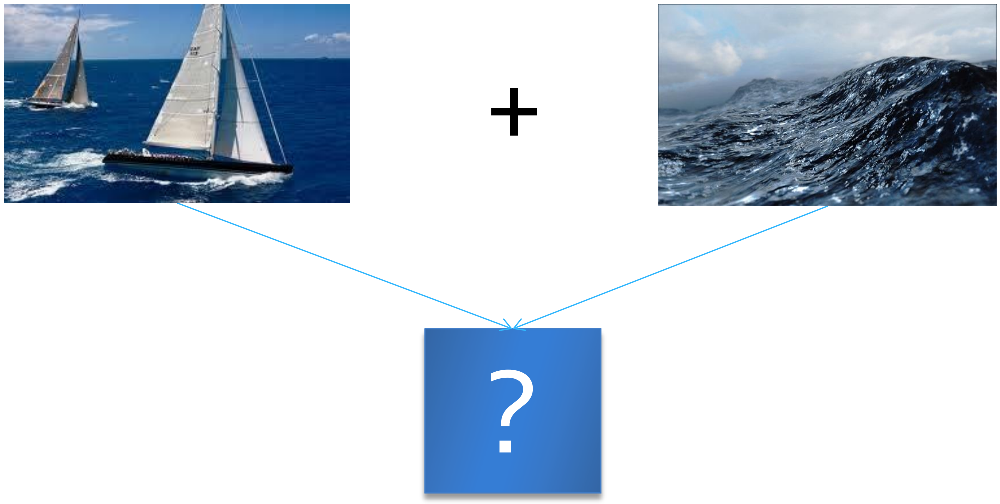




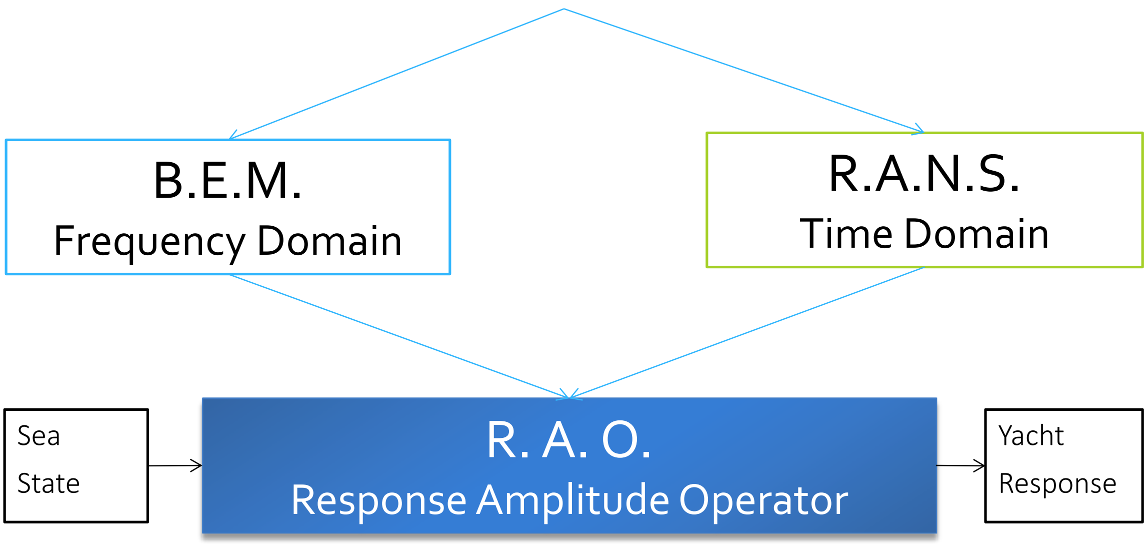
Seakeeping Analysis

- The seakeeping study is normally used to evaluate the ship response to a generic sea state.

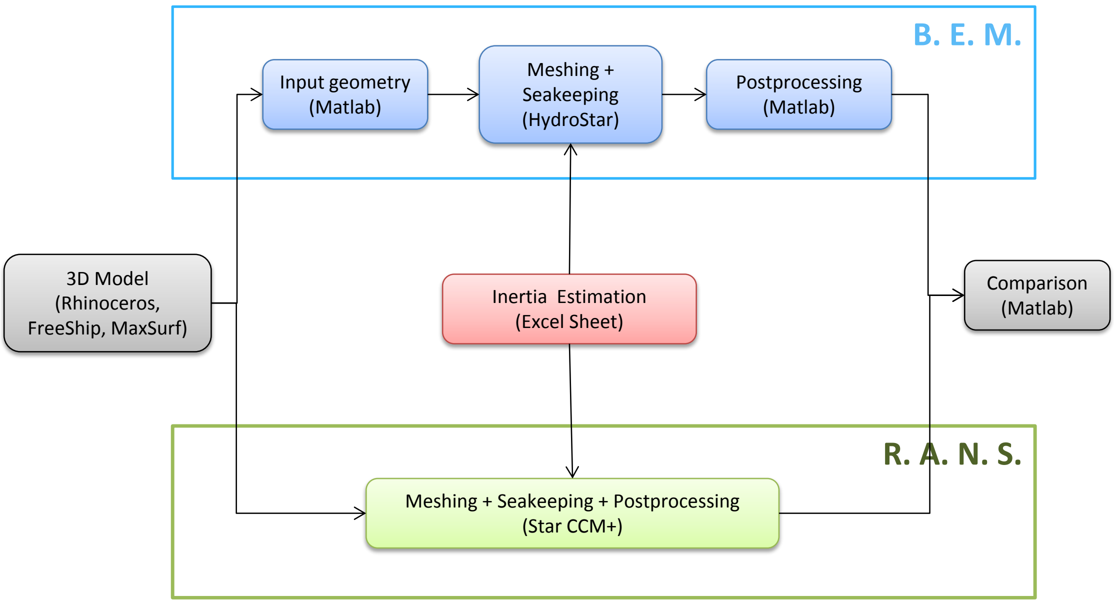


Seakeeping Analysis

- Computational methods can allow the evaluation of the yacht motion, velocity and acceleration in all the 6 DoFs



