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Final report

NumSim

Numerical simulation of complex systems involving interaction between elements with large and varying stiffness properties

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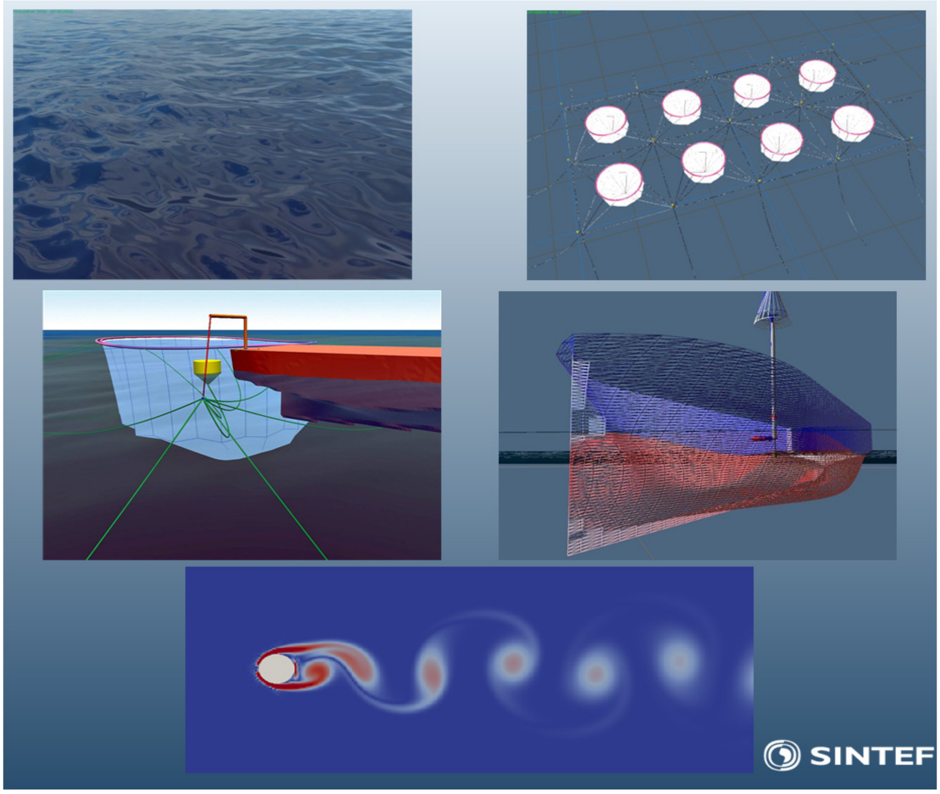

SINTEF Fisheries and Aquaculture
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ABSTRACT

This report is a short summary of the research activity and results obtained in the project Numsim – Numerical simulation of complex systems involving interaction between elements with large and varying stiffness properties. Main focus of the project has been to develop numerical time-domain simulation models for fisheries and aquaculture systems. The numerical models build on the in-house time-domain simulation framework FhSim. The project has been financed by the Norwegian Research Council (grant 199574/O70), The Norwegian Seafood Research Fund (FHF), Multiconsult AS and NOOMAS Sertifisering AS. Research partners in the project have been the Norwegian University of Science and Technology (NTNU), Dept. of Marine Technology and CNR-INSEAN, Italy. This report covers the research activity at SINTEF Fisheries and Aquaculture.

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Table of contents

APPENDICES

1 Introduction

The main objective of the project NumSim ("Numerical simulation of complex systems involving interaction between elements with large and varying stiffness properties") was to develop numerical simulation models for studying complex marine systems and operations. Although a primary focus was kept on systems specific for the aquaculture and fisheries industries (e.g. flexible fish farm structures, vessels operating fishing gear), the dynamics of similar systems such as oil booms were also modelled in the project. When the NumSim project was initiated, numerical models required to analyse such integrated, complex and flexible marine systems were either non-existing or inadequate. Consequently, the project needed to develop new or refine existing numerical models of marine system components, a task that required fundamental research. To enable simulations of how these components and systems will respond to realistic environmental conditions, an environmental model able to handle spatially varying water currents and regular or irregular wave spectra was developed.

Since the NumSim-project aimed to produce a versatile model package covering aspects of both structural dynamics and hydrodynamics, commercial modelling frameworks were rendered unsuitable as they at that time tended to exclusively focus on either the structural aspect (e.g. FEM-software) or the fluid mechanics (e.g. CFD-software) of a specific problem. Project outcomes were therefore implemented in a framework for numerical modelling and simulation developed at SINTEF called FhSim (Reite et al. 2014).

The motivation for the NumSim project was founded in the production increases within the fisheries and aquaculture industries at the time. As production levels increase, an industry will be faced by new challenges. Numerical models enabling the analysis and simulation of system responses could represent a basis for the development of predictive tools with which the fisheries and aquaculture industries may assess how such new challenges should be handled. Moreover, numerical models could also be employed as tools in the design, further development and maintenance of systems for aquaculture and fisheries. This could in turn lead to improved performance and reliability for systems and structures, and personnel safety.

2 Project organisation and management

The project work was organized into four work packages (WPs), with different focus areas. These work packages were:

- WP1: Realistic marine environment simulation model
- WP2: Numerical simulation model for fish farm systems
- WP3: Oil-booms in waves
- WP4: Stability of fishing vessels

3 Description of project results

3.1 WP 1: Realistic marine environment

3.1.1 Wave models

Implemented wave models are based on Airy and Gerstner linear wave theories, which are Eulerian and Lagrangian wave theories, respectively. Methods for calculation of wave-induced fluid motions, velocities, accelerations and pressures were implemented due to regular waves as well as irregular sea-states. The irregular sea states are either based on standard wave-energy spectra with user-defined parameters

(JONSWAP and ISSC), or by custom user-defined wave-energy spectra. Both long-crested and short-crested wave fields are supported. The latter means that different wave components are associated with different wave propagation directions.

3.1.2 Ocean current models

Simplified user-defined ocean currents can be specified by means of a depth-dependent horizontal flow velocity expressed in terms of magnitude and horizontal direction.
Sinmod – flow fields obtained from an in-house oceanographic simulation model can be imported into the marine environment model. This flow field is then superimposed onto the wave-induced fluid motions.

- One-dimensional model
  - Depth varying current
  - Magnitude and direction specified for a given layer of depth
- Three-dimensional model:
  - Current data for a given set of points in 3D-space imported using NetCDF
  - Current field data from Sinmod
  - Evaluation at any point using linear interpolation

3.1.3 The sea environment model

- Unified interface for implemented wave and current models
- Wave induced velocities and current velocities are superimposed
- Objects can ask for physical conditions at a given point and time instant
- Velocity, acceleration, pressure etc.
- Ocean surface is rendered on GPU for real-time visualization

3.2 WP 2: Numerical simulation of fish farm systems

Modern fish farms are built up by components with varying stiffness properties, ranging from rigid objects (e.g. buoys, anchors, point weights) to fully flexible structures (e.g. net structures, ropes). The main aim in WP 2 was to develop numerical models of these components and implement these in the FhSim framework. This would further facilitate the possibility of simulating full fish farm systems in FhSim by interconnecting the numerical models through their respective communication interfaces. Figure 1 contains visualisations of the most important models developed and implemented in FhSim in WP 2.

