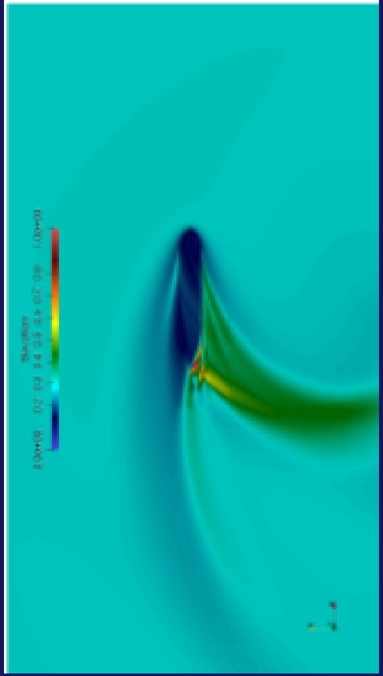
Institute for Fluid Dynamics and Ship Theory



Simulation of a steady turning circle manoeuvre in contact with fluid mud

Ivan Shevchuk

GOFUN, 24th March 2021

Fluiddynamik
und
Schiffstheorie

TUHH

Motivation

- In some areas of the port of Hamburg considerable amounts of fluid mud accumulate which restricts the effective fairway

- Fluid mud increases the ship resistance and affects its manoeuvrability, ship becomes sluggish

Aspect 1: Predict the influence of a particular fluid mud sample on the manoeuvrability

Aspect 2: Develop the recommendations regarding the contact with fluid mud
What is the effective nautical depth?

Aspect 3: Compute the manoeuvring coefficients for the use in the ship motion simulator

HPA
Hamburg Port Authority

Fluid-mud properties

- Density differs among the layers
- Non-Newtonian, rheological parameters differ among the layers
- Realistic model of a fluid mud stress-strain curve (Shakeel & Chassagne)

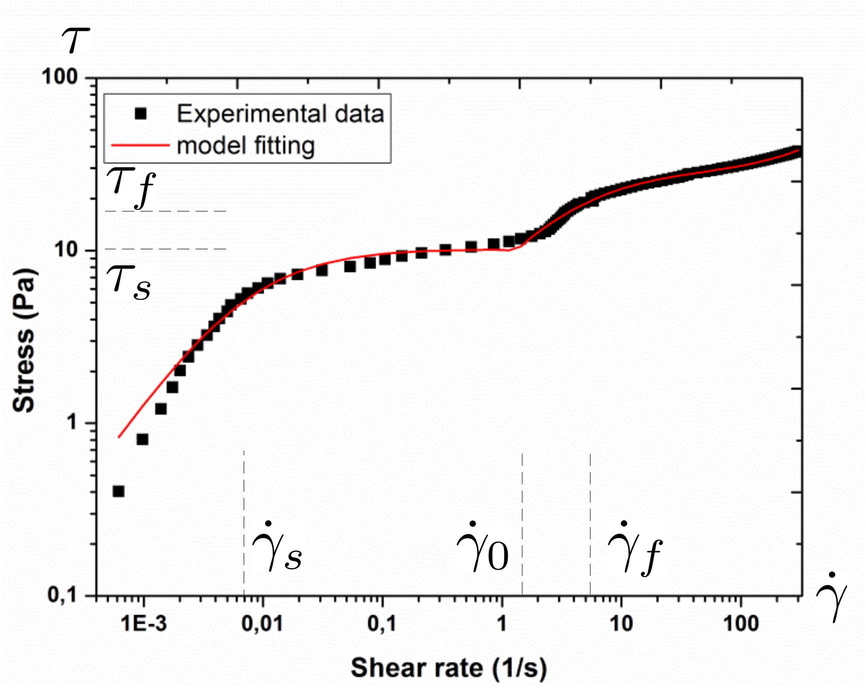
$$\tau = \lambda \tau_{stat} + (1-\lambda)\tau_{fluid}$$