Thesis Workflow



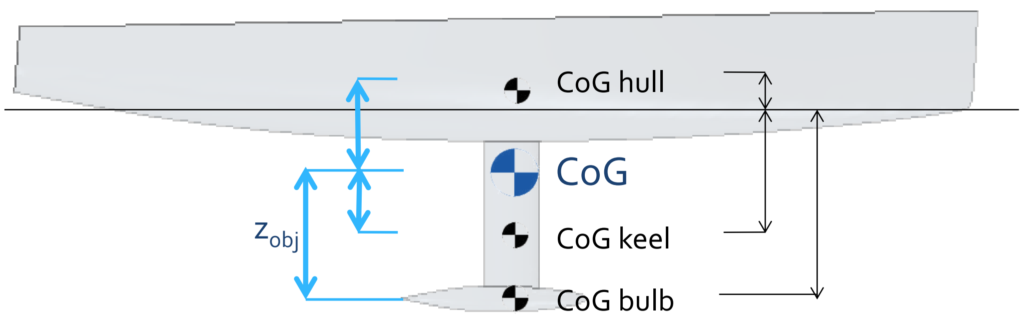
Inertia Estimation

- In order to solve the yacht dynamic system, mass inertias must be evaluated and then trasported to the relative CoG:

$$[M + A(t)]\{\ddot{X}\} + [B(t) + B_v]\{\dot{X}\} + [K]\{X\} = \{F(t)\}$$

$$I_{xx\_obj} = I_{obj} + z_{obj}{}^2 \cdot m_{obj}$$

$$I_{xx\_CoG} = \sum I_{xx\_obj}$$



Boundary Element Method

- The most used method for the seakeeping evaluation comes directly from the Potential Theory applied to a Panel Method:
  - Non viscous ($\nu = 0$)
  - Irrotational ($\nabla \times V = 0$);
  - Incompressible ($\rho = const$)

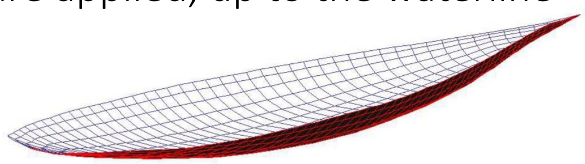
HydroStar

+ Fast computation
+ Spectral analysis possible
+ LTI system
+ 2nd order effects

- Only volume under waterline
- No lifting effect
- No viscous damping effect
- Optimum for simple geometry body

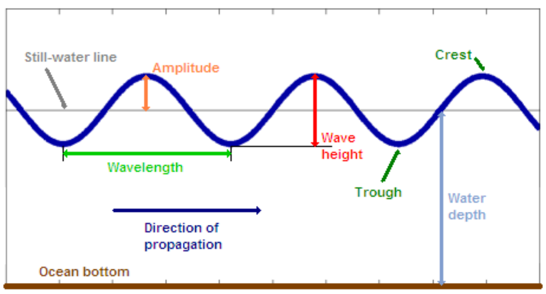
Computational Domain

- The yacht is modeled by 3D panels, where Green functions are applied, up to the waterline

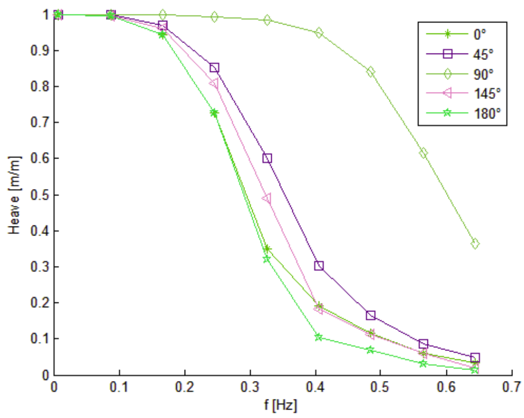


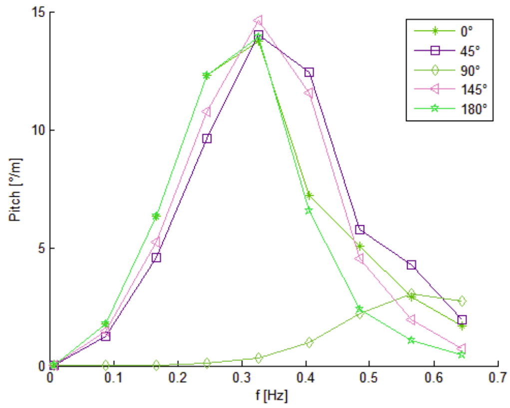
NO TOPSIDE VOLUME

- The Wave is computed as Monochromatic perturbation along the mean Free Surface with constant Amplitude



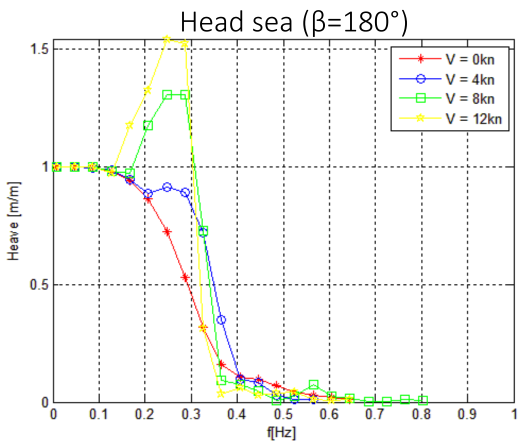
RAO: Heading Effect (V = 0kn)

