STAR European Conference 2010

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STAR-CCM+ V5

Advances in Simulation for Marine And Offshore Applications

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Introduction

- Extensions and enhancements in STAR-CCM+ for marine and offshore applications:
    - Creation of irregular long-crested and short-crested waves;
    - Wave damping near boundaries;
    - Improvement of robustness of 2nd-order time discretization for free-surface flows;
    - The possibility to combine region-wise rigid-body motion and morphing in moving-grid applications;
    - Extensions to modelling of external forces acting on floating bodies.
    - Overlapping grids, fluid-structure interaction etc...

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State-of-the-Art

- Automatic meshing for complex geometries;
- High-resolution interface-capturing for free-surface flows;
- Coupled simulation of flow and flow-induced motion of floating or flying bodies;
- Fifth-order Stokes waves;
- Coupled simulation of flow and conjugate heat transfer;
- Heat conduction and convection in porous media (anisotropic);
- Lagrangian and Eulerian analysis of multi-phase flows;
- Sophisticated turbulence models;
- Phase change (cavitation, solidification, melting, boiling...)...

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Long-Crested Irregular Waves, I

- The basis for the definition of long-crested irregular waves as inlet boundary condition in STAR-CCM+ is the document by DNV entitled "*Recommended Practice DNV-RP-C205*", as amended in April 2008, pages 24 – 34.
- Two kinds of irregular waves can be set up (currently using user-coding facility; in Version 5.06 this will be a standard code feature):
  - Waves based on Pierson-Moskowitz spectrum;
  - Waves based on JONSWAP spectrum.
- Current user coding is in FORTRAN95 (available on request).
- At inlet boundary, water level and velocities are computed from wave theory.

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Long-Crested Irregular Waves, II

- Pierson-Moskowitz Spectrum:

$$S_{\mathrm{PM}} = \frac{5}{16} H_{\mathrm{s}}^2 \omega_{\mathrm{p}}^4 \omega^{-5} \exp\left[-\frac{5}{4}\left(\frac{\omega}{\omega_{\mathrm{p}}}\right)^{-4}\right]$$

where:

H_s – Significant wave height

$\omega_p = 2\pi/T_p$ – the angular spectral peak frequency

T_p – Peak period (inverse of the frequency at which the wave energy spectrum has its maximum)

ω – angular spectral frequency

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Long-Crested Irregular Waves, III

- JONSWAP Spectrum:

$$S_{\mathrm{JS}} = S_{\mathrm{PM}} A_\gamma \, \gamma^{\exp\left[-0.5\left(\frac{\omega-\omega_{\mathrm{p}}}{\sigma\omega_{\mathrm{p}}}\right)^2\right]}$$

where:

S_{PM} – Pierson-Moskowitz spectrum

γ – Dimensionless peak shape parameter

$A_\gamma = 1 - 0.287\ \ln(\gamma)$ – Normalizing factor

σ – Spectral width parameter (one value used for frequencies below peak, and one above it)

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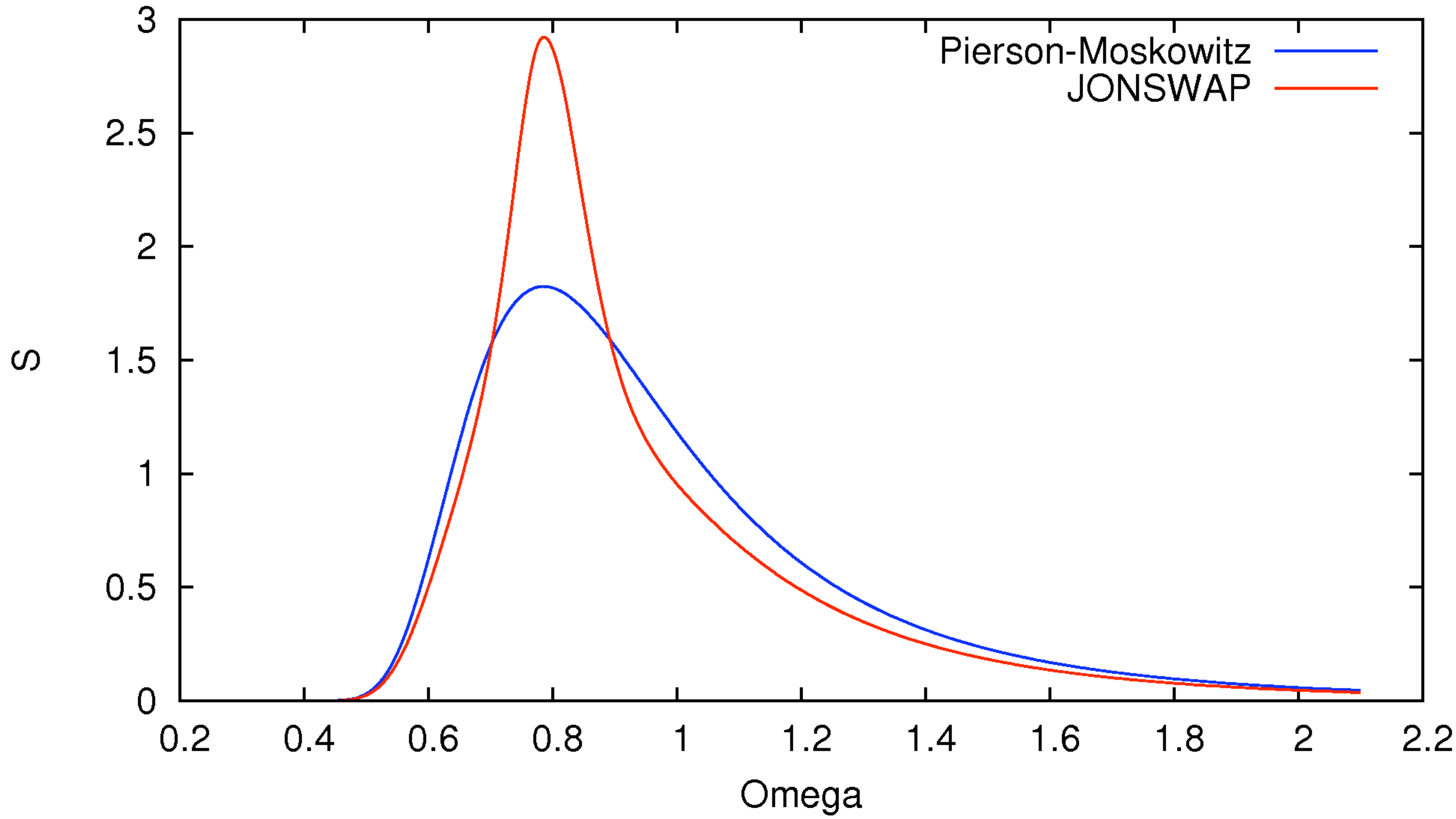
Long-Crested Irregular Waves, IV

- Wave spectra for one set of parameters (H_s = 4 m, T_p = 8 s, γ = 2, σ = 0.07/0.09):



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Long-Crested Irregular Waves, V

- Water elevation and velocities at inlet (using linear wave theory for wave components; here flow in x-direction):

$$\eta = \sum_{i=1}^{N} A_i \cos\theta_i$$

$$u = \sum_{i=1}^{N} A_i \omega_i \mathrm{e}^{k_i (z - z_{\mathrm{fs}})} \cos\theta_i$$

$$w = \sum_{i=1}^{N} A_i \omega_i \mathrm{e}^{k_i (z - z_{\mathrm{fs}})} \sin\theta_i$$

$$A_i = \sqrt{2 S_i \Delta\omega_i}$$

$$\theta_i = \omega_i t + \varepsilon_i - k_i U t$$

$$\lambda_i = \frac{2 g \pi}{\omega_i^2}$$

$$k_i = \frac{2\pi}{\lambda_i}$$

where A_i are the amplitudes, θ_i are the phase angles, ε_i are the random phases uniformly distributed between 0 and 2π, U is the current speed, t is time, λ is wave length and k is the wave number.