$$\lambda = 1 - \frac{1}{1+e^{-10(\dot{\gamma}-\dot{\gamma}_0)}}$$

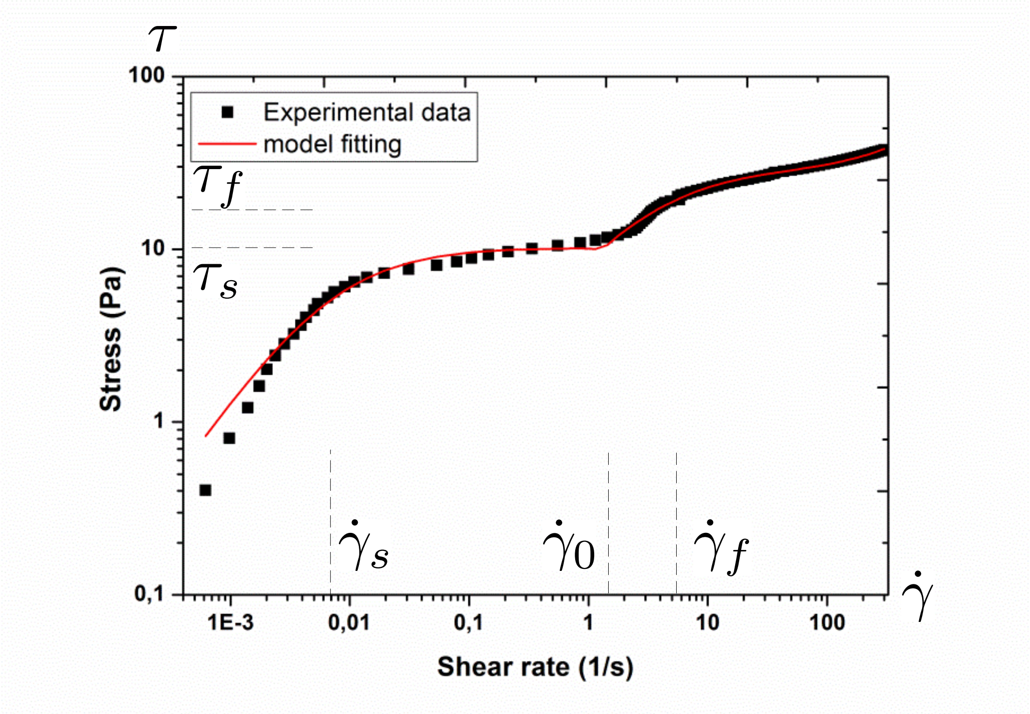
$$\tau_{stat} = \frac{\tau_s}{1+\frac{\dot{\gamma}_s}{\dot{\gamma}}}$$

$$\tau_{fluid} = \tau_s + \frac{\tau_f}{1+\frac{\dot{\gamma}_f-\dot{\gamma}_0}{\dot{\gamma}-\dot{\gamma}_0}} + \mu_\infty(\dot{\gamma}-\dot{\gamma}_0)$$

$$\tau_s, \tau_f, \dot{\gamma}_s, \dot{\gamma}_f, \dot{\gamma}_0, \mu_\infty$$



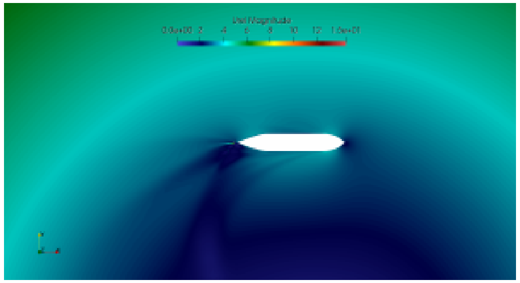
Parameters of the rheological model

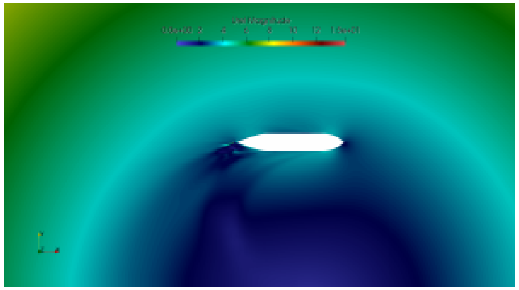


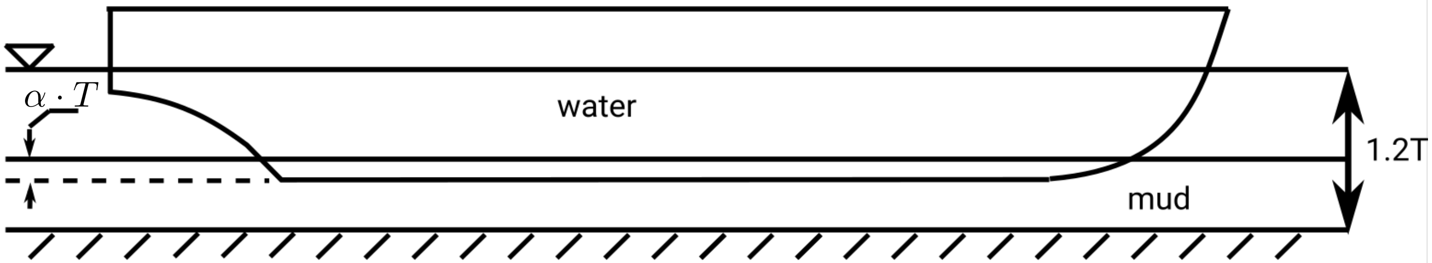
	$\dot{\gamma}_0$	τ_s	$\dot{\gamma}_s$	τ_f	$\dot{\gamma}_f$	μ_∞
Sample ID	(1/s)	(Pa)	(1/s)	(Pa)	(1/s)	(Pa.s)
KB2-8014	1.32	10.23	0.007	18.32	5.61	0.033

