Annual Report 2020

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SFI MOVE

Marine Operations in Virtual Environments

SINTEF NTNU

sfi Centre for Research-based Innovation

MOVE SFI Marine Operations

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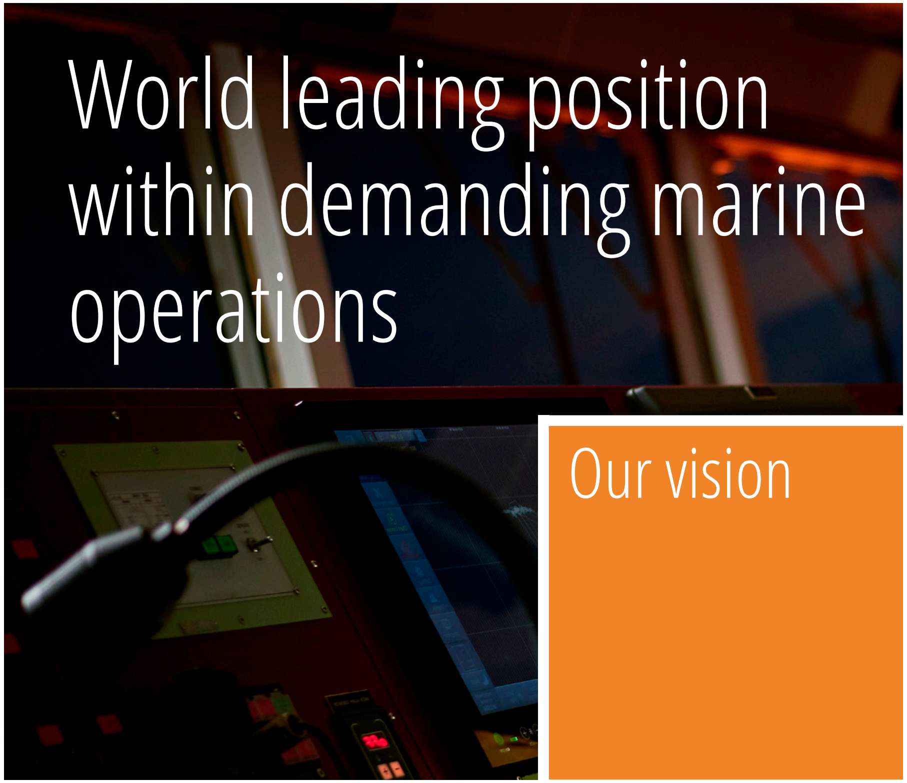
World leading position within demanding marine operations



Our vision

Our vision

To establish a world leading research and innovation centre for demanding marine operations.

Simulation has been used for decades to test the physical aspects of marine operations. Simulators are used to train crew to perform demanding operations. Next generation technology has the potential to provide Virtual Prototyping to pre-test marine operations, including the human component. Cutting-edge interdisciplinary research will provide a bridge between industrial needs, innovation and research.

Research
Our goal is to take a world leading position within demanding marine operations.

Innovation
Our goal is to put the industrial partners in front of defining needs and potential for innovation and business.

Education
The research shall lead to theory and new methods for education as well as training of professionals.

Arena
The goal is to establish an arena for research and industrial cooperation within demanding marine operations.

Objectives

The SFI centre shall support the entire marine operations value chain by developing knowledge, methods and computer tools for safe and efficient analysis of both the equipment and the operation. The developed methods shall be implemented in simulator environments to pre-test marine operations including the human component.

The SFI centre shall support the innovation process of the marine operation value chain through active involvement by industry, thus improving the competitiveness for Norwegian marine industry.

The centre shall:
- Achieve all-year subsea operations installation and service
- Perform safer and more cost-efficient operations
- Support innovation in existing and emerging ocean industries

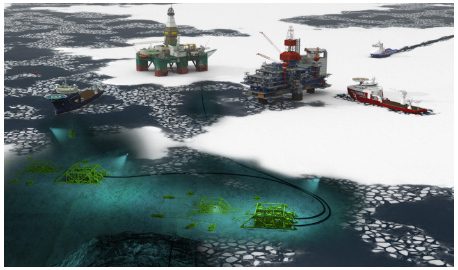
The idea is to optimize operations, from planning to execution, by better understanding of the responses. This is a simulation oriented approach where models are re-used throughout the value chain. To fulfil this goal the following is of vital importance:

- Improved understanding of complex physical phenomena
- Modelling and Virtual Prototyping (simulation)
- Simulation as an industrial standard
- Onboard decision support systems
- Online environment monitoring
- Improved crew performance (training & assessment)

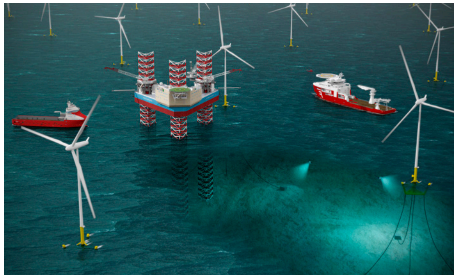
Business areas

The business areas focused on in 2020 are:

- Demanding marine offshore operations as at deep water, all-year availability, or arctic areas



- Installation and maintenance of offshore wind



- Management of marine operations and shipping

Director's report

Professor Hans Petter Hildre is the leader for SFI MOVE

Figure 2.