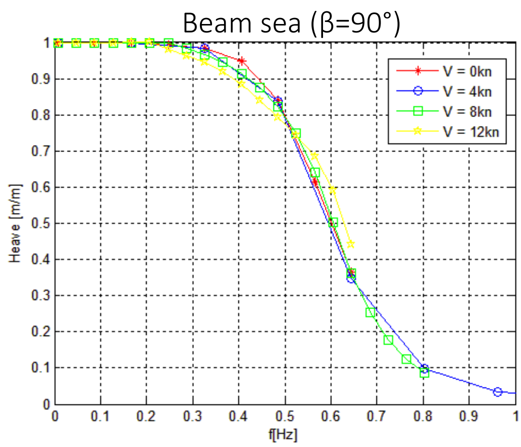




- Heave has a wider spectrum with beam seas
- Pitch motion present resonance around 0.3Hz hence waves of about 3s period

Speed Effect: Heave



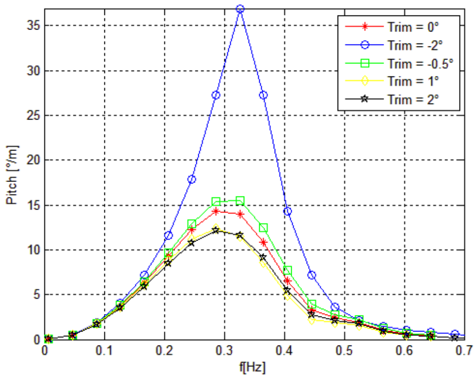


- The increase of velocity generates a peak of resonance
- The higher is the velocity the higher is the peak

- Very Slight modification

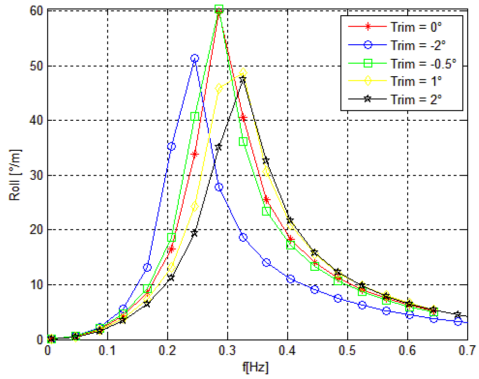
Trim effect: Pitch & Roll

Head sea (β=180°)



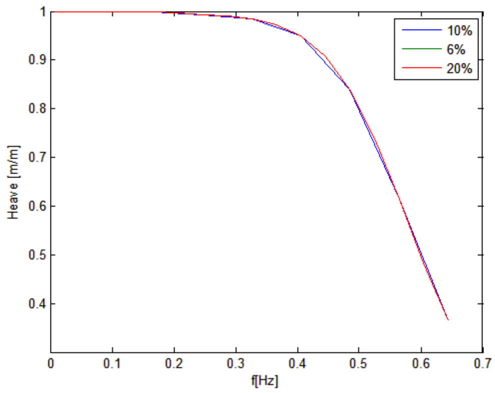
- Pitch motion peak enhanced by negative trim (bow up)
- Reduced by positive trim (bow down)

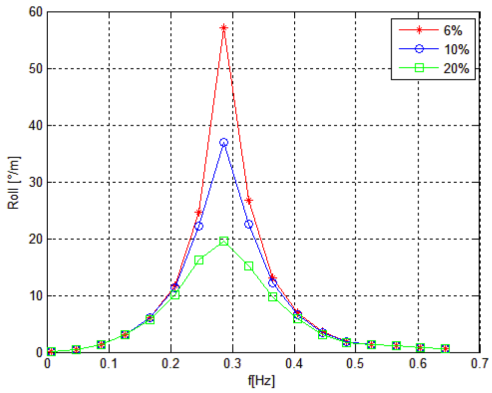
Beam sea (β=90°)



- The trim angle changes the underwater volume and thus the RAO spectrum, the resonance frequency and its peak.

Cricitcal Viscous Damping

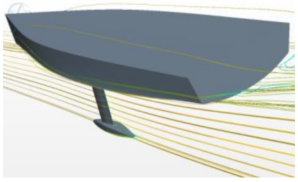


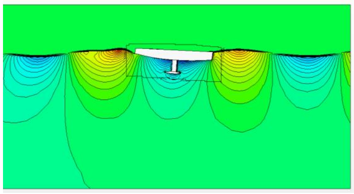


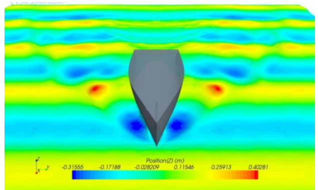
- Roll response amplitude strongly influeced by the vicous damping coefficient
- Need of exact coefficient for yacht roll performance estimation, seasickness and motion

R.A.N.S. CFD

- Numerical solution of the Reynold Averaged Navier-Stokes equations in a Finite Volume domain