Conditions

- Ship speed: 6 kn (~3m/s)
- Fn: 0.057, symmetry condition at the free surface
- No squat effect
- Steady turning circle at $\delta_R = 5, 15, 25, 35^\circ$
- Submersion in mud ($\alpha \cdot T$): 5, 8, 11, 15%
- Fluid mud sample: DII0003, density 1090 kg/m^3
- Roughness: 0.01mm







Solver

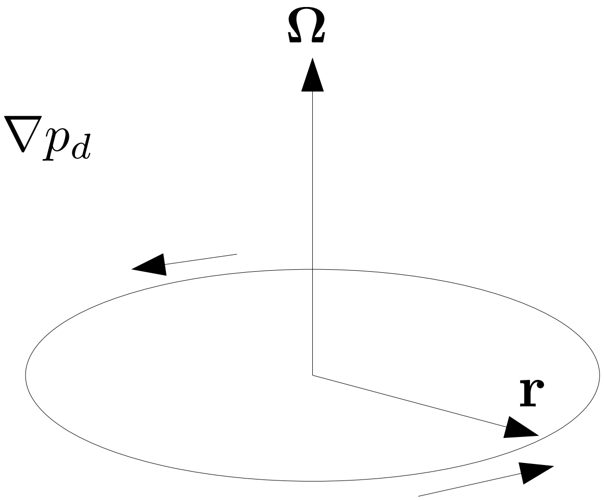
- Computations were conducted using Single Rotating Reference Frame method in a ship-fixed coordinate system
- A solver analogous to SRFPimpleFoam was developed for a two-phase formulation
- Complete system of equations (VOF + SRF)

$$\mathbf{u}_A = \mathbf{u}_R + \boldsymbol{\Omega} \times \mathbf{r}$$

$$\frac{\partial \rho \mathbf{u}_R}{\partial t} + \nabla \cdot (\rho \mathbf{u}_R \mathbf{u}_R) + \underline{2\boldsymbol{\Omega} \times \mathbf{u}_R} + \underline{\boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times \mathbf{r})} = -\nabla p_d - \nabla \rho \cdot \mathbf{g}h + \nabla \cdot (\rho \nu_{eff} (\nabla \mathbf{u}_R + (\nabla \mathbf{u}_R)^T))$$

$$\nabla \cdot \mathbf{u_R} = 0$$

$$\frac{\partial \alpha}{\partial t} + \nabla \cdot (\alpha \mathbf{u}_R) + \nabla \cdot (\alpha \mathbf{u}_c) = 0$$