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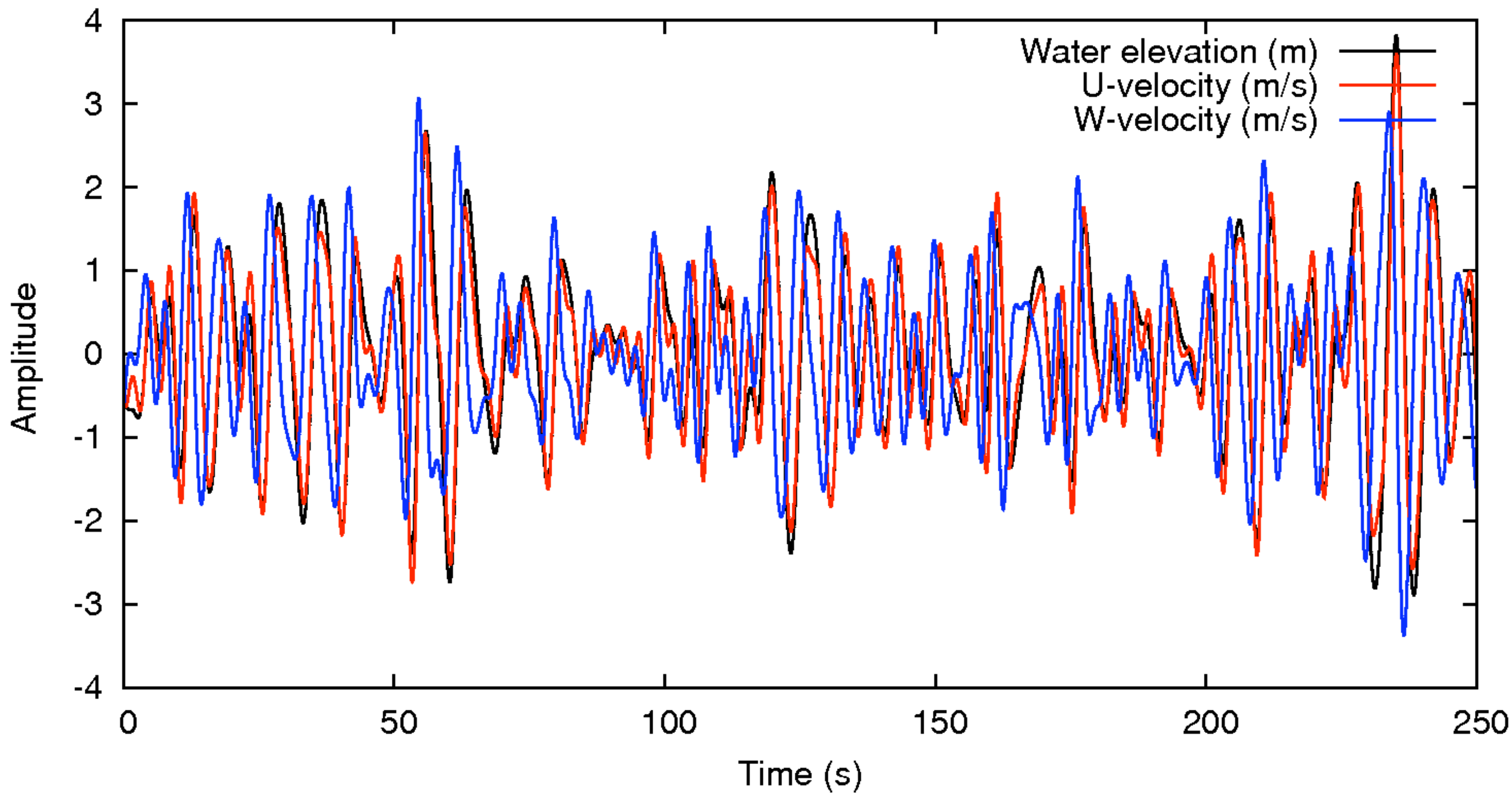
Long-Crested Irregular Waves, VI

- Water elevation and velocities at inlet (using linear wave theory for wave components, 450 samples from spectrum between ω = 0.3 and ω = 2.1 with step 0.004):



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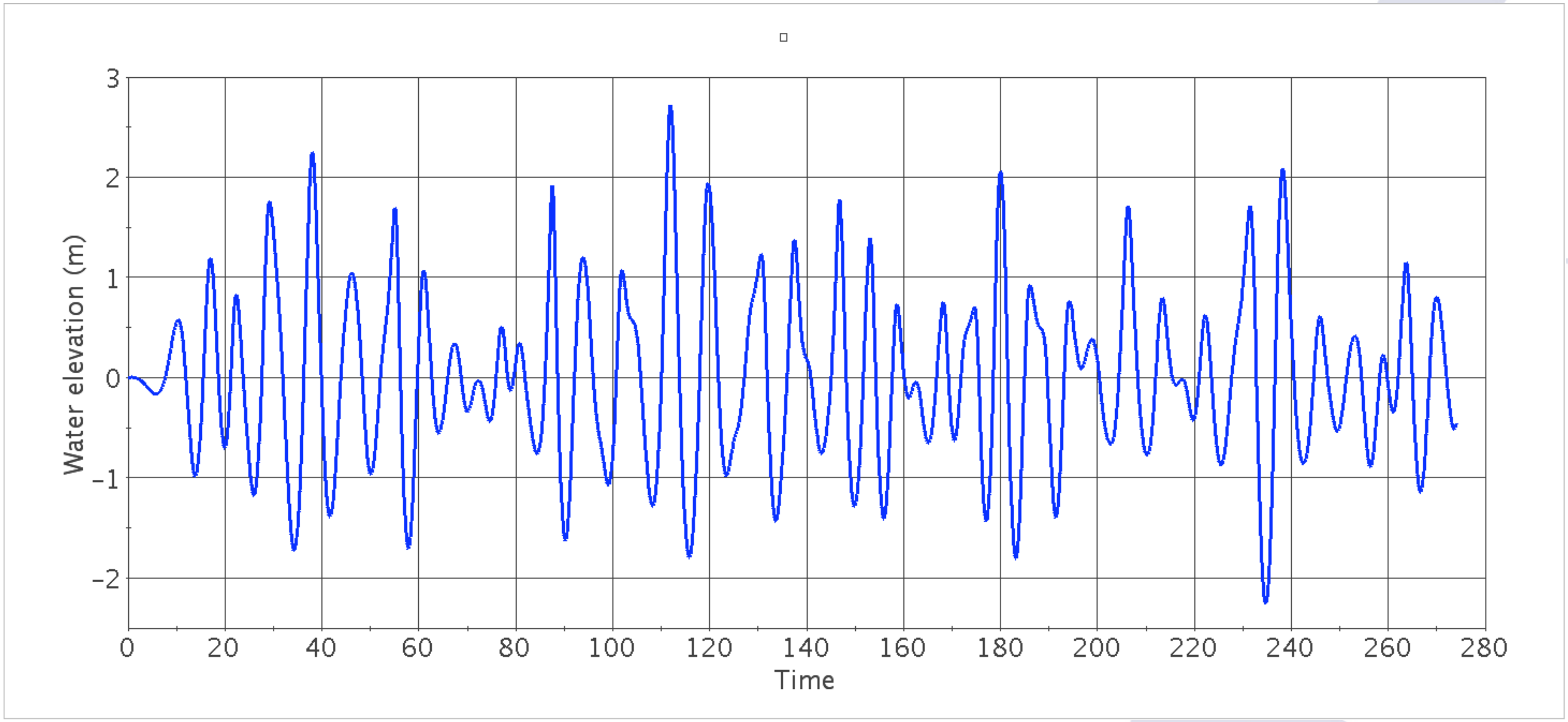
Long-Crested Irregular Waves, VII

- Water elevation 50 m downstream from inlet, computed by STAR-CCM+ (H_s = 4 m, T_p = 8 s, γ = 2, σ = 0.07/0.09):



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Short-Crested Irregular Waves, I

- Short-crested waves can be created by a superposition of regular waves with different amplitudes and periods.
- This feature has just been implemented in STAR-CCM+ using linear waves as the basis...
- The user can define any number of waves with varying direction of propagation, amplitude and wavelength.
- This can be used both for the initialization of solution in the whole domain and for the definition of boundary conditions at later times.
- A spectrum for short-crested waves will also be implemented (similar to long-crested version, with additional variation of propagation direction)...