3.2.1 Mooring frame

Modern fish farms are typically moored using mooring frames, which are networks of ropes arranged in a grid structure which is anchored to the seabed. The vertexes in the mooring frame represent points where several ropes coincide, and are therefore equipped with a device called a coupling plate, which is essentially a steel plate with several rope attachment points. Each cell in the grid structure is designed to contain a single cage which is attached to the coupling plates in each corner of the cell through bridle ropes. For ease of access to the cages, the mooring frame is always placed beneath the surface, often at depths of 5-10 m.

To model mooring frames in FhSim, a generic cable model was set up with the structural properties of rope types typically used in the moorings of commercial fish farms. These ropes were then arranged in a grid structure similar to those used in actual mooring frames, simulating the coupling plates in each vertex by using a combination between a mass object, a sum object and a multiplexing object capable of collecting inputs from several external objects (i.e. the ropes coinciding at the vertex). Anchors in the mooring system were not explicitly simulated but rather represented by fixing one end position of each anchor line.

3.2.2 Buoy

The primary roles of buoys in modern fish farms are to provide additional buoyancy for the mooring system and to increase the visibility of the farm. Buoys are therefore often attached at each vertex of the mooring grid structure, thus distributing their buoyancy contribution throughout the farm, and outlining the cells containing the cages visually. Consequently, the buoys are typically attached by ropes to the submerged coupling plates in the mooring frames.

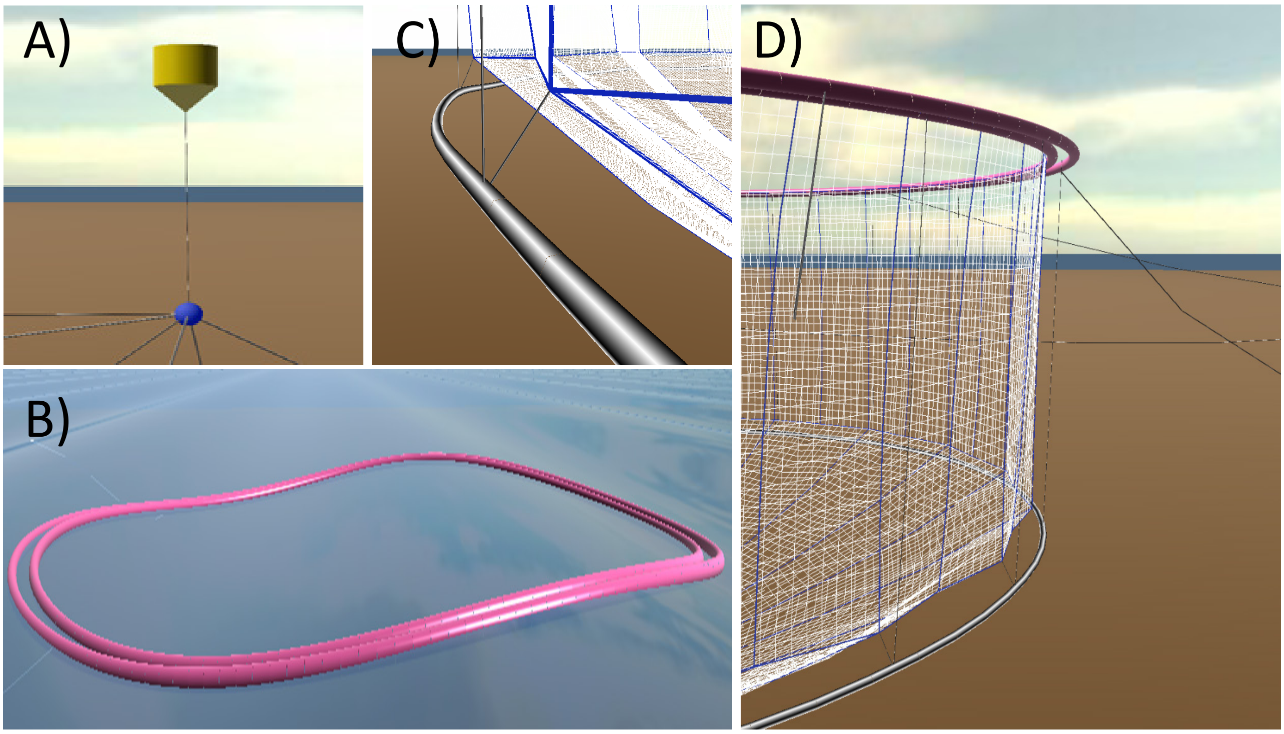

Figure 1: Visualisation of the main model results from WP 2. A) buoy model attached to coupling plate model; B) floating collar model; C) sinker tube model attached to net model; D) system model consisting of a floating collar model, a net structure model and a sinker tube model that are interconnected.

The buoy model was implemented as a rigid body object shaped as a vertical circular cylinder with a conical bottom. Hydrodynamic responses of the buoy model are determined by wave excitation forces (Froude-Kriloff, diffraction and non-linear forces), drag due to water current and buoyancy. In addition, the model has a single input for external forces located at the apex of the bottom cone. This input may be used to attach the buoy to other components, e.g. ropes to the coupling plate of a mooring system. Details of the buoy model are presented in Endresen et al. 2014.

3.2.3 Floating collar

A floating collar is one of the primary components of a fish cage, and is a hollow plastic tube attached to the upper edge of the net structure containing the fish. One of the main roles of a floating collar is to provide sufficient buoyancy to keep the upper edge of the net above the surface at all times to prevent escapes. In addition to the net, floating collars are also attached to the bridle ropes which fix the net cage to the mooring system through the coupling plates, and are often attached to chains from which sinker tubes are suspended. To avoid damages caused by environmental forces, floating collars are constructed from flexible PET materials, meaning that wave excitation will deform the ring which in turn results in that the ring will follow rather than resisting the wave motion. Floating collars used in the aquaculture industry today typically consist of two concentric rings that are interconnected through brackets. This reduces the risk of problems due to horizontal deformations of the ring.