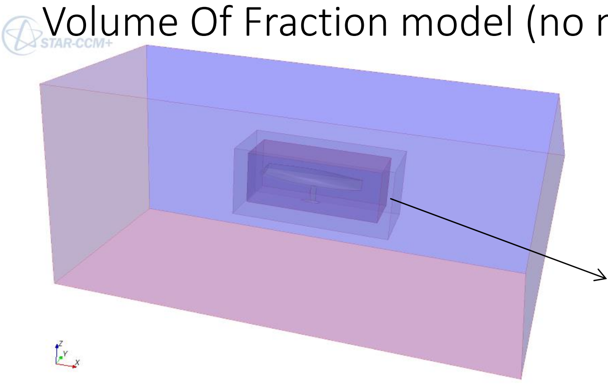
Star CCM+

- \+ Viscous effects
- \+ Lifting+Vorticity effects
- \+ Dynamic unsteady simulation
- \+ Complete body volume considered

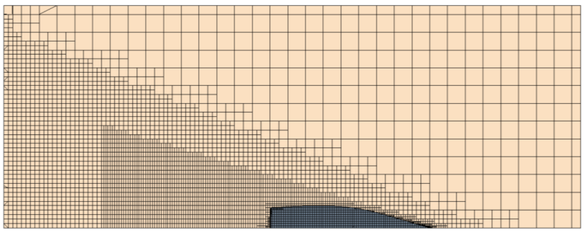
- \- Very long computation
- \- Strong Mesh influence
- \- Spectral waves input under development

Computational Domain

- Eulerian Volume with the fluids interface described by the Volume Of Fraction model (no multiphase)



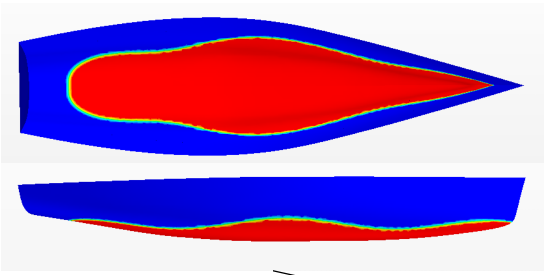
- Dynamic Fluid-Body Interaction
- Overset Mesh

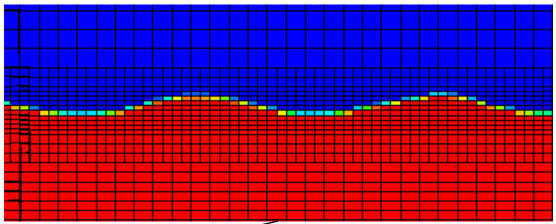


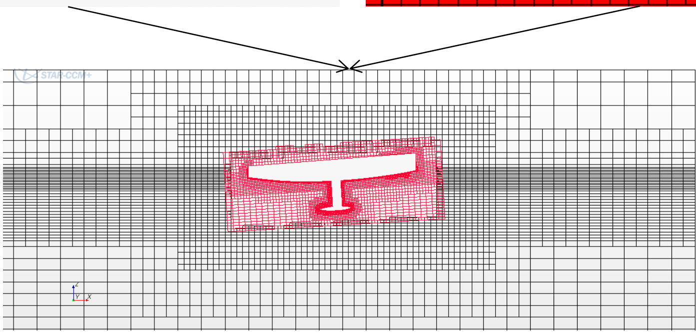
- Mesh refinement «ad-hoc»

Regular Waves Peculiarities

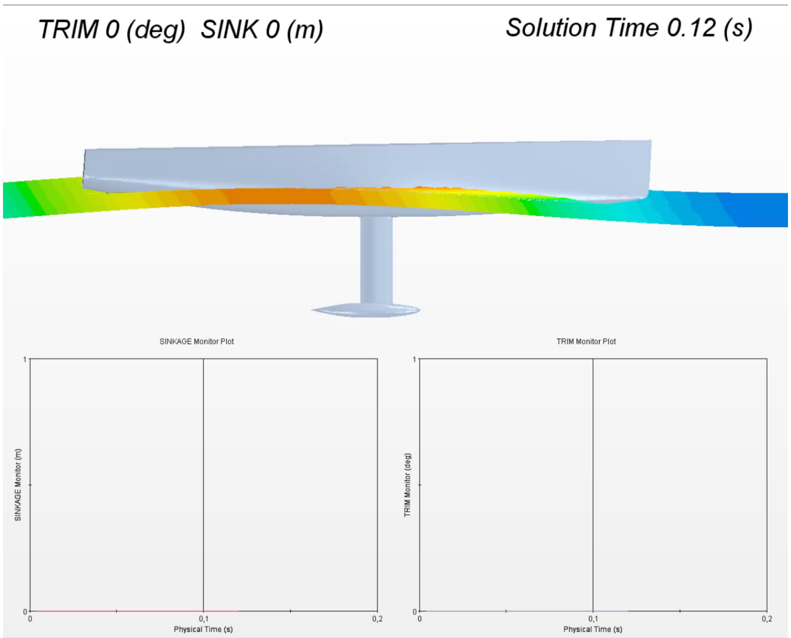
- Waves affect the wetted wolume
- Each Wave requires special refinement in order to avoid smearing