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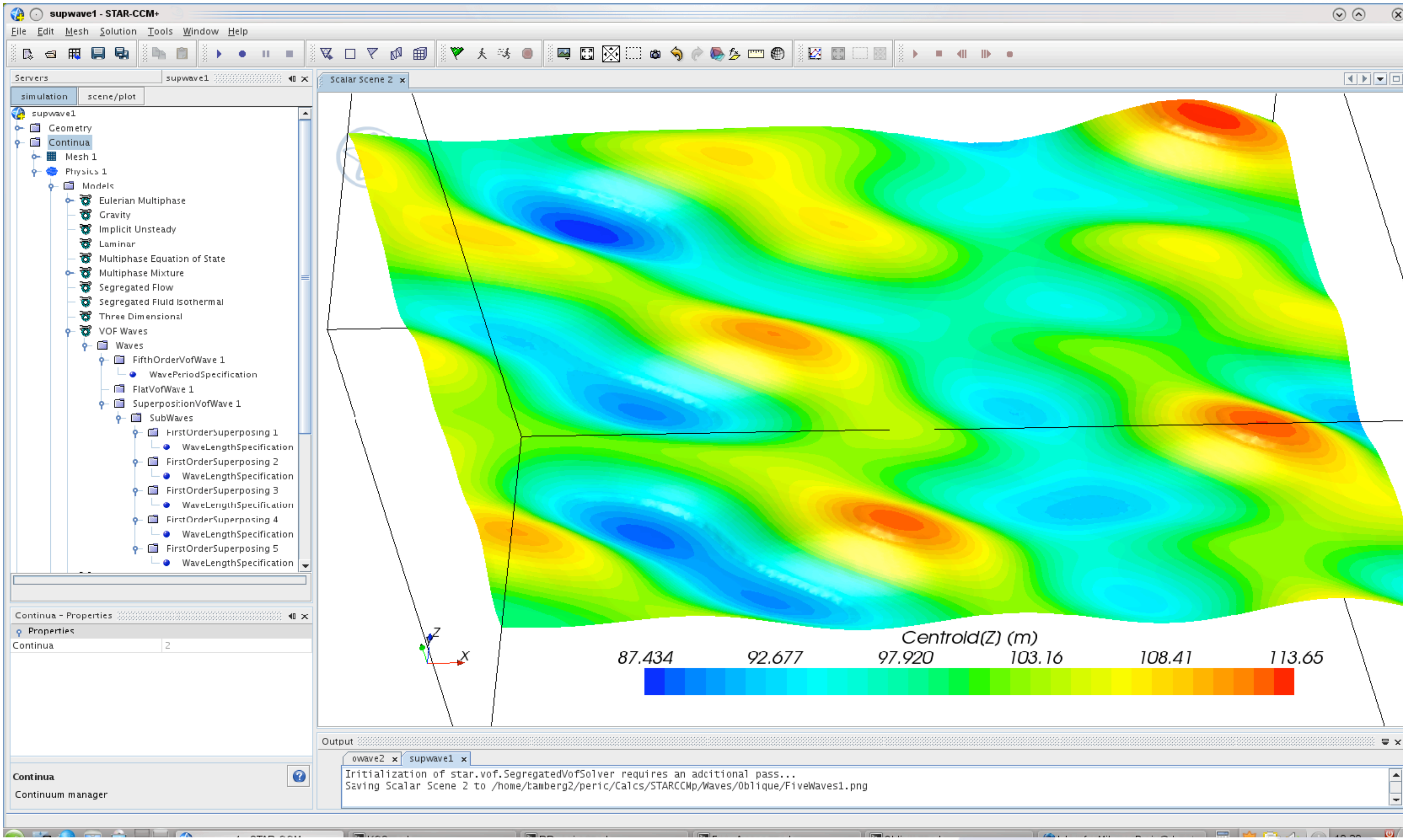
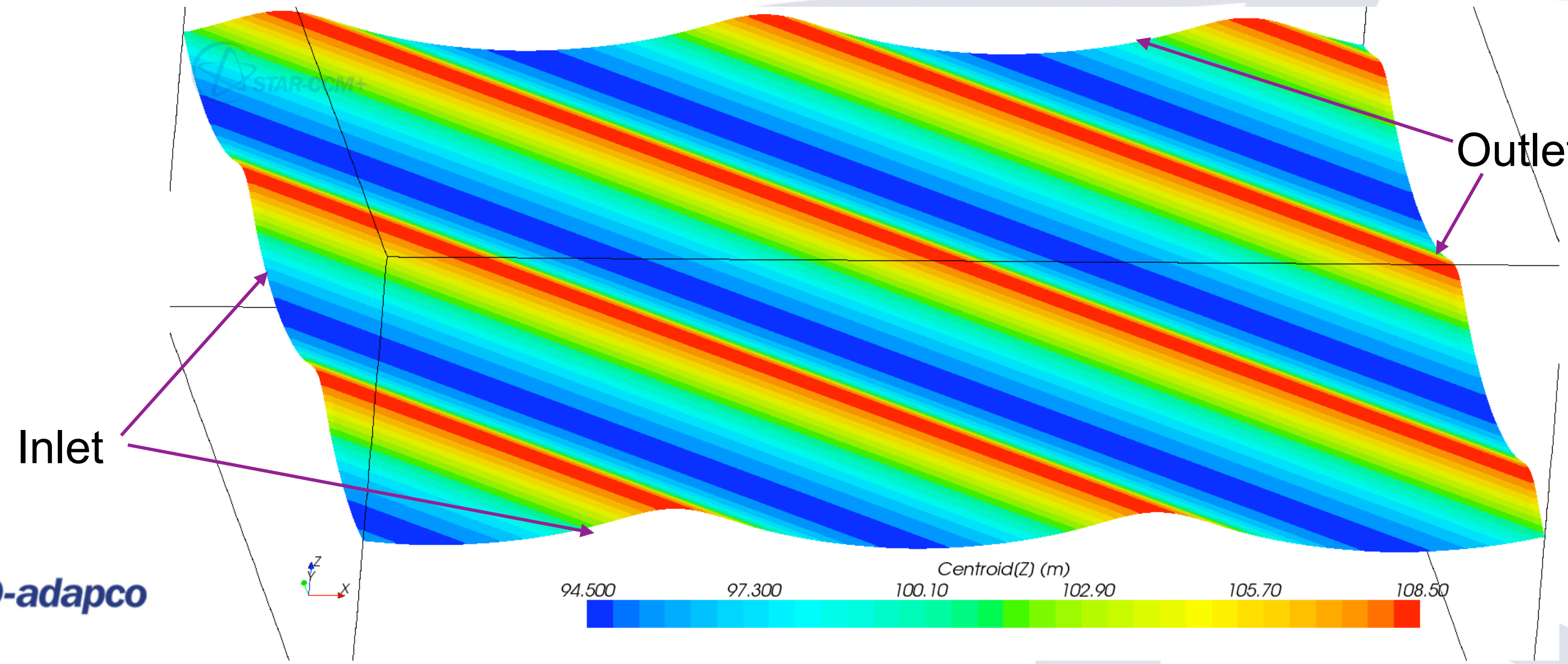
Short-Crested Irregular Waves, II



Oblique Waves

- Both short-crested irregular and oblique long-crested waves require inlet from two sides...
- In order to avoid reflection from other boundaries, damping has to be applied (akin to “beaches” in wave tanks)...
- Inlet waves also need to be damped where inlet meets outlet...



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Wave Damping, I

- Wave damping is needed to ensure that no unwanted reflection occurs at boundaries of solution domain.
- An alternative would be boundary conditions which allow waves to exit solution domain without reflection...
- This is difficult to realize when solving Navier-Stokes equations with irregular waves propagating toward boundary...
- Wave damping can be achieved using expanding grid and low-order discretization (numerical diffusion)...
- … which requires special efforts with grid generation, large solution domain, and the possibility to mix higher- and lower-order schemes.

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Wave Damping, II

- Another possibility to damp waves is introduction of resistance to vertical motion (like in porous media).
- Resistance can be implemented in STAR-CCM+ via *"field functions"* facility, e.g. the expressions from Choi & Yoon:

$$S_z^{\mathrm{d}} = \rho(f_1 + f_2|w|)\frac{\mathrm{e}^{\kappa} - 1}{\mathrm{e}^{1} - 1} w \quad \text{with } \kappa = \left(\frac{x - x_{\mathrm{sd}}}{x_{\mathrm{ed}} - x_{\mathrm{sd}}}\right)^{n_{\mathrm{d}}}$$

where:

x_{sd} – Starting point for wave damping (propagation in x-direction)

x_{ed} – End point for wave damping (boundary)

f_1 , f_2 and n_d – Parameters of the damping model

Choi J., Yoon S.B.: Numerical simulations using momentum source wave-maker applied to RANS equation model, J. *Costal Engineering*, Vol. 56, pp. 1043-1060, 2009.

Wave Damping, III

- Wave damping was tested using Stokes wave and a solution domain 4 wave lengths long (wave length 102.7 m, wave height 5.8 m, wave period 8 s)...
- First and second order discretizations in time were tested (2nd-order discretization in space).
- Original 2nd-order scheme (quadratic profile in time, three time levels, fully implicit) was stable in conjunction with HRIC-scheme for volume fraction only when Courant number based on wave-propagation speed was lower than 0.125...
- Enhanced scheme remains stable up to Courant number of 0.5 (wave propagates half a cell per time step)!
- The 1st-order scheme is stable for even higher Courant numbers, but it is highly inaccurate...