To simulate a cage floating collar, a model of a flexible ring structure with 6 DOF with regards to rigid body motion was implemented in FhSim. The ring model is affected by wave excitation (Froude-Kriloff and diffraction forces), structural, hydrodynamic and damping forces. In addition, the ring may be connected to other components (e.g. nets, ropes, chains) in which case forces transferred from these components to the ring will also impact the dynamic response of the model. The structural response of the ring was modelled using the modal superposition principle, where responses from the natural modes of the structure are summed to yield the total response of the ring. When using this technique, all forces influencing the model have to be converted to a modal form. Although the collar model in FhSim is specified as a single ring, structural effects representative of two rings were included through properties such as bending stiffness and hydrodynamic force coefficients. Details of the floating collar model are presented in Endresen et al. 2014.

3.2.4 Net model

The nets in fish cages are principal components in fish farms as they represent the boundaries containing the fish within the farm. In modern fish farms, net structures are often cylindrical with a conical bottom, and may measure circumferences up to 157 m and depths down to 50 m. Aquaculture nets typically consist of nylon materials with low bending stiffness, meaning that the net structures are very flexible and will be subject to large deformations when affected by hydrodynamic effects from waves and currents. Consequently, the net structure in a fish cage needs to be extended by less flexible components to ensure volume preservation. Today this is realised by attaching the upper edge of the net to floating collars, and attaching either point weights or sinker tubes to the bottom edge of the net.

The net model used in WP 2 was based on an existing model designed to simulate the dynamics of trawl nets that are towed behind vessels. In this model arbitrary net geometries are described as a set of interconnected triangular surface elements and cable elements. Each of the triangular net elements have defined mesh directions relative to the orientation of the panel, and hydrodynamic forces on the panel is computed by decomposing the incoming water velocity generated by waves and currents between the two mesh directions. The hydrodynamic normal and tangential forces on one twine in each mesh direction is then computed and multiplied with the number of twines arranged similarly within the panel. A sum of the forces working in each mesh direction then yields the total hydrodynamic force on the panel. Since aquaculture nets are designed differently than nets used in trawls, and are exposed to a different external environment, some modifications were made throughout the project period to accommodate the model for use in aquaculture.

Whereas incident water current speeds affecting trawl nets tend to be dominated by the speed of the towing vessel, the currents affecting net cages in a fish farm will be determined by naturally occurring events and phenomena such as tidal changes and ocean currents. Furthermore, while trawl nets tend to be towed either in the pelagic zone or near the seabed, net cages are exclusively placed near the surface and are thus more strongly affected by waves. Together these effects contribute to make the water movements affecting net cages more variable both in size and direction than trawl nets. Based on these observations it was determined that the net model needed a more detailed representation of how variations in incident water velocity affects the drag coefficients of the net to produce realistic estimates of the hydrodynamic forces on net cages. The net model was therefore expanded with a Reynolds dependent drag coefficient for the twines.

In 2012, a series of experiments featuring fixed net panels subjected to three different water current speeds with angles of attack ranging from 0 to 90°. These results were also simulated using the net model in FhSim, and the model estimates were subsequently validated against the experimental data (Enerhaug et al., 2012).

Although the model was proven able to reproduce realistic values for the drag and lift forces for higher angles of attach (30-90°), deviations between model output and experiments increased from 30 to 0°. Considering that the model predicted hydrodynamic loads with high precision for high angles of attack, and that the net panels were fixed during the experiments and thus did not deform, it was apparent that these deviations were caused by the lack of a wake effect in the net model. The term wake effect is used to describe how an object downstream from another object will be affected by a flow pattern that differs from that affecting the upstream object. These differences are caused by the presence of the upstream object, and for a segment of netting this has significance when the angle of attack between the incident water current and the net segment decreases as the twines in the net then will increasingly position themselves downstream from other twines. In the results from the panel experiments, it was apparent that this phenomenon started having an impact when the angle of attack became less than 30°. However, it is apparent that wake effects will be even more important when simulating a cylindrical net structure similar to those used in aquaculture net pens, as the downstream half of the net cylinder will then effectually be in the wake of the upstream proportions of the net.

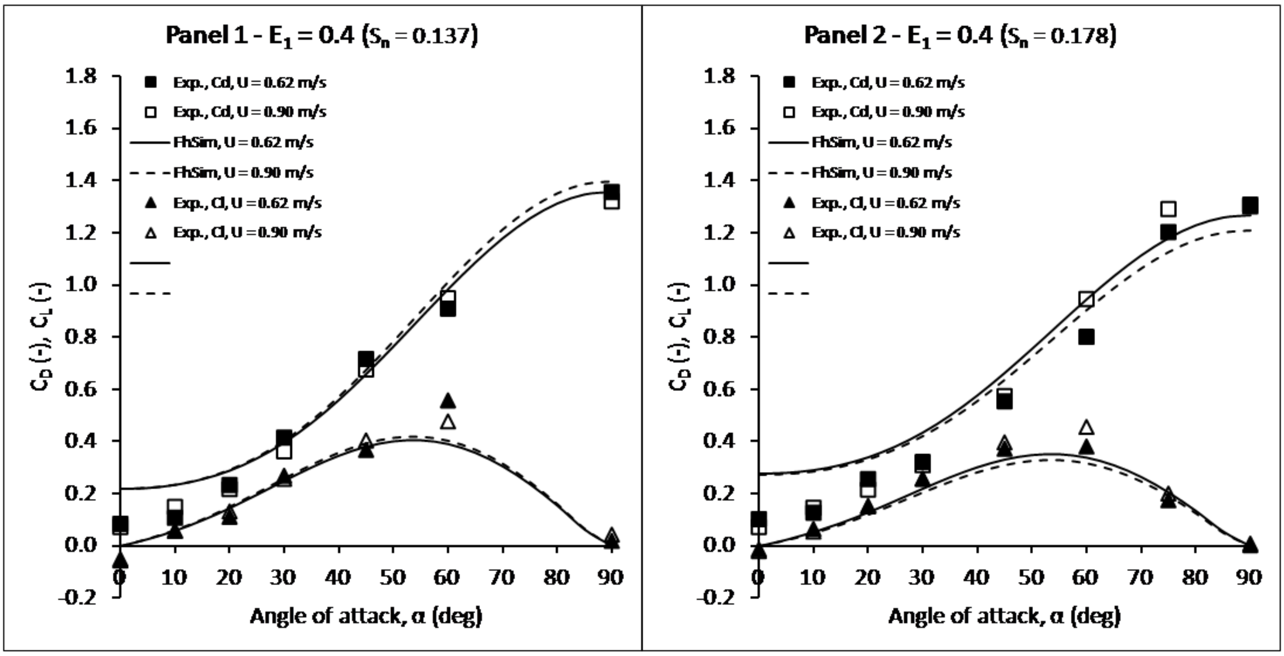

Figure 2: Comparison between the net model in FhSim (lines) and experimental results on net panels in currents (squares and triangles). Horizontal axes represent angle of attack between the net panels and incident current, while the vertical axis provides the non-dimensional drag- and lift coefficients of the panel.