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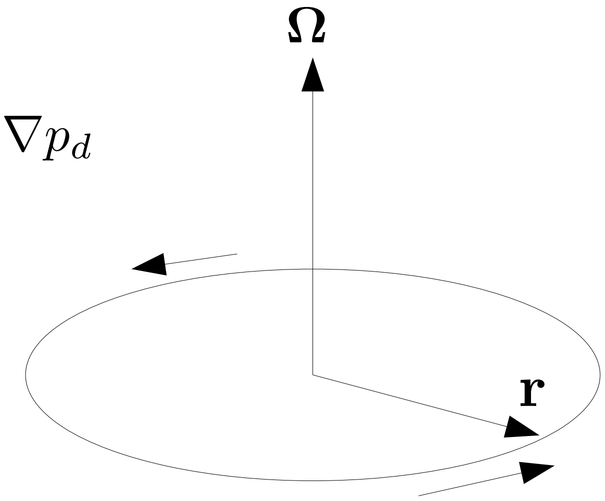
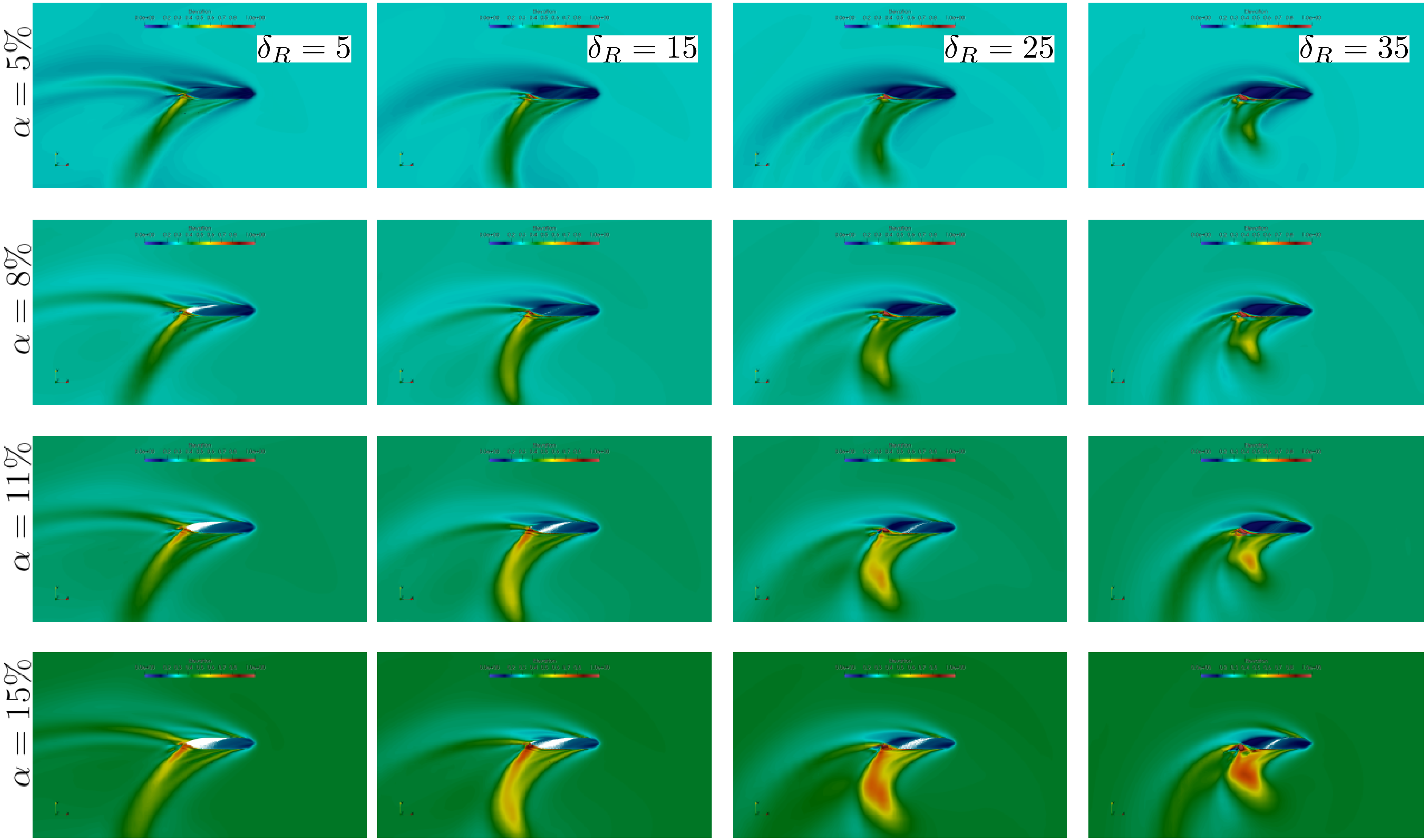
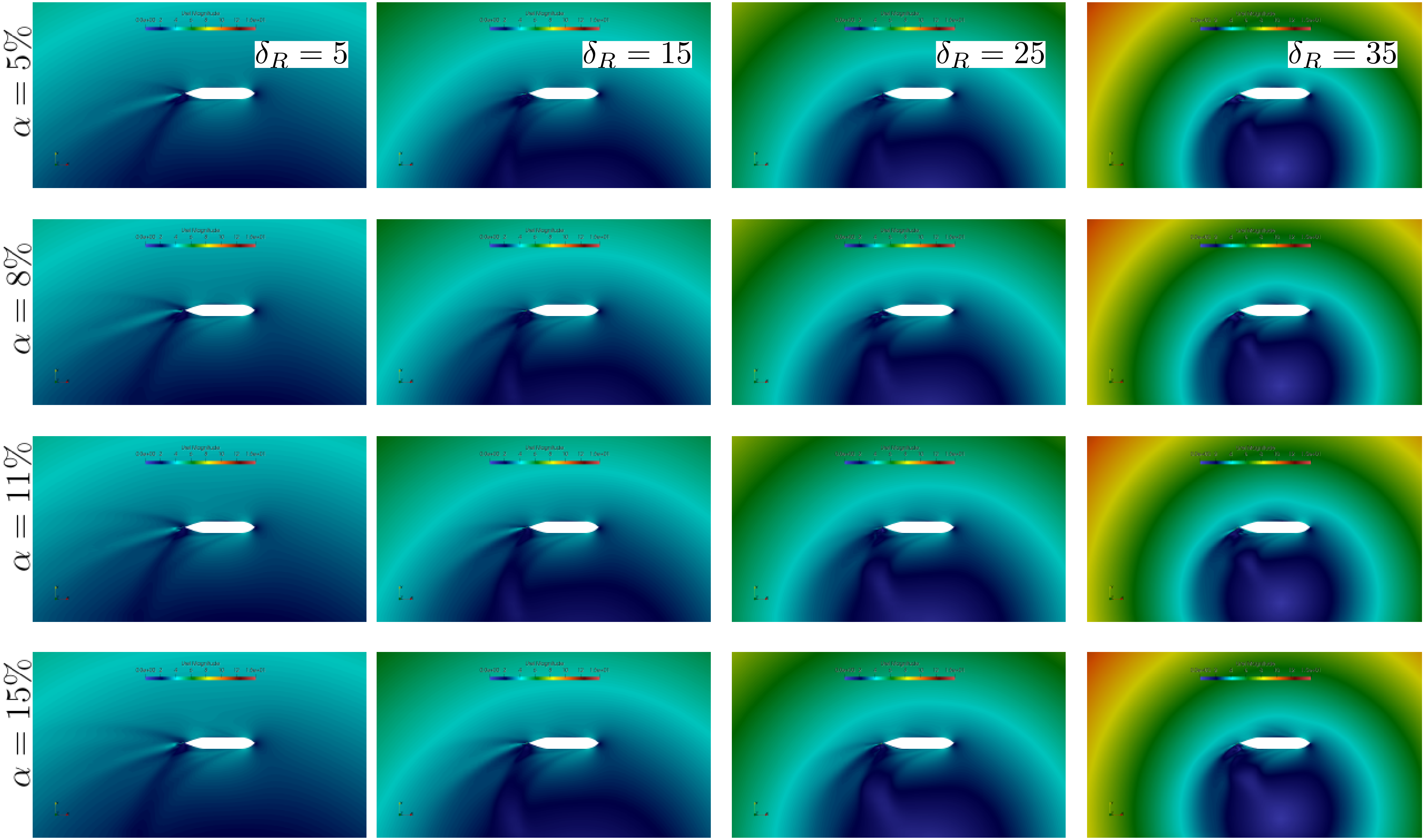