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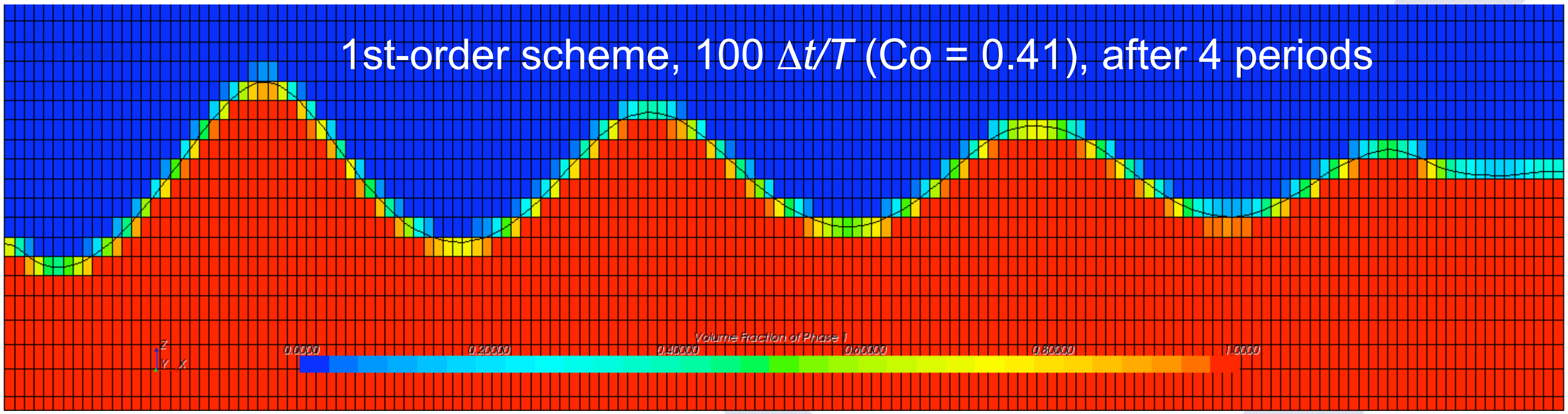
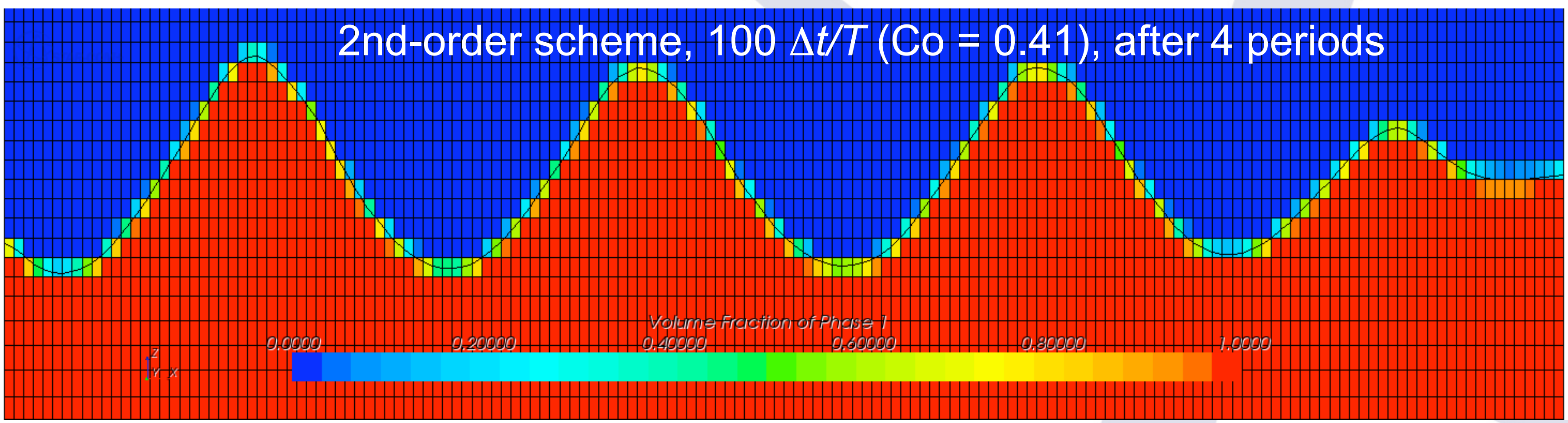
Wave Damping, IV

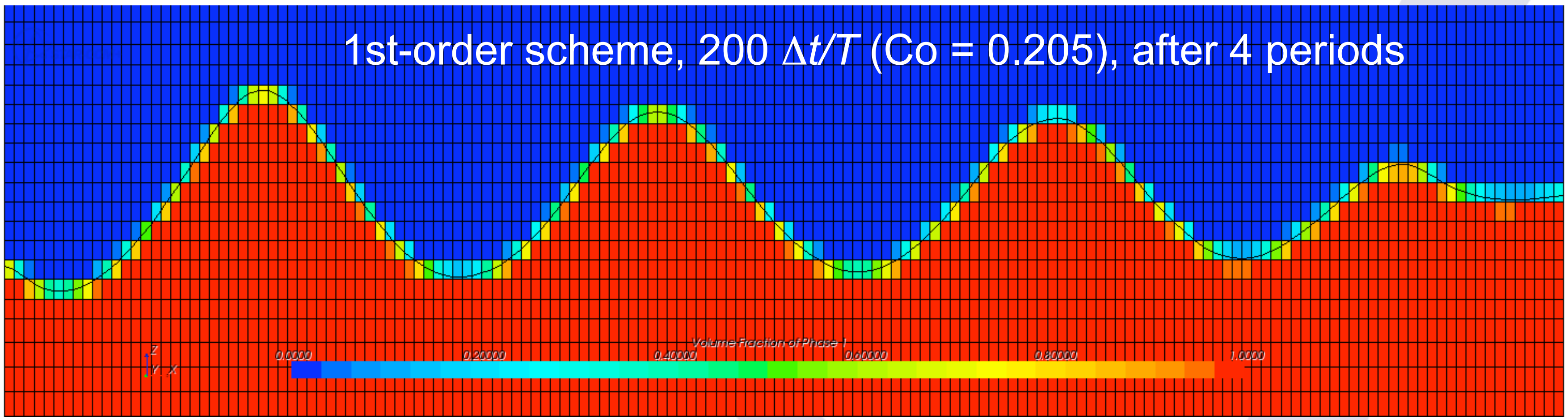
- Wave damping was applied over the last 100 m before outlet... 41 cells per wave length, 11.5 cells per wave height ($\Delta x = 2.5$ m, $\Delta z = 0.5$ m)

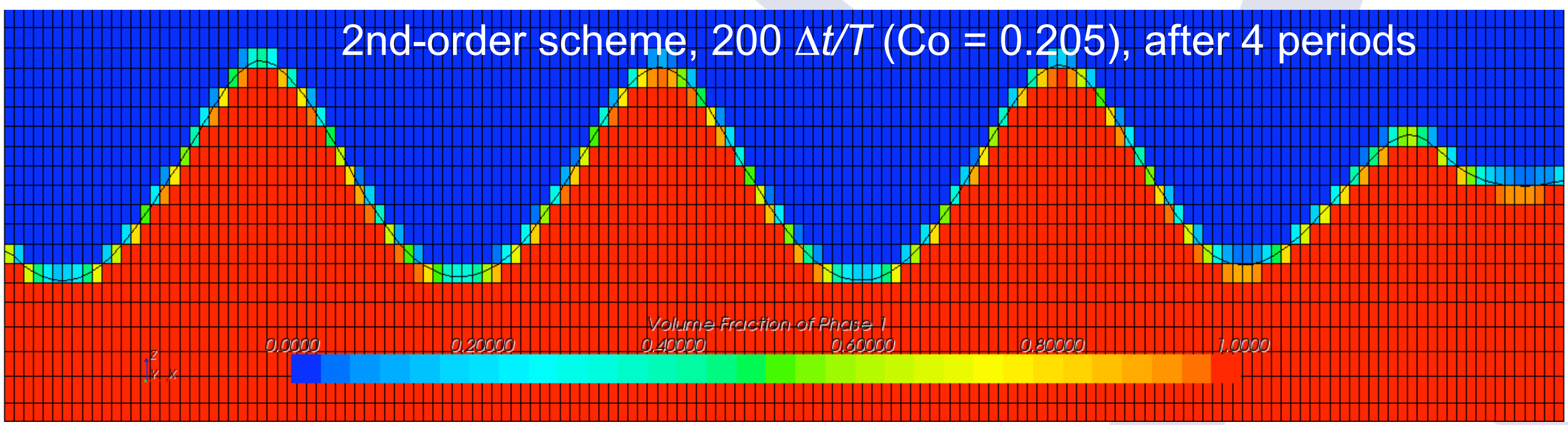




Wave Damping, V

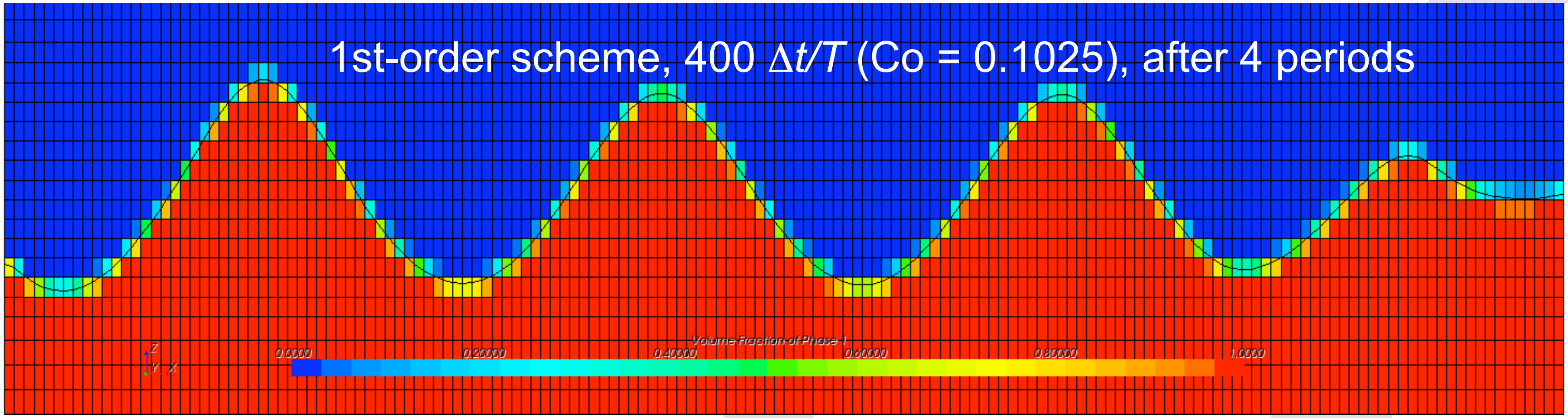
- Wave damping was applied over the last 100 m before outlet... 41 cells per wave length, 11.5 cells per wave height (Δx = 2.5 m, Δz = 0.5 m)