To accommodate wake effects in the net model, a set of expressions for how the wake effects between the twines within a net panel (local wake effect) and between separate net panels (global wake effect) were derived. The resulting expressions depended on the angle of attack between the net panel and the incident water current, the mesh width of the net and twine diameter. In addition the global wake effect expressions depended on the distance from the downstream net segment to the upstream net segment producing the wake effect.

After the local and global wake formulations had been implemented into the net model in FhSim, a series of simulation runs based on previous experiments were conducted. The model experiments were first replicated by numerical simulations with net model in FhSim without the wake formulation. A second sequence of simulations was then performed in which the wake formulations were activated. Subsequent comparison between the model outputs from both simulation series with experimental data revealed that the wake effect formulations were able to draw the simulation results considerably closer to the experimental values, suggesting that the new model produced more realistic results than the model without the wake formulation. Results from this work are presented in Endresen et al. 2013.

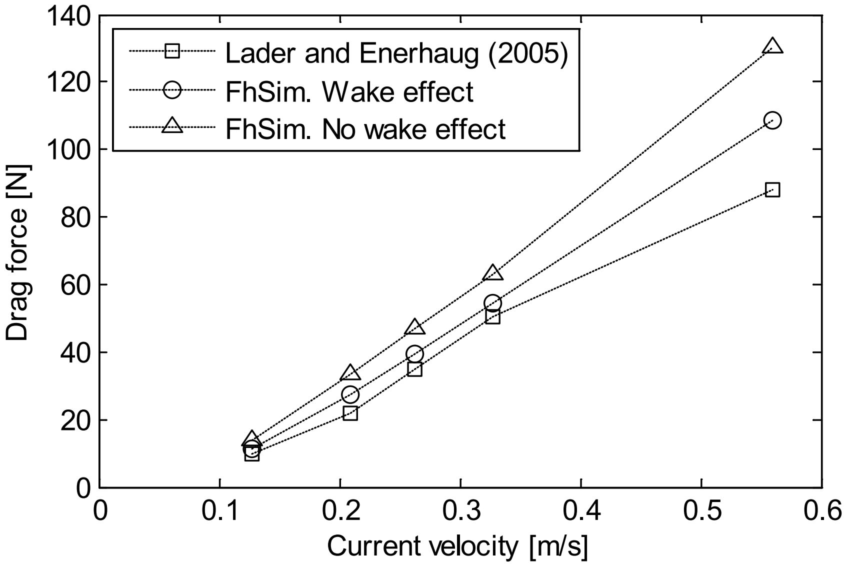

Figure 3: Comparison between experimental results (squares) for a cylindrical net structure affected by current and estimates by the net model with (circles) and without (triangles) wake effect formulations activated.

Typically, the net is the component with the largest contribution to the total forces acting on a fish farm system. Due to this, the net model implemented in FhSim has been subject to a closer scrutiny and more validation studies than the other components developed in this project (Moe Føre et al., 2014).

3.2.5 Sinker tube

Sinker tubes are devices that are attached to the deep end of the nets used in net cages in modern fish farms. This is intended to ensure that the deformations of the net structure when affected by waves and currents are reduced, thus ensuring that a larger internal volume is maintained inside the net cage. Physically, sinker tubes are typically realised as plastic tubes filled with metal cables, chains or other objects with a sufficiently high density to produce a net downward force when suspended in water.

Sinker tubes were modelled in FhSim using a model that was derived from a generic cable model by interconnecting the two end points of the cable to yield a continuous ring structure. Forces affecting the responses of the sinker tube model include gravity forces and hydrodynamic loads (hydrostatic, Froude-Kriloff, diffraction and non-linear viscous forces). The sinker tube model is also equipped with the capability of generating connection points through which other components may convey their forces to the model, a feature that is used when connecting the sinker tube to net structures or floating collars to produce a system model. Unlike the floating collar model, the sinker tube is element based, meaning that the response of the structure is found by summing up the forces affecting each element in the ring and deriving the individual responses of each element. The total response of the ring is then found by applying constraints depending on the material properties of the ring (i.e. bending, torsional and axial stiffness) to the couplings between the elements comprising the ring. Apart from the tube radius (m), total length of the tube (m) and mass per unit length (kg m^{-1}), the sinker tube model therefore needs input parameters determining the axial, torsional and bending stiffness of the tube.

3.2.6 Full system setup

Setting up a full system simulation of a fish farm in FhSim requires the usage of all the models developed in this project. Since each model corresponds to a physical component in modern fish farms, the setup procedure mirrors the methods used when deploying a real fish farm:

1. A mooring system model is set up by interconnecting cable models set up with parameters representative for the properties of the ropes used in real mooring systems. The cable models are interconnected through combined multiplexing/summation/mass models representing the coupling plates. End points of anchor lines are fixed to positions at the seabed
2. Buoys are attached to the coupling plate models through cables parameterised in accordance with the ropes and chains normally used to attach the buoys of a real system to the mooring system
3. Net cages are set up by interconnecting a net structure model with a floating collar model. In cases where point weights are used to weigh down the net, a static vertical force is applied to the net structure at the points at which the point weights are placed. When a sinker tube is used instead, a sinker tube model is attached along the bottom edge of the cylindrical part of the net structure
4. Cable models parameterised in accordance with typical specifications for bridle lines used in aquaculture are attached to the floating collar and the coupling plates located at the corners of a cell in the mooring system. This fixes the net cages to the mooring system
5. Set up the environmental model with a desired set of conditions that will affect the system.

A simulation set up using the procedure given above would, if set up correctly in FhSim, yield a full system simulation of how the fish farm responds to the chosen environmental conditions.

In 2013, laboratory experiments using a scaled down physical model of a single fish cage system were conducted in the ocean basin at MARINTEK. The cage system comprised scaled down versions of a floating collar, a cylindroconical net structure, a sinker tube and chains attaching the floating collar to the sinker tube. This system was attached to a simplified single cell mooring system which featured scale models of mooring ropes, anchor lines, buoys and coupling plates. The mooring system was further anchored to the bottom of the tank. Results from these experiments were compared with the outputs of a system model set up in FhSim using the components developed in this project (Endresen et al., 2014). This validation study yielded acceptable correspondence between experimental values and model output, suggesting that system models of net cages implemented in FhSim will produce realistic output values and responses.

