German OpenFoam User meetiNg 2017 (GOFUN 2017)

Development and application of a new free-surface flow solver

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- Solver Description: Sea Waves / A New Wave Damping Method
- Comparison to Star-CCM+ and interFOAM

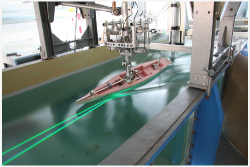
Who we are:

FACHHOCHSCHULE KIEL
University of Applied Sciences

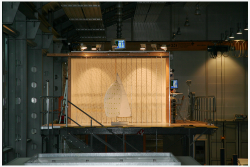
Forschungs- und Entwicklungszentrum
Fachhochschule Kiel GmbH

Yacht Research Unit Kiel

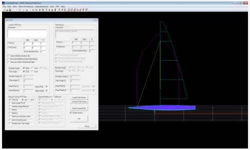
YRU - Main Competences 1/2



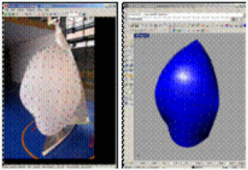
Circulation-Tank



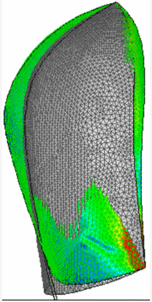
Twist Flow Wind Tunnel



VPP-Development

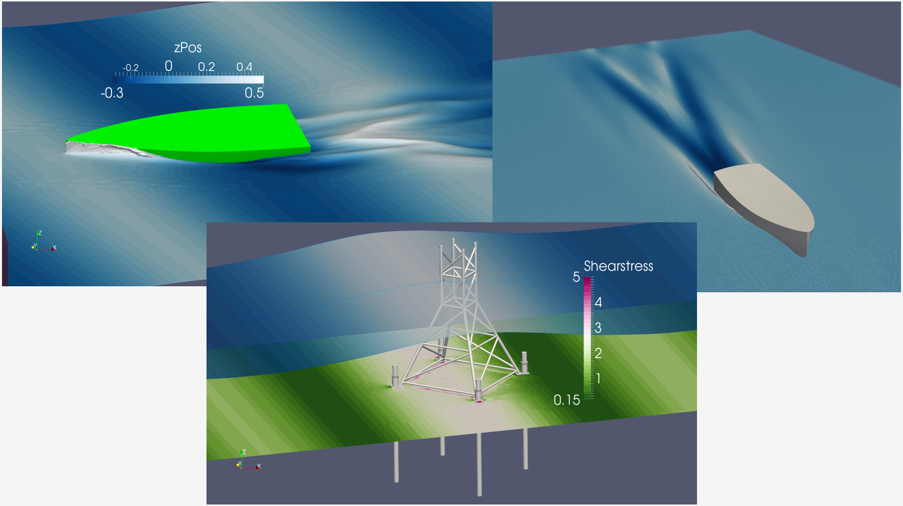


Full- and Model-Scale Photogrammetry



FSI

Free-Surface Simulations (RANSE) / OpenFOAM Development



Problems using standard OpenFOAM (interFoam / interDyMFoam):

- solver stability
- numerical ventilation
- computation time (Strong Courant number limitation)

→ Development of a new "state-of-the-art" OpenFOAM solver for free-surface flows around ships based on extensive review of literature.

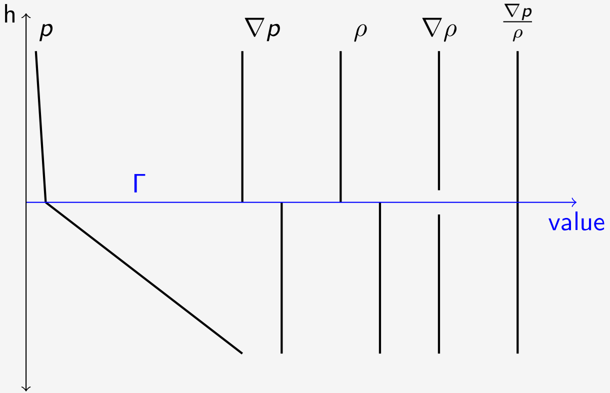
InterFoam:	**OurSolver:**
SIMPLE-like algorithm (p_{rgh})	SIMPLE-like algorithm (p)
VoF-method (MULES, explicit / implicit)	VoF-method (implicit)
compression term	High-Resolution Schemes (HRIC, BICS, BRICS)
No reconstruction	Reconstruction of free-surface Discontinuities
Motion (unsuitable unstable)	Motion (robust)
	Improved turbulence models
	wave generation / wave damping
	velocity acceleration
	anisotropic grid refinement (SHM)