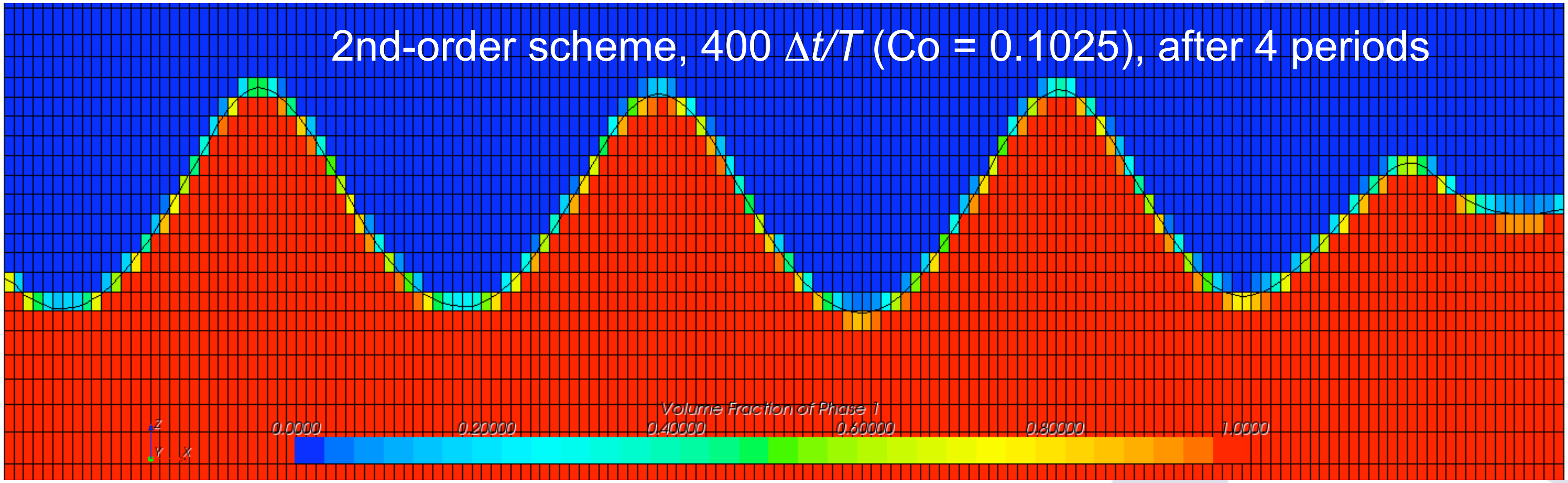




Wave Damping, VI

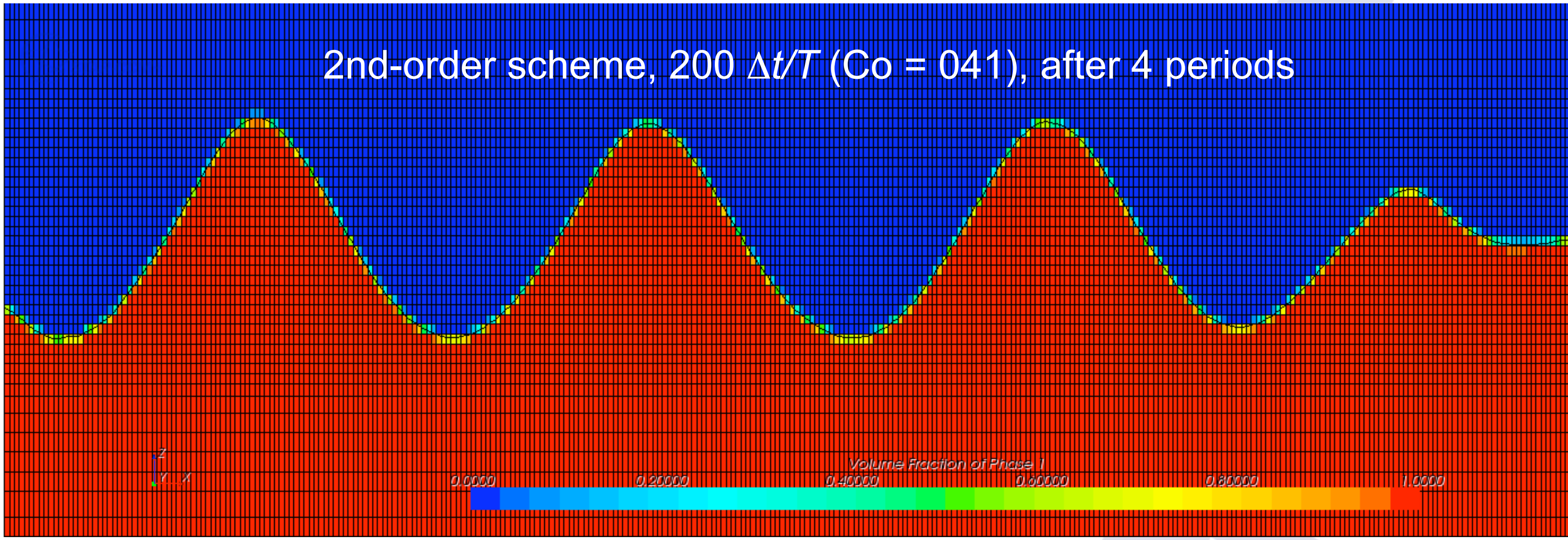
- Wave damping was applied over the last 100 m before outlet... 41 cells per wave length, 11.5 cells per wave height (Δx = 2.5 m, Δz = 0.5 m)



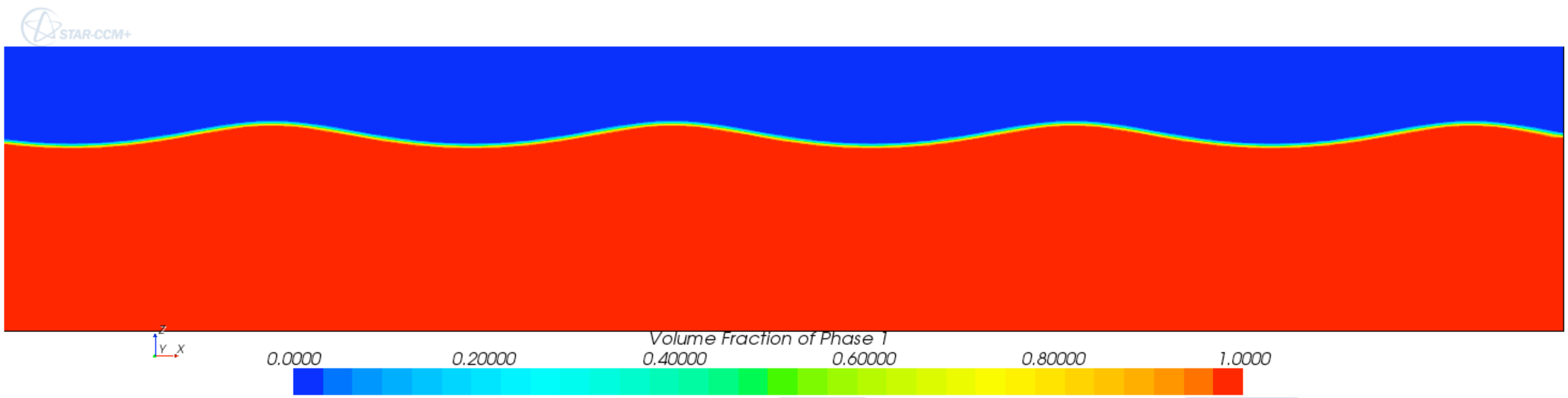


Wave Damping, VII

- Wave damping was applied over the last 100 m before outlet... 82 cells per wave length, 23 cells per wave height (Δx = 1.25 m, Δz = 0.25 m).
- Even at Co = 0.41, the 2nd-order time discretization leads to a very low wave amplitude damping – the wave remains preserved over 3 wave lengths...