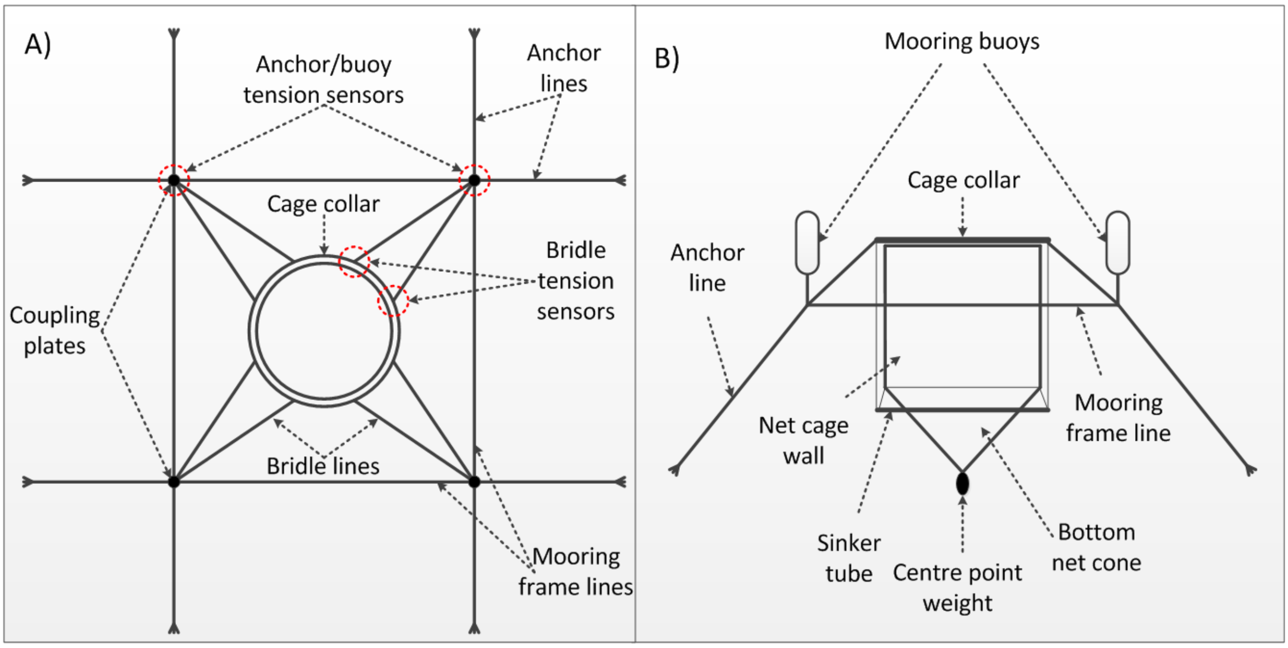

Figure 4: Setup of scaled net cage model in a simplified mooring system using the components developed in WP 2.

3.2.7 Work shop

On 26th of September 2012, a workshop was held at SINTEF Fisheries and Aquaculture in Trondheim entitled "Internal scientific workshop on physical and numerical analysis of net and flexible structures". The main aim of the workshop was to stimulate the exchange of results and experience among the scientific personnel working within the NumSim project. Presentations were held by researchers at SINTEF as well as PhDs and post.docs at NTNU, and the presentations were thereafter discussed in plenary sessions.

3.3 WP 3: Numerical simulation of oil-booms in waves (post Doc. project)

A numerical flow solver was developed to investigate complex flow effects related to failure modes (leakage) of oil-booms. The motivation for this was to address failure modes for leakage of oil from the boom in operation (Figure 5). The present numerical flow solver for viscous flows is based on the lattice-Boltzmann method (LBM), with theoretical background from statistical mechanics and kinetic theory. The numerical model was implemented for parallel execution on graphic processing units (GPU) for high efficiency simulations using CUDA™ (www.nvidia.com/cuda).

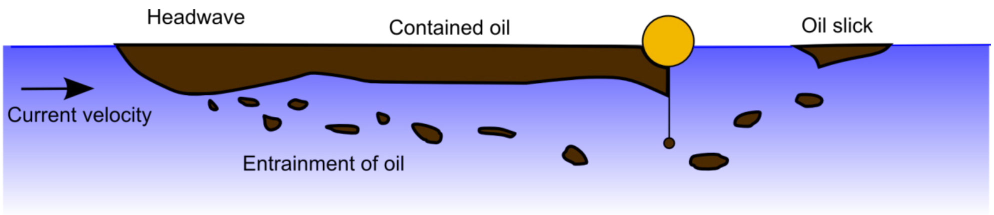

Figure 5: Example of failure mode (entrainment failure) for a conventional oil-boom in operation. Entrainment occurs from the so-called head wave of the contained oil.

3.3.1 Flow past objects and computation of forces

The numerical flow solver was developed to handle flow past structural objects relevant for conventional oil booms. An immersed boundary method was applied to obtain a robust method suitable for future simulations of flexible geometries. Further, a local grid refinement model was implemented to increase local resolution of the computational grid for better accuracy of computed forces while keeping the computational costs at an acceptable level. The numerical model was tested and verified by comparison of results with published theory and numerical data. Results from this work were presented at the *EFMC12 – the European Fluid Mechanics Conference* (Kristiansen and Faltinsen, 2012), and at the *Conference on CeSOS highlights* (Kristiansen, 2013). Example results are shown below (Figure 6 and Figure 7).

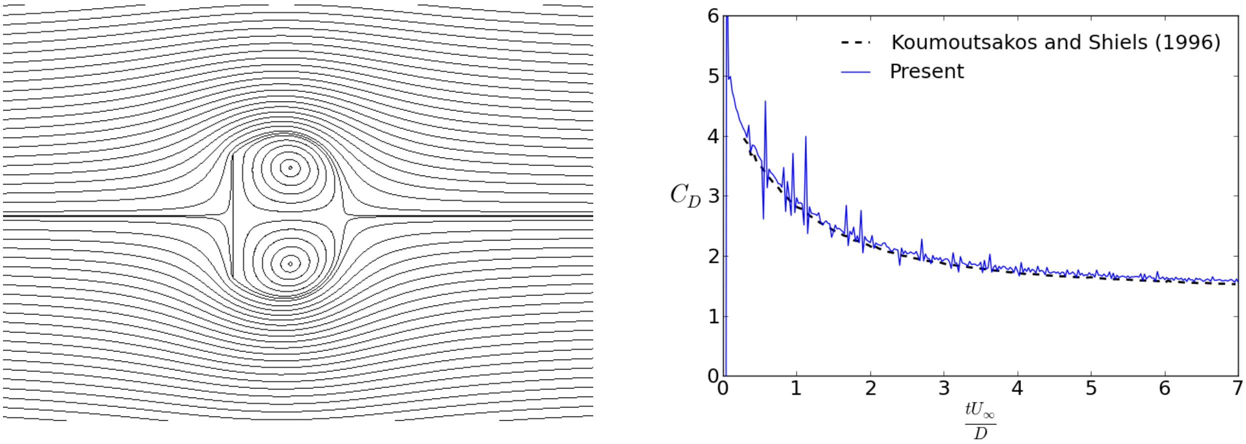

Figure 6: Verification test of the numerical flow solver. Left: streamlines from simulation of abruptly started flow past a flat plate. Right: verification of results by comparison of the temporal evolution of the drag coefficient. Spikes are due to acoustic wave reflections from the domain boundaries.