Volume of Fluid transport equation:

$$\frac{\delta \alpha_i}{\delta t} + \nabla \cdot (\alpha_i \mathbf{u}) = 0$$

three schemes implemented:

- High Resolution Interface Capturing Scheme (HRIC)
- Blended Interface Capturing Scheme (BICS)
- Blended Interface Capturing Scheme with Reconstruction (BRICS)



Characteristics of pressure and density at the free surface

Solution: Reconstruction of the shown characteristics with a method presented in:

QUEUTEY, P., VISONNEAU, M.: *An interface capturing method for free-surface hydrodynamic flows*, Computers&Fluids, **36**, (2007), 1481-1510.

Why wave damping

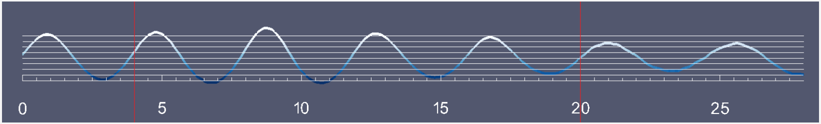


Figure : 2D-Wave at $t = 40s$, no damping

Common sponge layer method:

$$s^{\mathrm{z}}_{\mathrm{damping}} = -\rho\left(f_1 + f_2|u^{\mathrm{z}}|\right) w u^{\mathrm{z}}$$

with the weight-function

$$w = \frac{e^{\kappa} - 1}{e^{1} - 1} \text{ and } \kappa = \left(\frac{x - x_{\mathrm{sd}}}{x_{\mathrm{ed}} - x_{\mathrm{sd}}}\right)^{3.5}$$

New method:

$$\mathbf{s}^{\mathrm{z}}_{\mathrm{new\ damping}} = \chi w \left(\nabla \tilde{p} \cdot \mathbf{e}^{\mathrm{z}} - \mathbf{s}^{\mathrm{z}}_{\mathrm{w/o\ p}} + \sum_{n} a_{\mathrm{n}} \mathbf{u}^{\mathrm{z}}_{\mathrm{n}}\right)$$

Full derivation given in:

Meyer, J., Graf, K. and Slawig, T.: *A new adjustment-free damping method for free-surface waves in numerical simulations*, Preprint submitted to International Conference on Computational Methods in Marine Engineering (MARINE 2017), (2017)

Simulation Setup 1/2

Similar Setup as in Perić, R. and Abdel-Maksoud, M., *Reliable Damping of Free Surface Waves in Numerical Simulations*, Ship Technology Research, Vol **63**, Iss. 1, (2016)

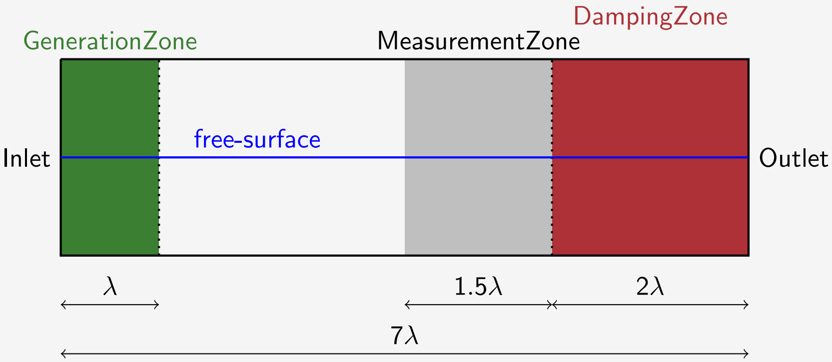


Figure : 2d Simulation Setup

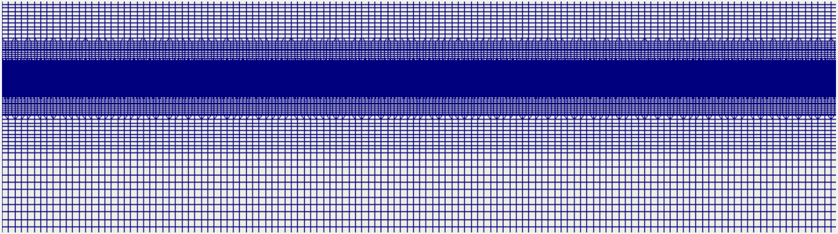
Simulation Setup 2/2

Grid Setup:

- 20 cells / waveheight h
- 100 cells / wavelength λ

Solver Setup:

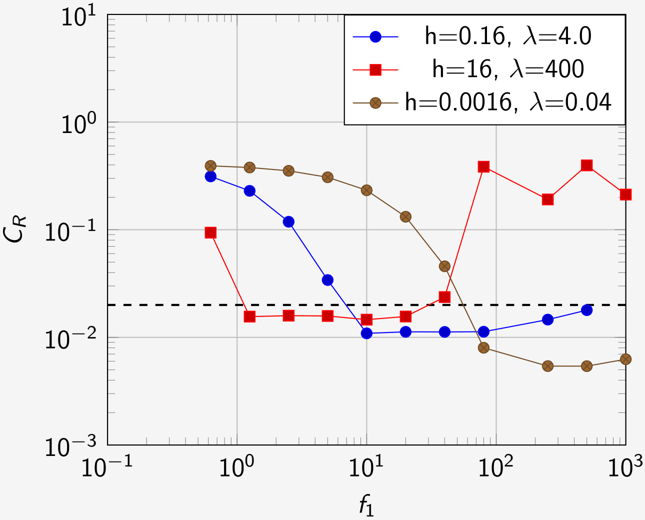
- 2nd order time discretization
- $\Delta t = \frac{1}{500} T$ ($\rightarrow Co_{max} \sim 0.17$)
- 10 SIMPLE Iterations
- Simulationtime $= 25\,T$



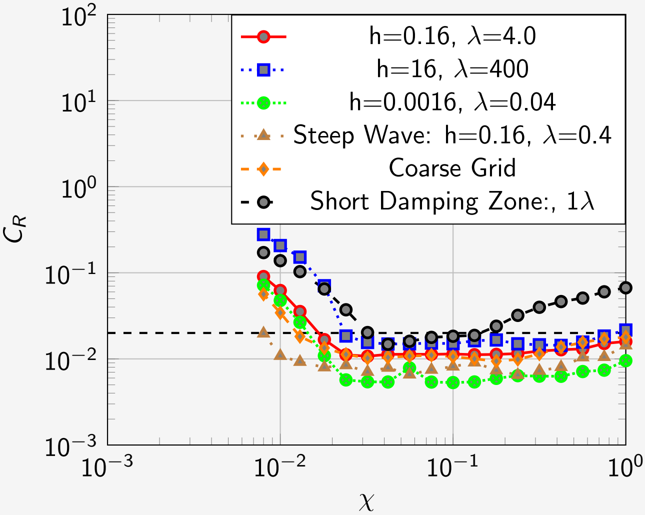
Investigations on:

- wave scale
  - “normal”: $h = 0.16m, \lambda = 4m$
  - “big”: $h = 16m, \lambda = 400m$
  - ”small“: $h = 0.0016m, \lambda = 0.04m$
- steepness $(h = 0.4m, \lambda = 4m)$
- grid coarsening (10 cells / waveheight, 50 cells / wavelength)
- damping zone length (1λ)

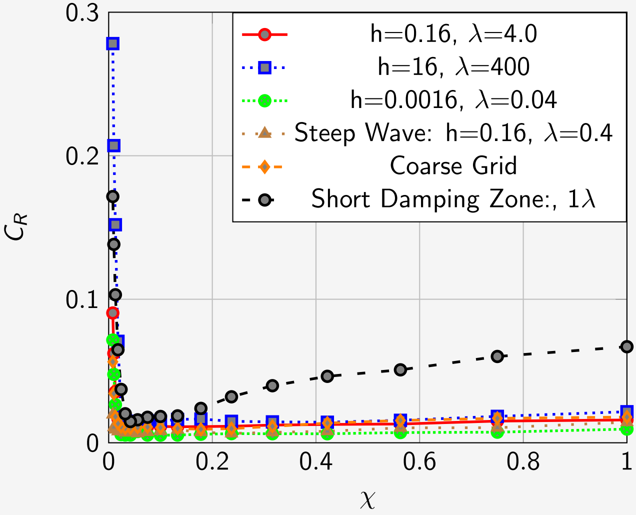
Sponge-Layer-Method (linear) - Different Wave Scales