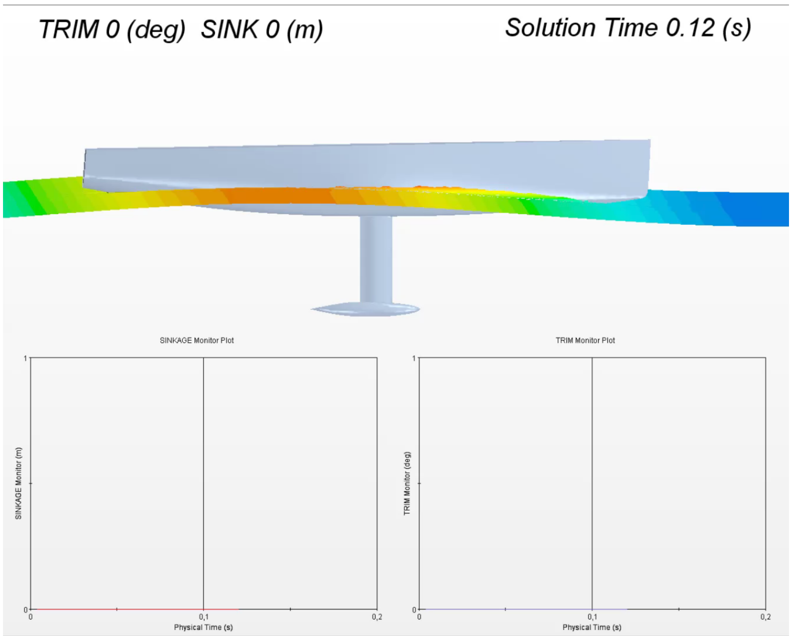




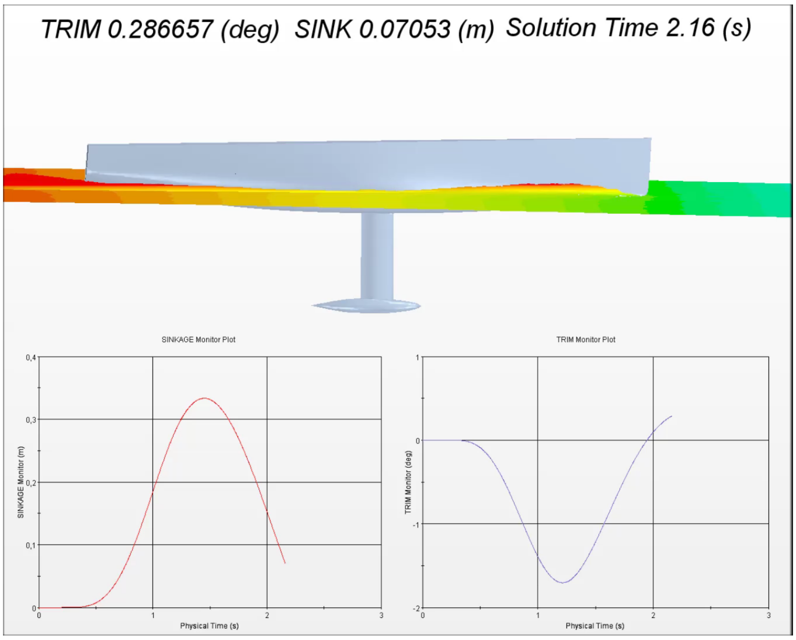
1st Order Wave (T=2.5s)



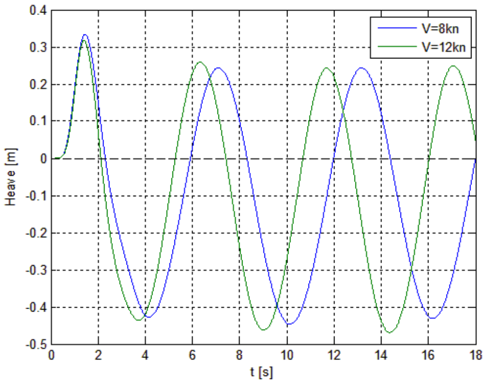
1st Order Wave (T=4s)

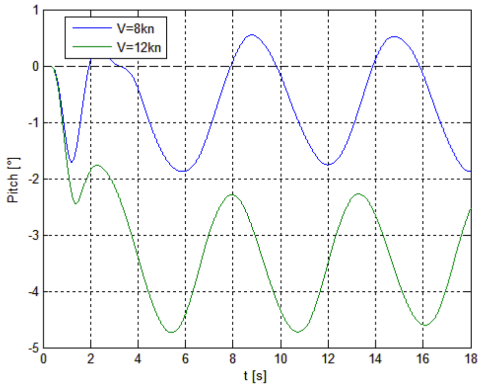


1st Order Wave (T=8s)



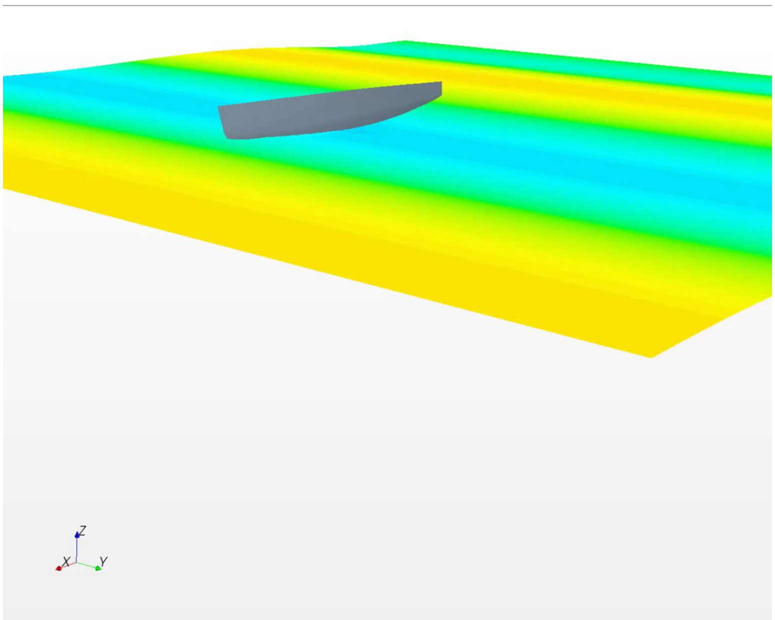
RANS: Speed Effect





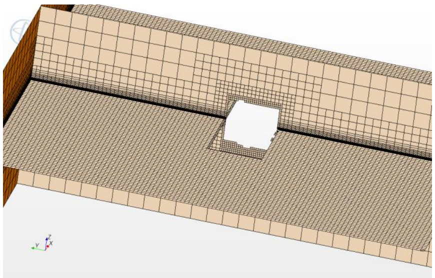
- Different response period because of different encounter frequency
- No differences in Heave motion Amplitude
- Different mean Dynamic Trim but not visible amplitude difference