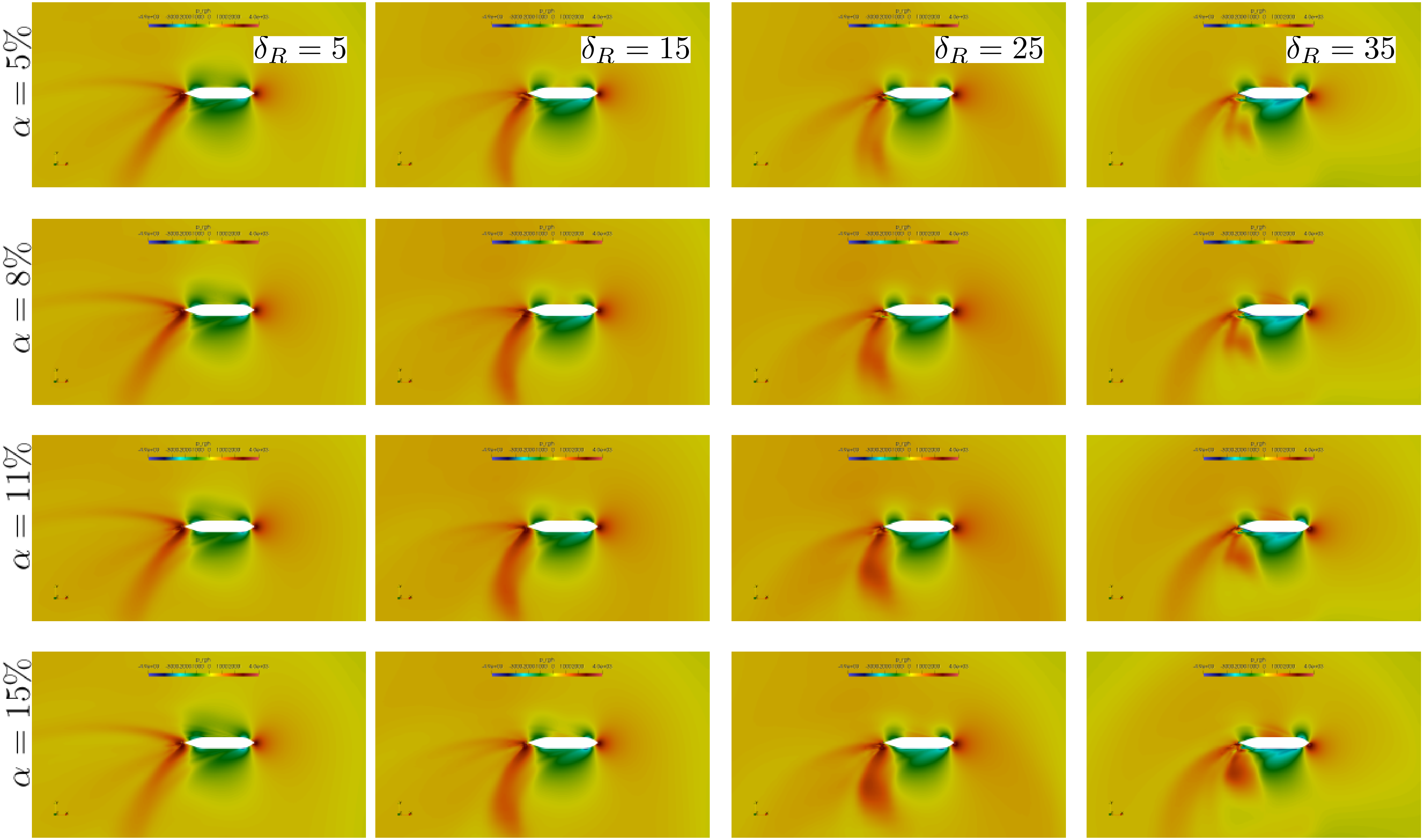
Interface elevation



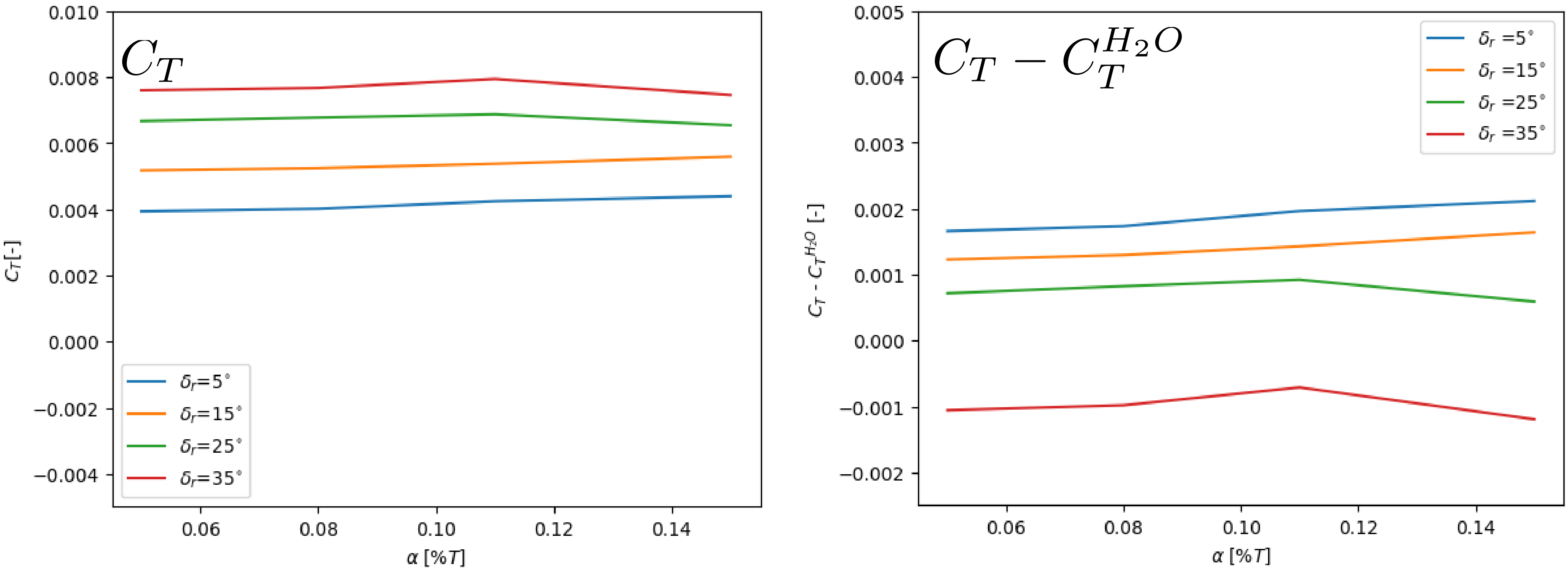
Relative velocity fields



Dynamic pressure field

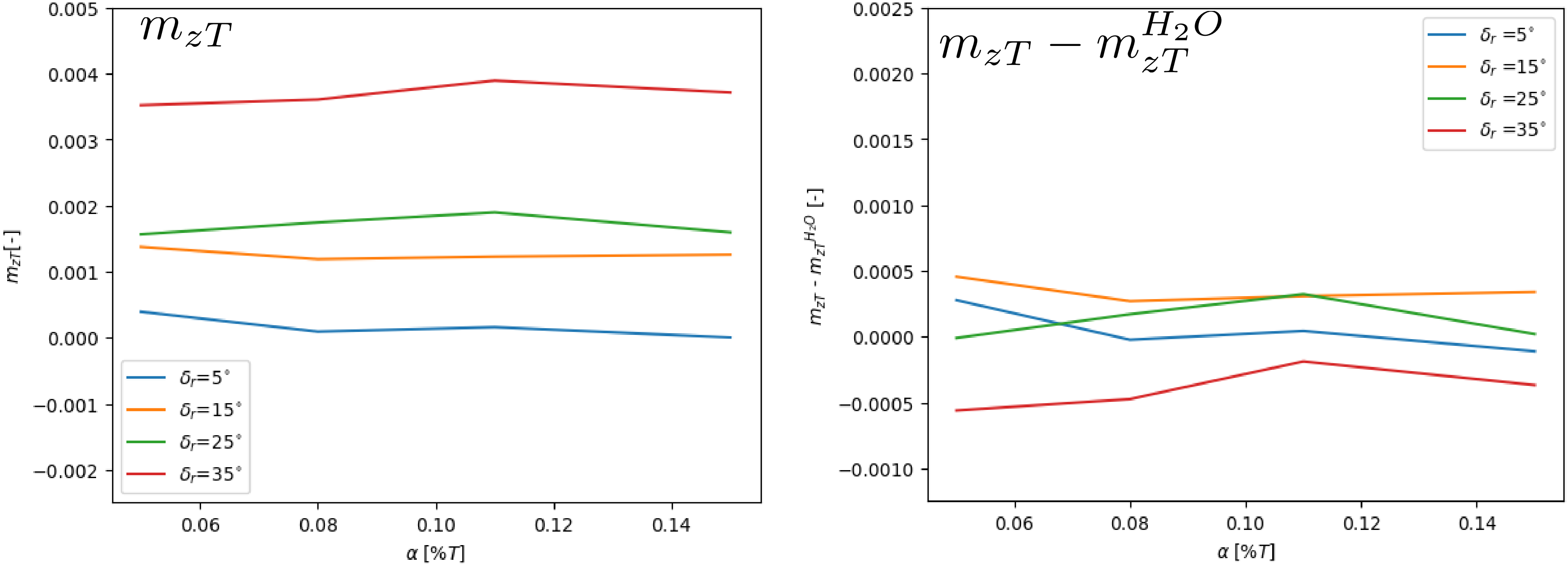


Results / Drag coefficient



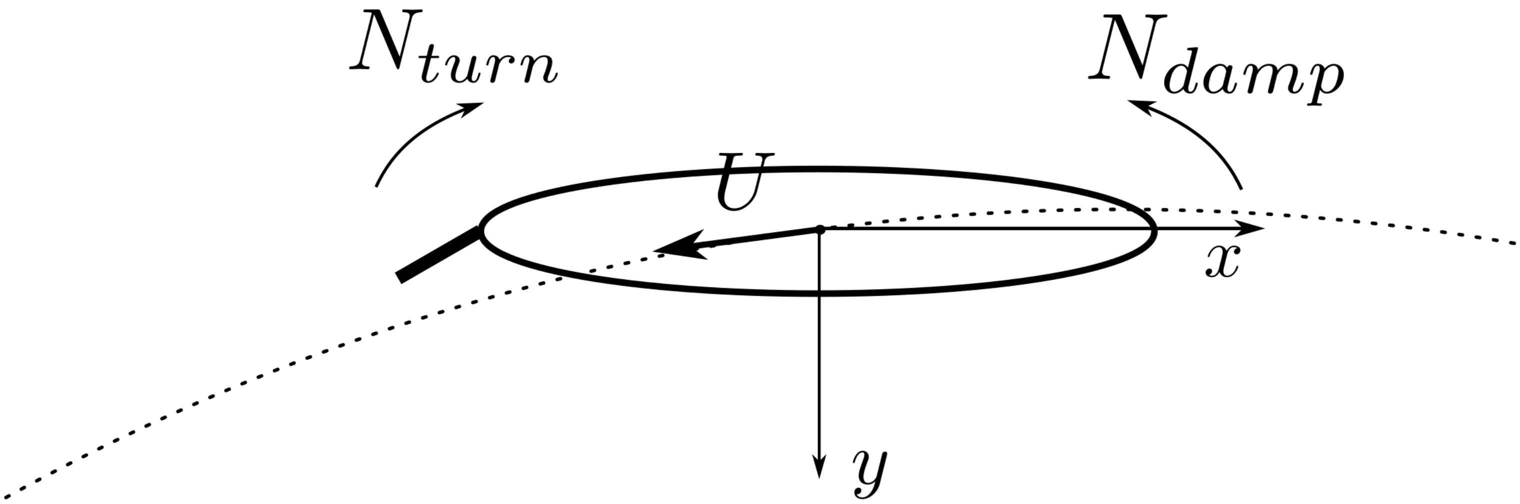
- The influence of the submersion depth is moderate, almost linear (max. 10% increase)
- At small rudder deflection angles (>15 deg) - monotonic increase of drag
- At higher rudder deflection angles – first increases and then drops (separations?)

Results / Yaw moment coefficient



- At a first glance – no sensitivity to the submersion depth
- No clear trend / depends on the rudder deflection
- Additional analysis is required to get an insight into rudder efficiency

Yaw moments in a turning circle



- Relative action of these two moments determines the ship's turning ability

Linear stability analysis (Nomoto)