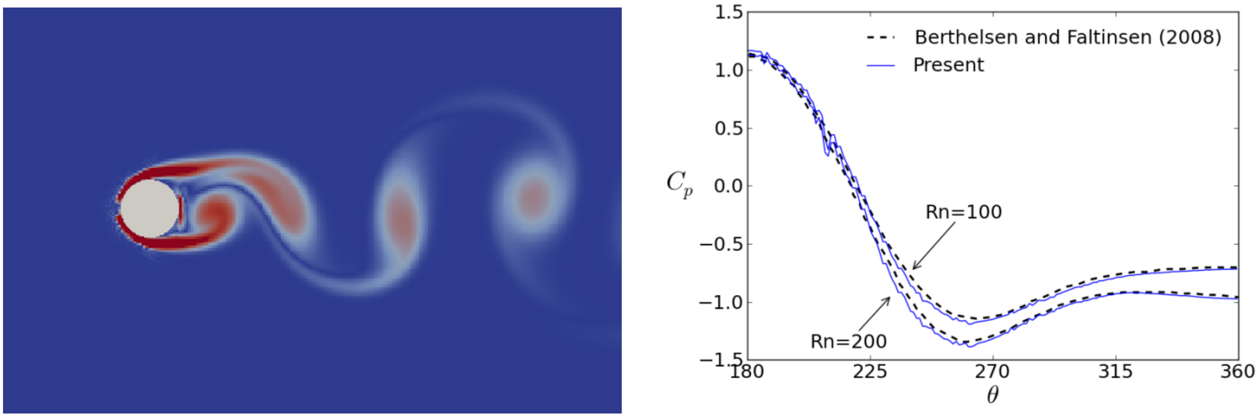

Figure 7: Verification test of the numerical flow solver. Left: Von Karman street illustrated by the vorticity magnitude field obtained from simulation of a circular cylinder at Reynolds number 200. Right: verification of results by comparison of obtained pressure coefficient with published numerical data.

3.3.2 Two-phase flow simulations

The numerical model was further developed to simulate two-phase flow problems, which was necessary to address physics related to entrainment failure of oil booms. A phase-field method was applied and coupled with the present LBM flow solver. The model can handle differences in fluid density and viscosity between the two fluids, in addition to surface tension at the interface between the two fluids/phases. These properties are important to consider when modelling flow phenomena that may lead to entrainment failure. Several verification tests of the two-phase flow model were performed.

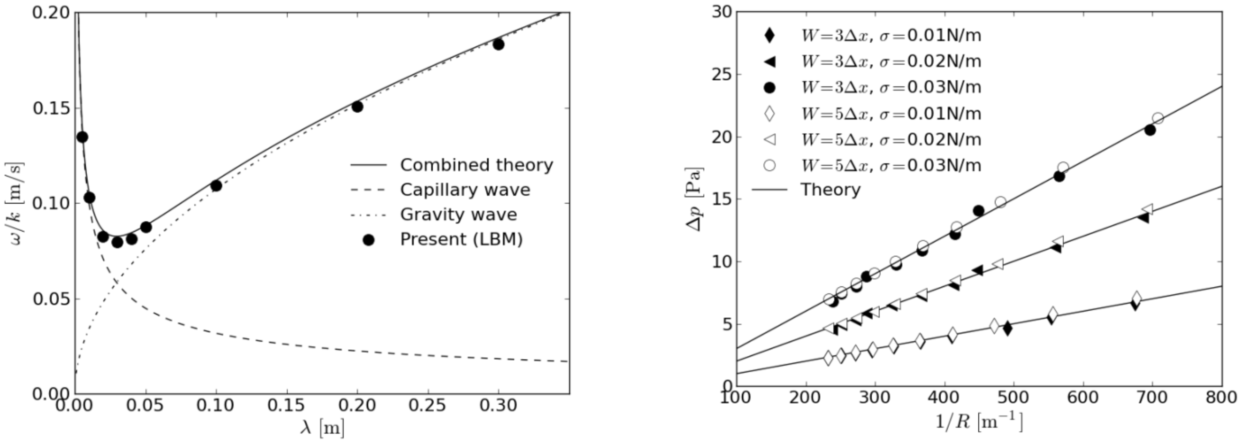

Figure 8: Verification of two-phase flow model. Left: Oscillation frequency divided by wavelength of standing internal wave (gravity-capillary wave). Comparisons of numerical results with theory. Right: Test of surface tension model by simulation of a stationary bubble. Comparisons between numerical results and theory of pressure difference inside and outside the bubble for different surface tension coefficients and curvatures.

3.3.3 Entrainment failure of oil-booms

The numerical model was applied to study instabilities of stratified shear flows, which has relevance for the entrainment failure mode of oil booms (Figure 5). This work resulted in the publications Kristiansen and Faltinsen (2014) and Kristiansen and Faltinsen (2015). First, the different instability modes of stratified shear layers were studied by numerical simulations with idealized conditions. Under given flow conditions, three different interface instability modes were observed: Kelvin-Helmholtz mode, symmetric Holmboe mode and asymmetric Holmboe mode (Figure 9). The obtained results were in agreement with linear stability theory from literature.

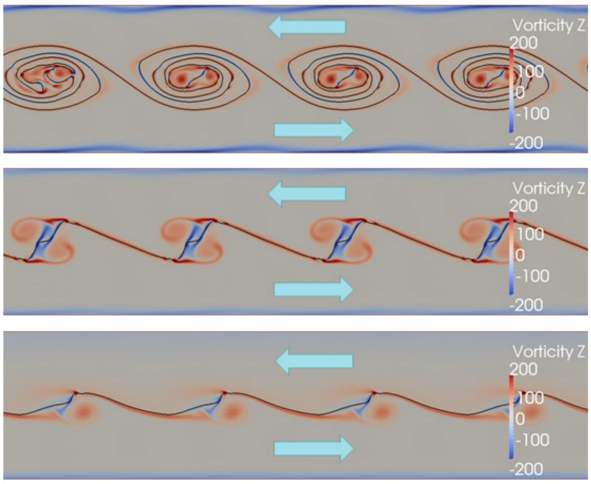

Figure 9: Interface instability modes of stratified shear layers obtained with the present two-phase flow model. The interface is represented by a black line. Top: Kelvin-Helmholtz mode. Middle: Symmetric Holmboe mode. Bottom: Asymmetric Holmboe mode. Arrows indicate flow direction.

Then the two-phase flow solver was applied to study complex flows of water and oil. Simulations of gravity currents were conducted, where the flow is driven by gravity due to differences in mass density of the oil and the water (Figure 10).