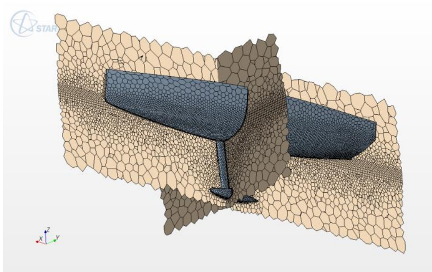
Upwind Sailing: Heeled Condition

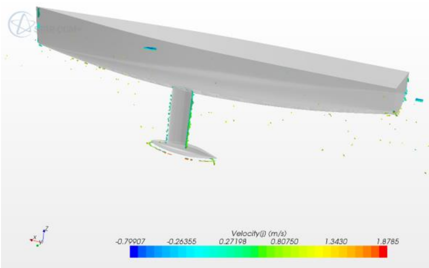


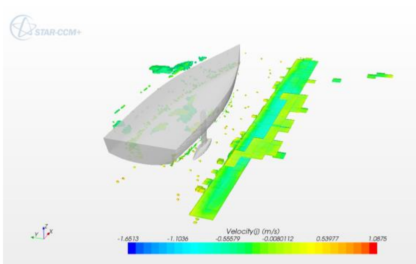
Roll Motion: mesh

- The domain loses symmetry: nr. cells at least doubled
- The informations don't spread in a favourite direction