Animation, Wave Damping



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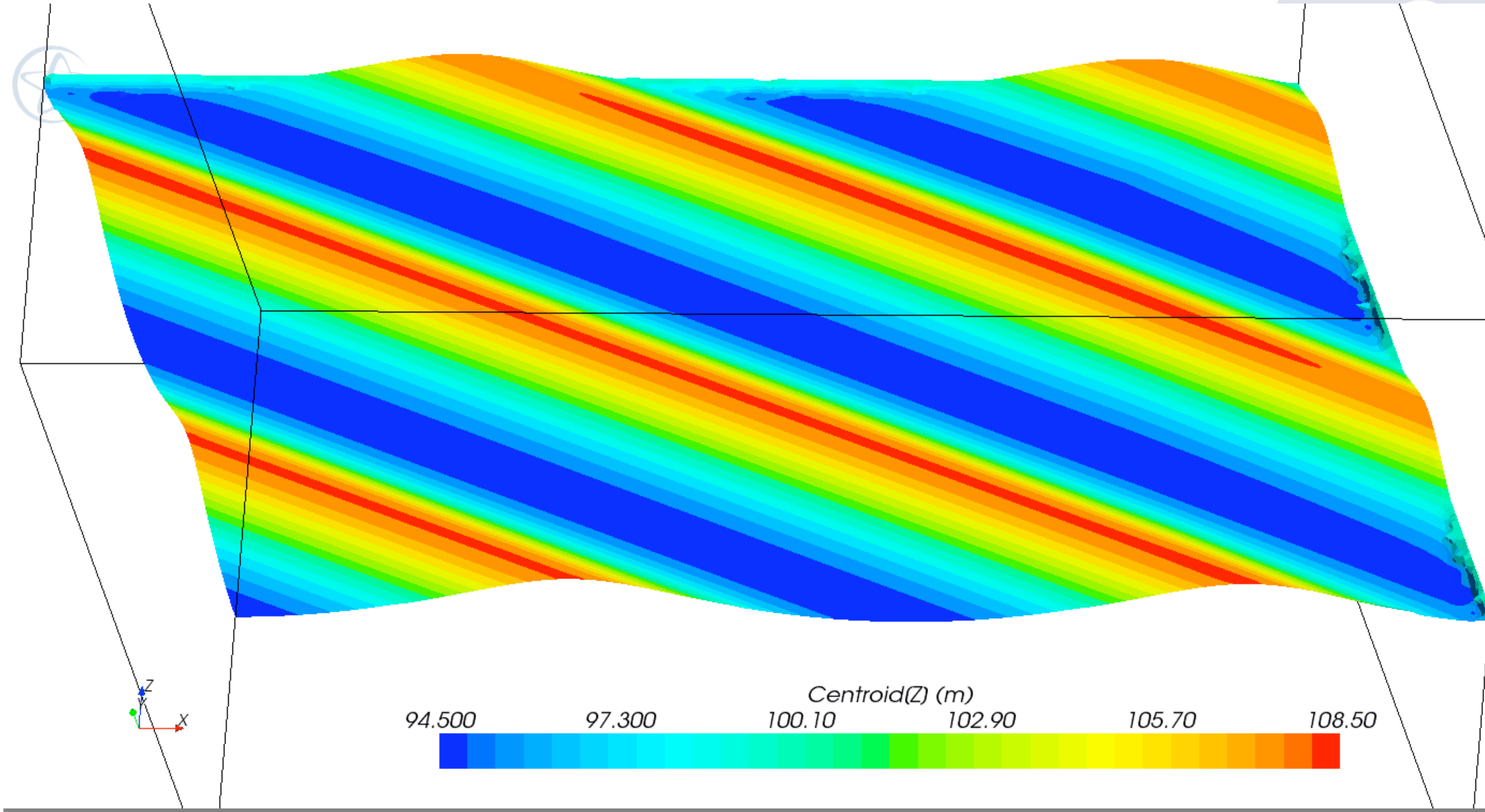
Animation, Oblique Wave Damping

Damping was not applied to any part of inlet boundary, hence reflections...



Further Developments, I

- Moving grids (prescribed or part of DFBI solution):
  - From V 5.04, morphing and rigid-body motion can be combined (region-wise)...
  - For a floating body: region around body can move with it without deformation, while morphing is applied to the surrounding grid.
  - The advantages:
    - The grid near body remains the same, no quality deterioration;
    - Morphing in the distant region requires only few control points, making the morphing process much faster...
  - From V 5.04, morpher will run much faster in parallel (can be activated in V 5.02 using a java-macro).

Further Developments, II

- Hierarchy of coordinates systems:
  - A blade moves relative to propeller;
  - Propeller moves relative to hull;
  - Hull moves relative to sea bed...
- External forces acting on floating bodies:
  - Springs with a variable stiffness:
    - Since V 5.02, there is a report “6-DOF Spring Elongation”...
    - When activated, it registers a field function that can be used in the expression for spring stiffness...
    - Thus, spring stiffness can be a function of its elongation...
  - Catenaries (connected bodies)...

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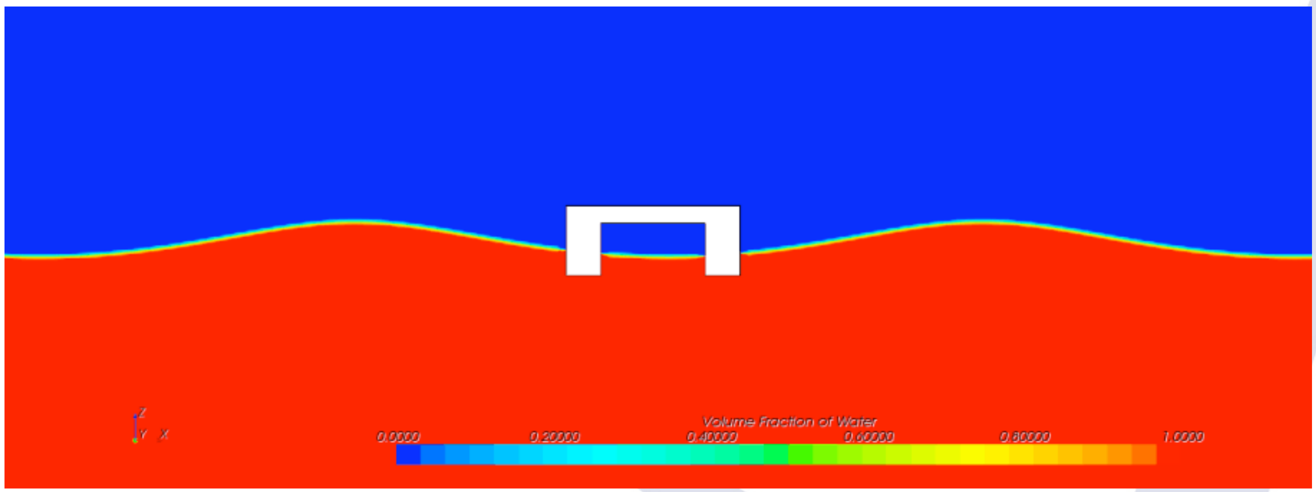
Animation, Floating Platform (Springs)



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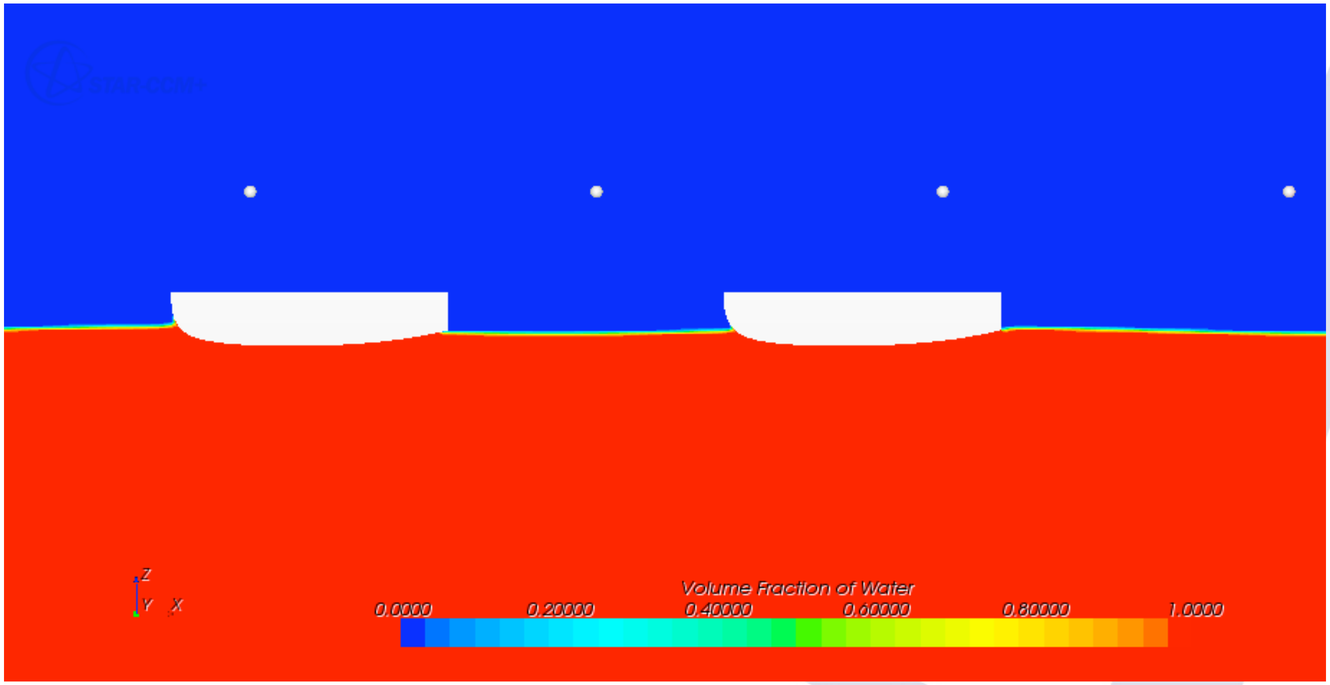
Animation, Ship Towing (Catenary)



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Conclusions, I

- CD-adapco is committed to further develop functionality needed for marine and offshore applications, like
  - Models for propellers (actuator disc);
  - Standard maneouvring tests (zig-zag, circle, PMM-tests etc.);
  - Short-crested wave spectra;
  - Overlapping grids for easier handling of arbitrary motion, etc.
- CD-adapco collaborates with major classification societies (LR, GL, DNV, ABS) and towing tank facilities (Marintek, HSVA) regarding future developments...
- Enhancement requests from users of STAR-CCM+ continually lead to improvements of usability and applicability..