Figure 10: Numerical simulation with the present flow solver of two-phase flow. Simulation shows gravity currents obtained from a lock-exchange configuration, driven by gravity due to differences in fluid density. A breaking head-wave with droplet entrainment, as typical for contained oil of conventional oil-booms in operation, is observed.

3.4 WP 4: Stability of fishing vessels

In this work package, research has been focused on dynamic stability of fishing vessels and the instability mode called parametric rolling.

3.4.1 Development of a fishing vessel hull

A hull-form in the style of a medium sized Norwegian fishing vessel was developed for scaled model experiments and numerical calculations. The hull was developed as to be susceptible for parametric roll and to include bilge-keels and skeg. It was named SFH112 and the body plan, with and without skeg, are presented in Figure 11. The hull geometry is made freely available for research and academic use at http://www.sintef.no/fisk/sfh112.

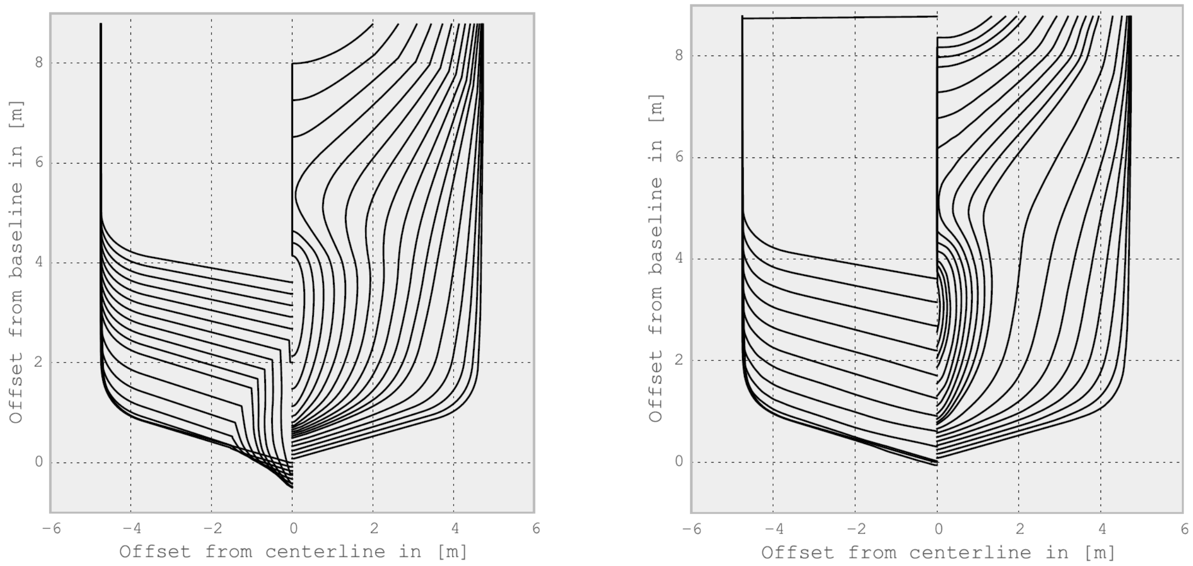

Figure 11: Body plan for the fishing vessel hull SFH112, with skeg (left) and without skeg (right).

3.4.2 Scaled model tests

A series of model experiments has been performed at the hydrodynamic laboratories of CNR-INSEAN, Italy, with the scaled model of the SFH112 hull. The time history of the experimental work is presented below.

Year 2011:

- Definition of the model geometry and ship dimensions.
- Construction of the ship model without skeg and propeller and with removable appendages.
- Construction of the skeg and rudder.
- Construction of the anti-rolling tank and balance to measure roll moment.

Years 2012 – 2013:

- Execution of free-decay tests in roll with and without appendages for five forward speeds (0, 2, 3, 6 8 knots in full scale). Separate effects of appendages (bilge keels, rudder, propeller, skeg, shaft) were investigated.
- Repeatability analysis
- Identification of roll damping contributions induced by each appendage

Years 2013 – 2014 (Jan. 2015):

- Execution of tests in head regular waves around the conditions of parametric resonance (bare hull conditions)
- Execution of tests in head regular waves around the conditions of parametric resonance (with appendages)
- Execution of forced sloshing tests for the isolated sloshing tank. Measurement of the roll moment.
- Execution of tests in head regular waves around the conditions of parametric resonance (with anti-rolling tank)

Details of the model tests are presented in a separate report (Lugni, 2014).

3.4.3 Numerical modelling and simulation of roll damping effects

Numerical models of roll damping due to skeg, bilge-keels and hull-form were implemented to an existing ship simulation model according to state-of-the-art engineering methods. A component-wise approach was applied, where damping due to different physical effects were added to the ship dynamic model. Then, the roll damping characteristics of the numerical model were investigated by replication of the physical scaled model tests. Obtained results from the simulations were compared with those from the experiments (example results presented in Figure 12). It was found that some of the numerical damping models recommended by ITTC do not apply for the present vessel, as large deviations were observed. In particular, the effect of the skeg was not satisfactory represented with the state-of-the-art models. However, the effects of bilge-keels were very well captured by the numerical model. This work resulted in the publication Aarsæther et al., 2015. Associated work was published by the research partners at NTNU and CNR-INSEAN (Greco and Lugni, 2013).