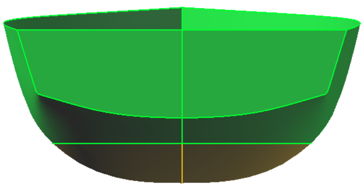




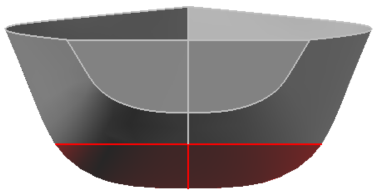


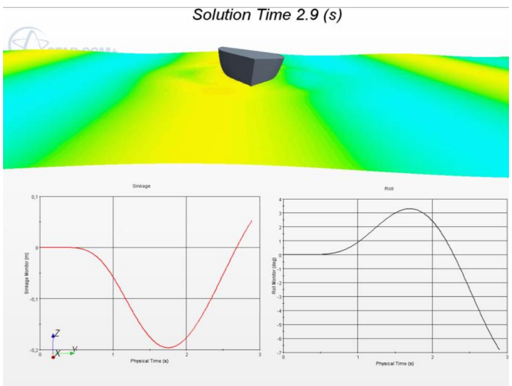
Hull Aft Shape

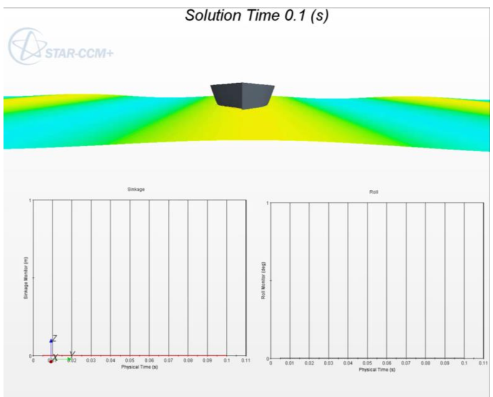
NIKKA: Soft Chines



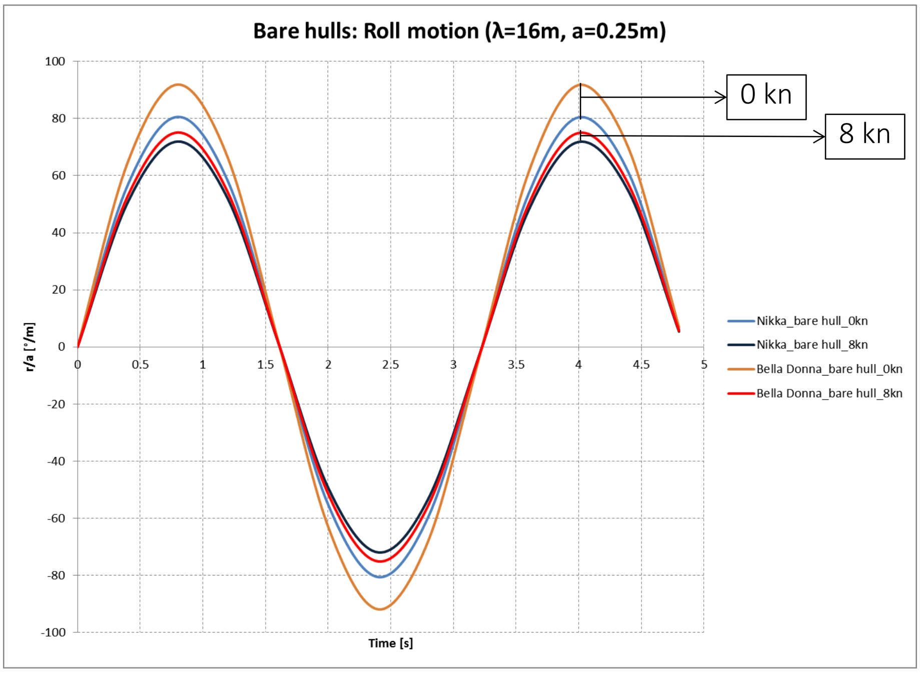
BELLA DONNA: Round Stern



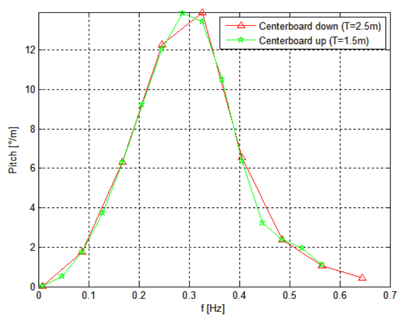




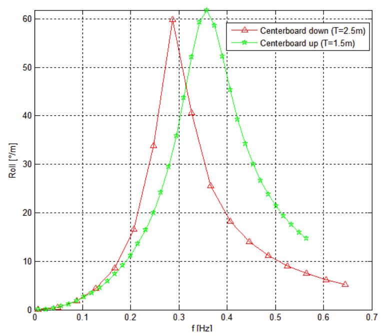
Hull Aft Shape: Speed Influence

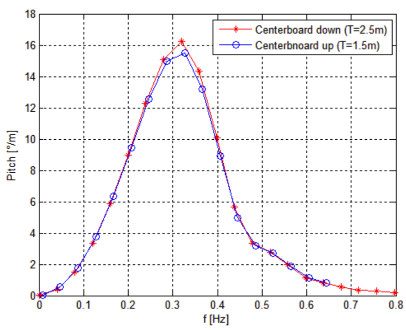


Centerboard up/down: RAO Comparison



NIKKA





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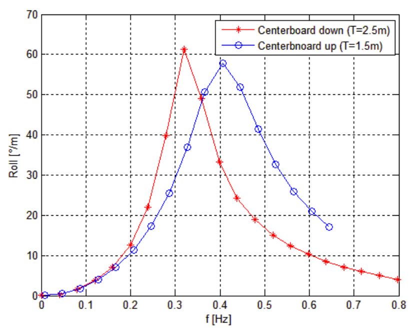
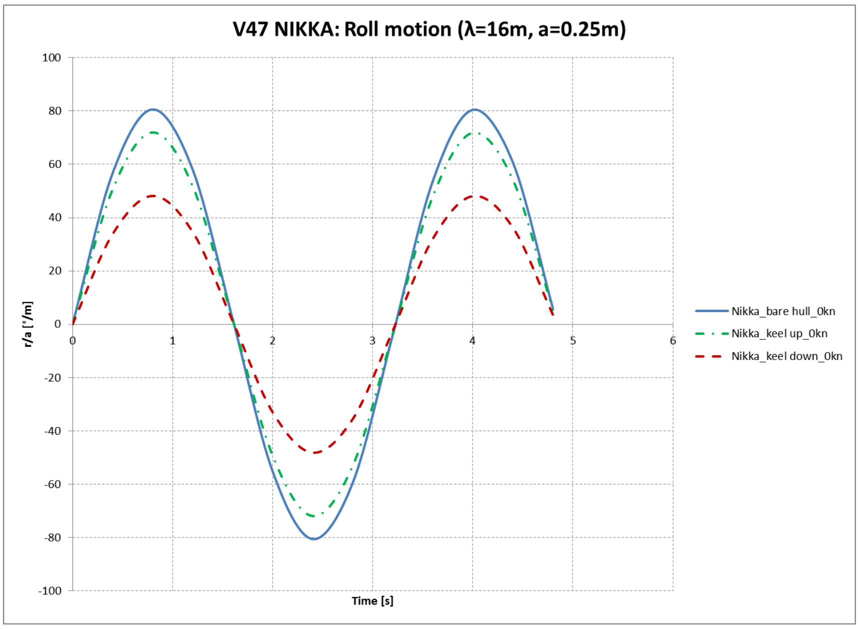
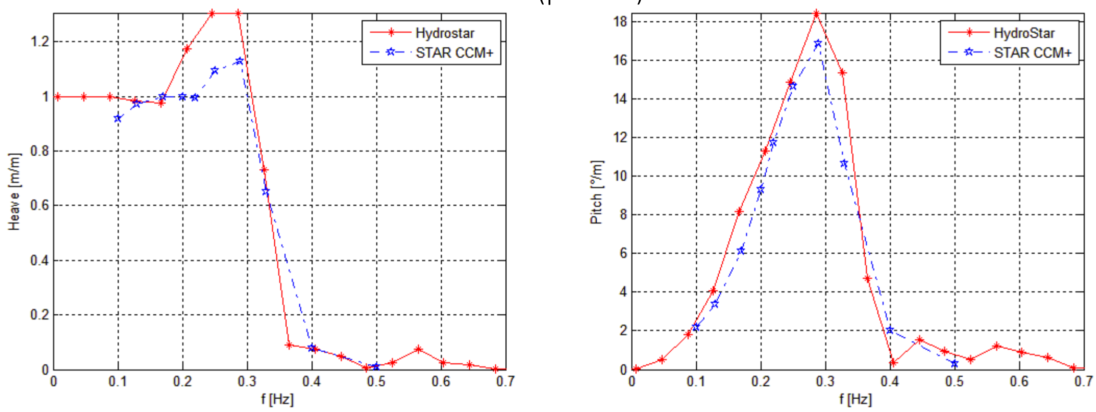


Centerboard up/down: Focus on Roll



NIKKA: *HydroStar* vs *Star CCM+*

Head sea (β=180°)