- Simulation of the straight ahead motion with deflected rudder $\delta_R = 15^\circ$ and submersion depths 5% und 15% + in water → derivative $N_\delta = \dfrac{\partial N}{\partial \delta_R}$

$$N_\delta \approx N/\delta_R$$

- Simulation of the turning circle manoeuvre under the same conditions:

$$N_r = \frac{\partial N}{\partial r}$$

$$N_r \approx N/r$$

- The ratio N_δ/N_r quantifies the rudder effectiveness

$$(N_\delta/N_r)^{H_2O} = -0.215$$

$$(N_\delta/N_r)^{5\%} = -0.168$$ (+19%)

$$(N_\delta/N_r)^{15\%} = -0.137$$ (+33%)

Rudder efficiency diminishes!

Conclusions

- The new solver and the improved boundary conditions were developed for simulating the steady turning-circle manoeuvre in contact with fluid mud
- The set of BC used allows for SRF computations in a rectangular domain with minimal disturbance at truncation boundaries
- The ship drag coefficient increases almost linearly with the submersion depth. In most cases the resistance in mud is higher than that in water
- At the largest rudder deflection angle resistance in water is lower (?) Stronger separations - large modelling error is expected

Conclusions

- The yaw moment does not show clear dependency on the submersion depth
- **But** the rudder efficiency is clearly reduced with increasing submersion depth (faster than linear)

  - at 5% submersion – 19% depletion of rudder efficiency (as compared to water)

  - at 15% submersion – 33% depletion of rudder efficiency
- The effect of FM can be expected even if the ship is moving fully above it

Future work

- Full **PMM** procedure for a range of fluid mud samples for an exhaustive description of FM influence on the ship manoeuvrability

- **Challenges:**

  1. Applicability of RANS (and even LES) closures in non-Newtonian fluids. Ways of improvement?
  2. Multi-layer simulations
  3. Mixing of different layers with each other and its interaction with turbulence at the ship (Schmidt numbers?)
  4. Grid convergence study / uncertainty estimation

Thanks for
your attention!