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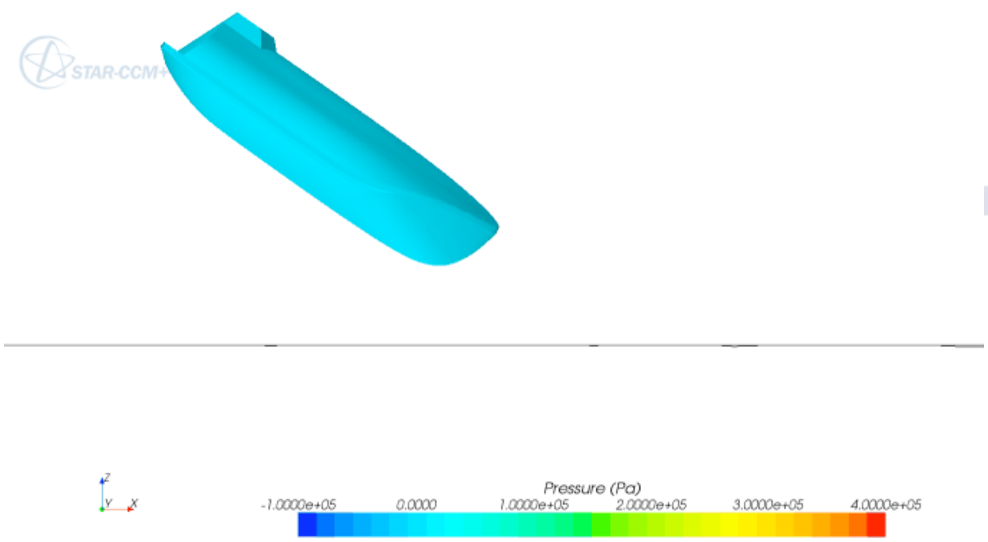
Conclusions, II

- DNV have developed new rules for lifeboats and now accept CFD analysis instead of experimental evidence (after extensive comparisons of CFD and measurements)...



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A Success Story

- VOITH Turbo Schneider Propulsion, Germany, has been using CD-adapco software for the past 10 years...
- The performance of Voith-Schneider Propeller (VSP) has been improved by design changes driven by simulation (15% higher bollard pull)...
- The new Voith Radial Propeller (VRP) has been completely designed and optimized using CFD and optimization software...
- The nes Voith Linear Jet has been optimized for delayed inception of cavitation using CFD...
- The latest success: prediction of performance of VRP and VST under ventilation conditions (later confirmed by experiments)...

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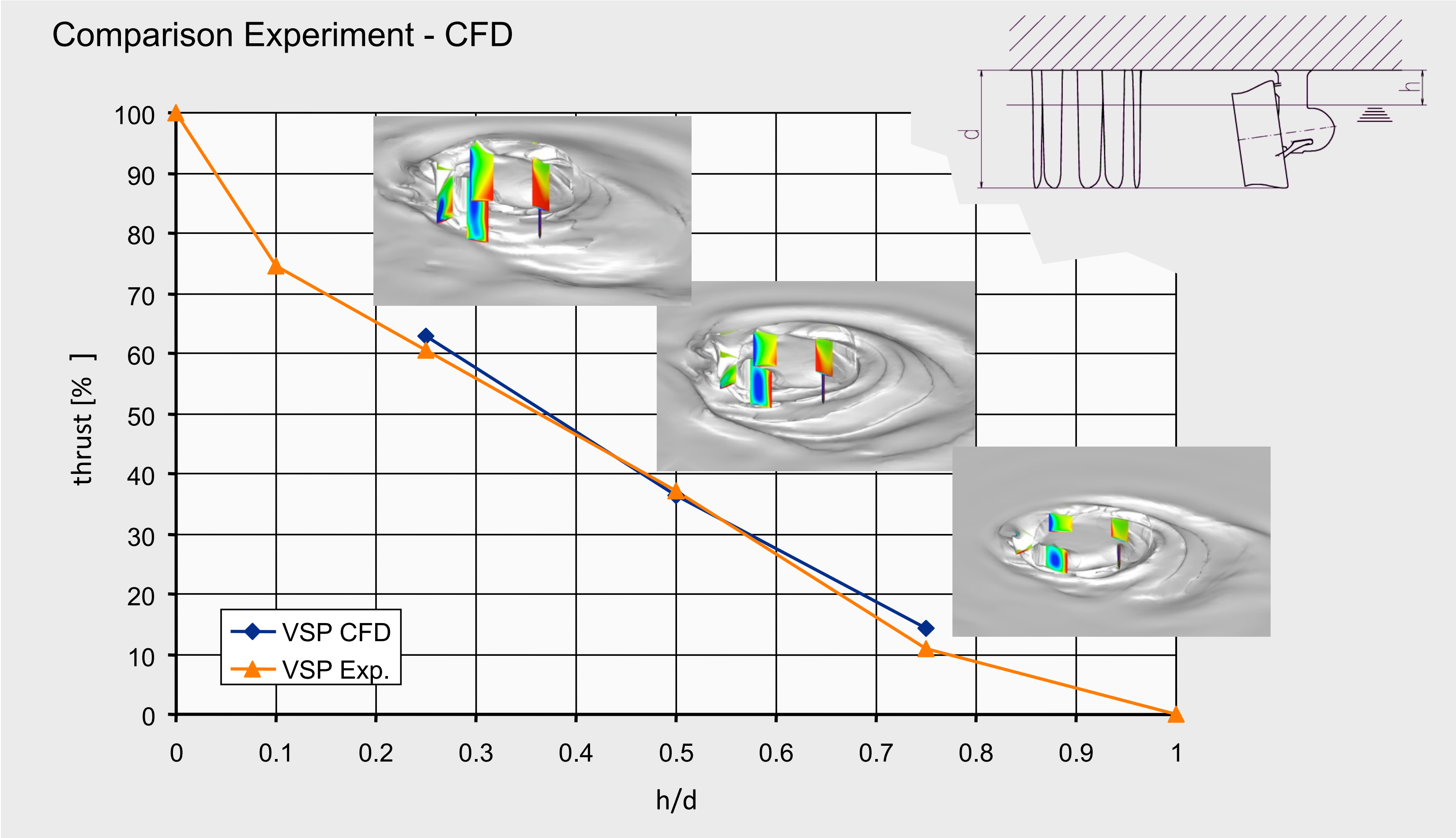
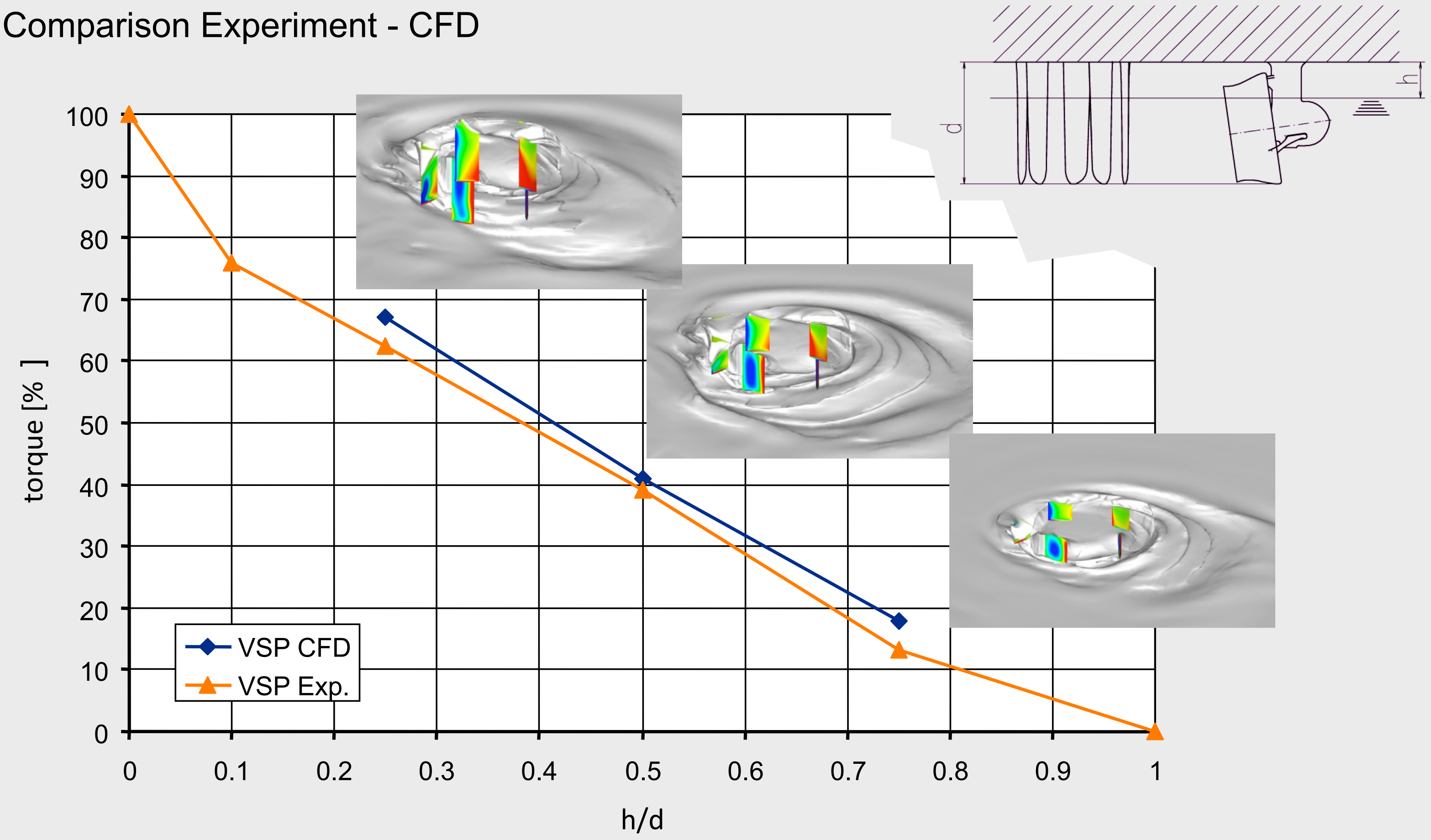
Simulation of Propeller Ventilation, I