- The general trend between the two methods is similar
- Heave resonance behaviour seemed halved with viscous simulations
- At very long periods/low frequencies a lower ratio of Heave amplitude is shown for *Star CCM+*

BELLA DONNA: *HydroStar* vs *Star CCM+*

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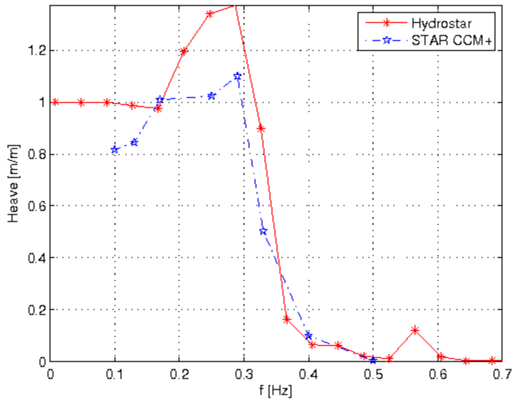

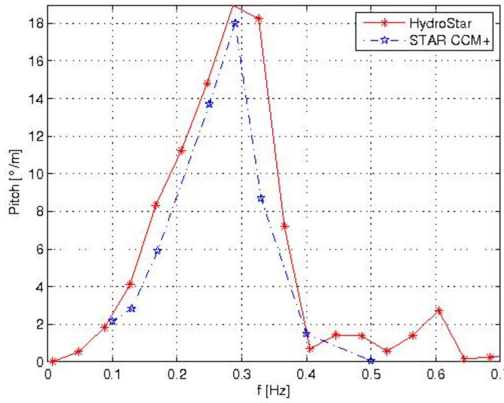

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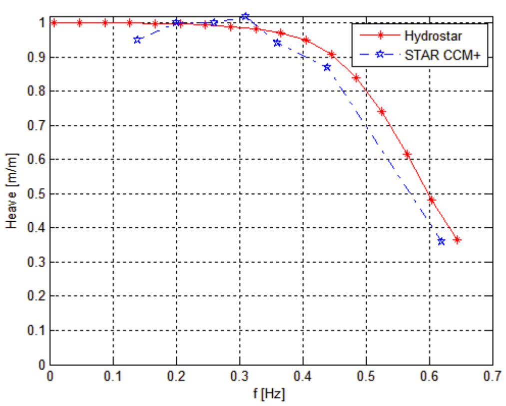
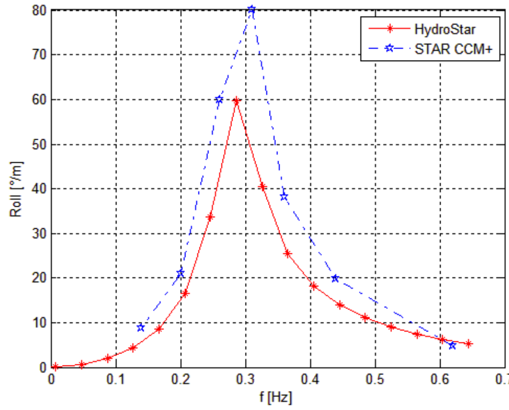
HydroStar vs *Star CCM+*

Beam sea (β=90°)





- Heave motion shows a slightly reduced spectrum for RANS solver
- Concerning sailing yachts, Roll motion cannot be correctly predict by non-viscous solver

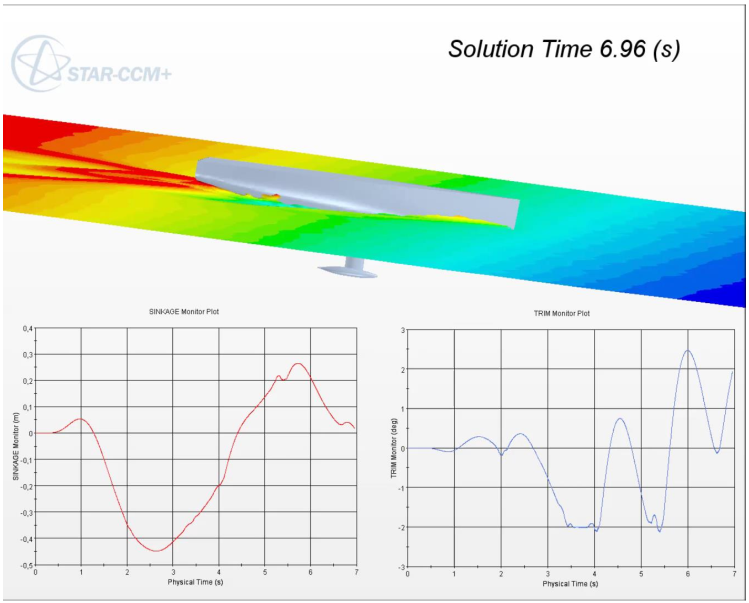
Conclusions

- For the seakeeping of complex dynamic systems like the sailing yachts, **RANS** solvers are needed.
- **Forward velocity** resonance effects that need to be experimentally validated;
- **Soft Chines** damp mostly the Roll response but its influence decreases increasing the velocity;
- The **Lifting Centerboard** don't affect the longitudinal motion in heeled condition with head sea (roll fixed) while strongly modifies the rolling behaviour.

Future Developments

- **Experimental** validation at forward speed
- Modern trend of **Hard Chined hulls** (Volvo, Vendeé Globe, Mini Transat 6.5, Class 40);
- Influence of **Bulb** shape on roll damping;
- Heading Angle + 6 DoFs: the **future of VPP**;
- **Aerodynamic + Hydrodynamic RANS** simulation (America's CUP - Oracle USA)

Questions?



Thanks