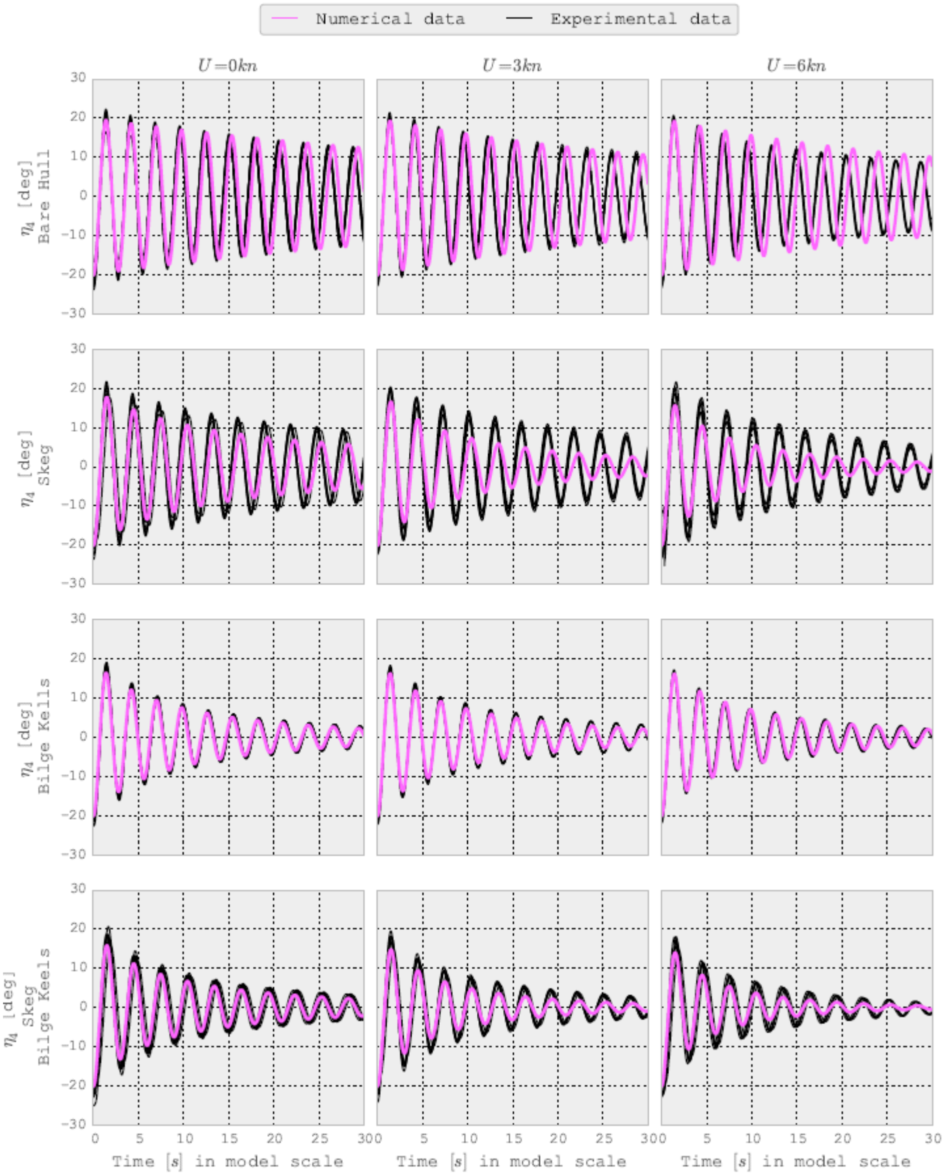

Figure 12: Example results from tests of free decay roll motion with the SFH112 ship model. Comparison of numerical simulation data with experiments.

3.4.4 The PhD-project

A PhD-position at NTNU was financed by the Numsim project. Title of the PhD-project is *Hydrodynamics related to parametric resonance and capsizing of fishing vessels* (Ghamari, 2012). Supervisor is Prof. O. M. Faltinsen. Published work so far is Ghamari et al., 2015.

3.5 Publications in scientific peer reviewed journals and conference proceedings

Aarsæther, K. G., Kristiansen, D., Su, B., Lugni, C. Modelling of roll damping effects for a fishing vessel at forward speed. In Proceedings of the ASME 2014 34th International Conference on Ocean, Offshore and Arctic Engineering , OMAE2015-41856, May 31 - June 8, 2015, St. John's, Canada.

Ghamari, I., Faltinsen, O. M., Greco, M. Investigation of parametric resonance in roll for container carrier ships. In Proceedings of the ASME 2014 34th International Conference on Ocean, Offshore and Arctic Engineering , OMAE2015-41528, May 31 - June 8, 2015, St. John's, Canada.

Greco, M., Lugni, C. Numerical study of parametric roll on a fishing vessel. In Proceedings of the ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering, Nantes, France.

Kristiansen, D., Faltinsen, O. M. A numerical study on stratified shear layers with applications to oil-boom failure. In Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, San Francisco, USA.

Kristiansen, D., Faltinsen, O. M. A numerical study on stratified shear layers with applications to oil-boom failure. Journal of Offshore Mechanics and Arctic Engineering, 137(4), 041301, 2015.

Enerhaug, B., Føre, M., Endresen, P. C., Madsen, N., Hansen, K. (2012). Current loads on net panels with rhombic meshes. In Proceedings of the ASME 2012 31st International Conference on Ocean, Offshore and Arctic Engineering, Rio de Janeiro, Brazil.

Endresen, P. C., Føre, M., Fredheim, A., Kristiansen, D., Enerhaug, B. (2013). Numerical modelling of wake effect on aquaculture nets. In Proceedings of the ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering, Nantes, France.

Endresen, P. C., Birkevold, J., Føre, M., Fredheim, A., Kristiansen, D., Lader, P. (2014). Simulation and validation of a numerical model of a full aquaculture net-cage system. In Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, San Francisco, USA.

Moe Føre, H., Endresen, P. C., Jensen, J., Aarsæther, K.-G., Føre, M., Kristiansen, D., Fredheim, A., Lader, P., Reite, K. J. (2014). Structural analysis of aquaculture nets: comparison and validation of different numerical modelling approaches. In Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, San Francisco, USA.

Reite, K. J., Føre, M., Aarsæther, K.-G., Jensen, J., Rundtop, P., Kyllingstad, L. T., Endresen, P. C., Kristiansen, D., Johansen, V., Fredheim, A. (2014). FhSim – time domain simulation of marine systems. In Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, San Francisco, USA.

Reite, K.-J., Føre, M., Aarsæther, K. G., Jensen, J., Rundtop, P., Kyllingstad, L. T., Endresen, P. C., Kristiansen, D., Johansen, V., Fredheim, A. FHSIM – Time domain simulation of marine systems. Paper submitted to Journal of Offshore Mechanics and Arctic Engineering, January 2015.

3.6 Other publications

Lugni, C. (2014). RP-NSCS Numerical Simulation of Complex Systems. Parametric Roll of a Norwegian Fishing Vessel. Experimental Activity at INSEAN: Design, model construction, set-up and test matrix. Report. CNR-INSEAN.

Ghamari, I. (2012). PhD project description: *Hydrodynamics related to parametric resonance and capsizing of fishing vessels.*NTNU, Dept. Marine Technology.

3.7 Conference presentations

Kristiansen, D., Faltinsen, O. M. A lattice-Boltzmann method applied to hydrodynamic cross-flow problems. Presented at 9th European Fluid Mechanics Conference (EFMC9), University of Rome "Tor Vergata", Rome, Italy, Sept. 2012.

Kristiansen, D. Fluid simulations with applications to oil-booms using a lattice-Boltzmann method. Presented at Conference on CeSOS highlights, NTNU, May 2013.

3.8 Popular science publications

- News article in the trade magazine TU about the MarinSim project – a training simulator for aquaculture operations in Rørvik, Norway, where the main simulation models (sea environment, fish cage, ship) has been developed in the Numsim-project. (http://www.tu.no/industri/2013/09/11/ny-simulator-skal-sikre-oppdrettslaksen)
- Presentation of NetCageDesignTool at Havbrukskonferansen (Aquaculture seminar) in Tromsø, Norway, arranged by the Research Council of Norway, a software for design of aquaculture net cages where main components are developed in the NumSim-project.
  (Attachments: 6_bjørnson.docx, Havbruk2014.pptx)

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