Courtesy of Voith Turbo Schneider Propulsion, Heidenheim, Germany

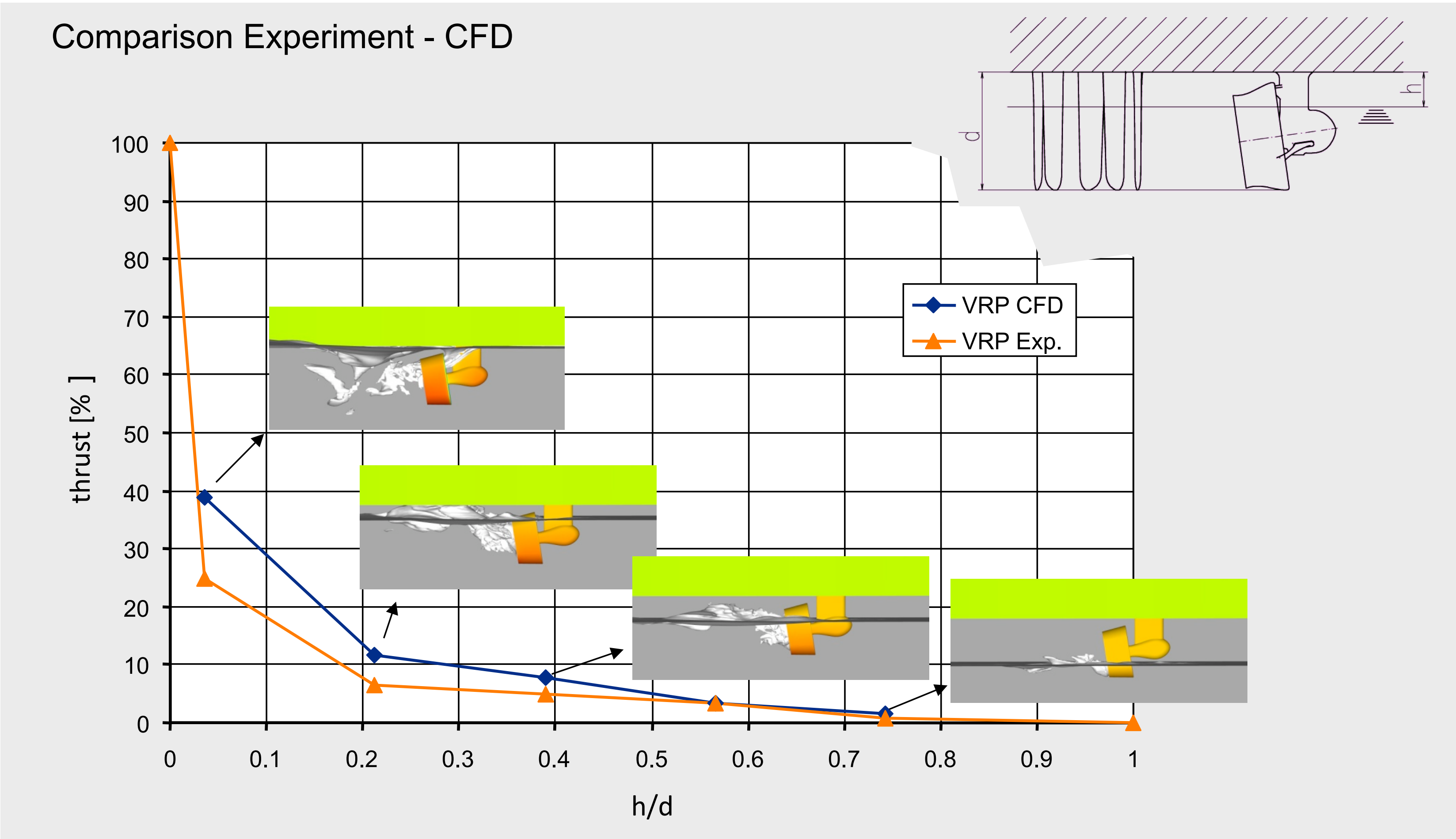
Simulation of Propeller Ventilation, II

Comparison Experiment - CFD



Courtesy of Voith Turbo Schneider Propulsion, Heidenheim, Germany

Simulation of Propeller Ventilation, III



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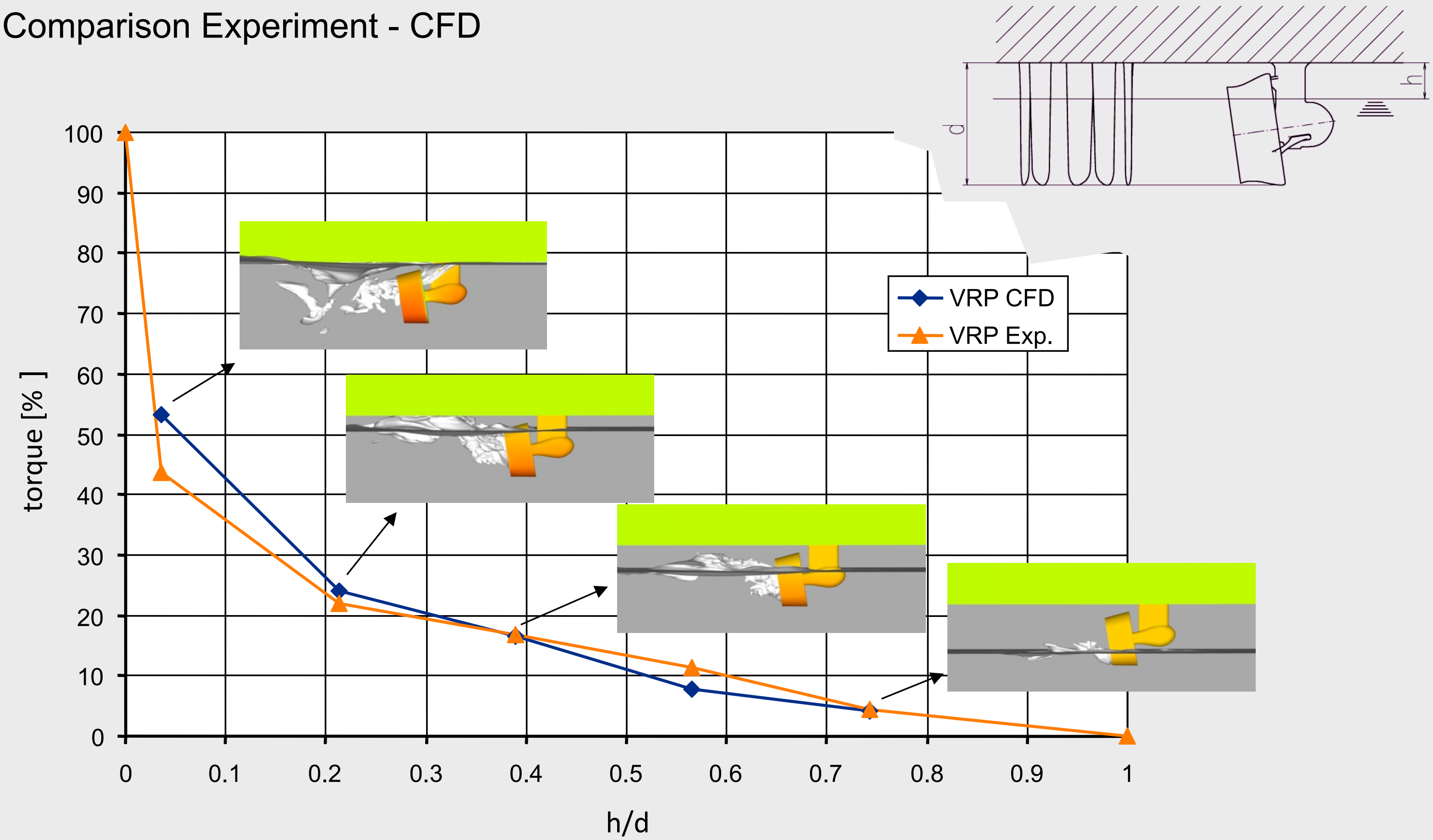
Courtesy of Voith Turbo Schneider Propulsion, Heidenheim, Germany

Simulation of Propeller Ventilation, IV

Comparison Experiment - CFD



Courtesy of Voith Turbo Schneider Propulsion, Heidenheim, Germany