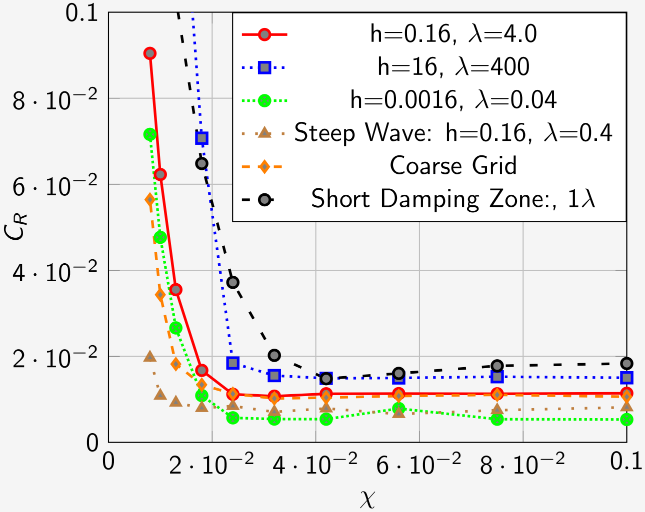
New Method - Everything (log scale)



New Method - Everything



New Method - Everything Detail



Damping vs No Damping

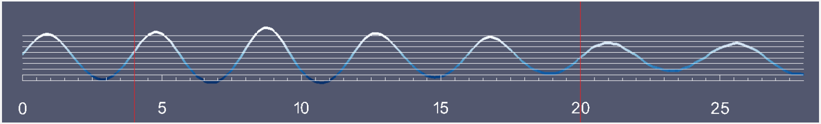


Figure : 2D-Wave at $t = 40s$, no damping

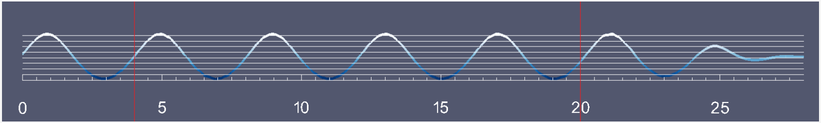
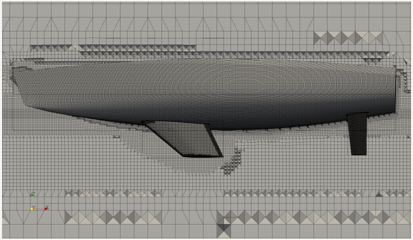


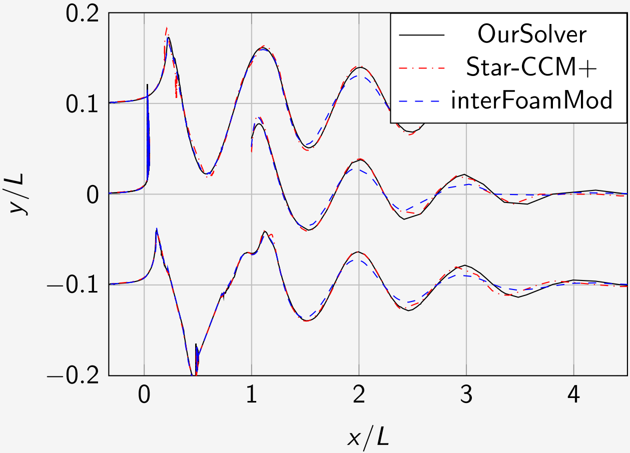
Figure : 2D-Wave at $t = 40s$, damping with $\chi = 0.1$ (optimal damping)

OurSolver vs StarCCM+ vs InterFoam/InterFoamMod

Sysser60 testcase of the Delft Systematic Yacht Hull Series:

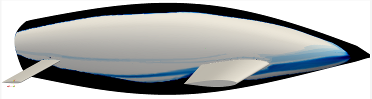
- 2.7 million cells
- without motion
- $u = 1.806\frac{m}{s}$ →Froude no. 0.39
- bow knuckle above water
- same solver setup



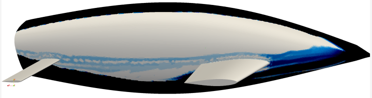


Sysser60 longitudinal wavecuts

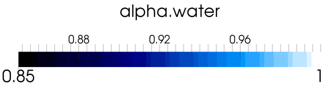
(a) OurSolver



(b) Star-CCM+



(c) interFoamMod



Numerical ventilation of the Sysser60 test case

Conclusion

- stability improved
- unphysical velocity overshoots prevented
- solution time reduced
- quality of the results improved
- sea waves / new damping method

Video - Yacht in waves from behind