The overall objective for SFI MOVE is to facilitate marine operations taking place in a commercial and cost-efficient manner and thereby contributing to position the Norwegian maritime industry towards the market of such operations worldwide. As operations are getting more extensive, there is a need for more all-year marine operations. All-year operations will have a significant impact on both technology, operational procedures, costs, and will require very different solutions depending on the environment in which you are operative.

Marine operations are designed, simulated and planned for a long time before the operation is carried out. Wind, waves, behaviour towards objects in air and sea, which ship and load condition are assumed. The result of simulation is that the operation can be carried out if a given wave height is not exceeded. Therefore, simulations based on a series of assumptions, and thereby uncertainty. How can we reduce this uncertainty?

In this year's Report I will emphasise two fundamental areas in SFI-MOVE:

- To calculate responses and let responses be criteria for an operation. Examples of such responses can be speed of the crane tip or least/largest force of the wire during a lift.
- To perform simulations on board and in remote centres based on measured data before and during an operation. In order to achieve this, we develop digital twins where sensors on the ship replace assumptions with measured values before and during an operation.

We are now seeing a furious pace of development of digital twins within several areas of technology and it is exciting to introduce this technology within maritime operations. In general we can say that digital twins gives us the following possibilities:

Building experience: Real data from previous operations can be used to improve understanding and reduce uncertainty. This is useful for correlating variables or running machine learning algorithms.

See present situations: It is regularly updated with sensor data, often through IIoT connectivity to detect anomalies and improve model accuracy.

Predict the future: It synthesizes and contextualizes historical and real-time data to give insights into potential future states.

SFI-MOVE has realised this development in the following 3 projects.

On-board Decision Support System (ODSS)

Marine operations are today designed and simulated by engineers before they are executed. The main idea of this project is to develop a framework for digital twin technology allowing on-board support calculating responses taking into account the present ship behaviour and metocean.

Theoretical hydrodynamic models used in the engineering phase are corrected by use of real time measurements of vessel motion and responses. Combined with information about development of the environmental conditions through weather reports and the development over time of the actual measured responses of the vessel, this will form the basis for prediction of the vessel behaviour. Based on these predictions, the system shall be capable of predicting the present and near future vessel responses. Combined with limiting criteria for operations, required weather window, safety factors etc., real time advice on feasibility of performing the marine operation will be given. The core of the project will be effective onboard predictive simulation and predictive simulation and predictive analytics tools. The simulations can then be useful to support the rigging, briefing the crew, preparation at position, in operations, and finally de-brief.

Present simulation software must be re-designed to include real-time information from sensors. A key feature will be to transfer the models in engineering to the on-board system. (Fig. 1.)

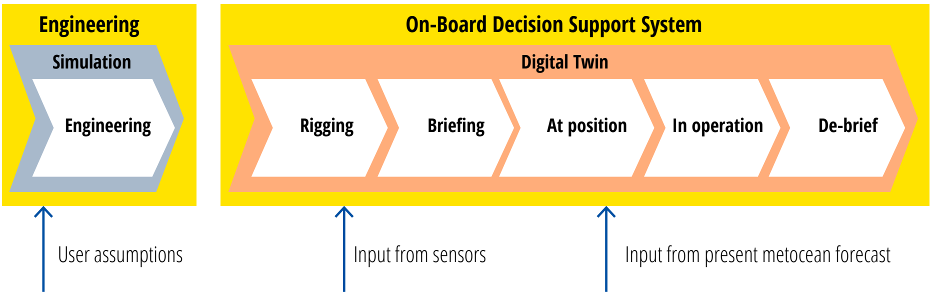


Figure 1.

Case: Subsea lifting operations

A lifting operation will be a case for this development. The case will include rigging, lifting in air, through splash zone and in water column.

A reliable on-board decision tool depends on good hydro-dynamic models for structures to be installed. Data from model tests and literature is collected and systemized and is available for the MOVE partners. Additional model tests are made to improve understanding and fill gaps in the literature.

Coefficients for splash zone behaviour will be included in 2021. When a structure is lowered into the sea, the forces on the structure directly from the passing waves in most cases dominate them over the forces due to ship and crane motion. Sort wave components in the sea state tend to give the most significant contribution to wave forces. Bot experience from offshore operations and from initial simulations show that shielding effect from the ship hull is significant when a structure is deployed on the leeward side. Such shielding effect will be included in the simulation software.

Remote operation support

Marin operations are getting more technology based. New technological solution as digital twins, cloud computing and machine learning enables faster change, creates more complex and dynamic work environments, which is followed by organizational changes, implementations of new and more flexible structures and ways of working.

The driver for such development is reduced costs by having remote support replacing physical support onboard. But also increased quality by access to a broader variety of competence and reduced risk by capacities to perform advanced analytics and trade-of scenarios.

A remote operations framework can be established by adding a copy of the on-board digital twin to a remote centre. The sensors signals will be transferred to the remote centre and all responses will be calculated by the twin. Having a twin and simulation capacity at the remote centre gives several advantages.

- Low demand for transmission bandwidth.
- Alternative scenarios can be executed while the ship is waiting
- The users in the operation centre can choose view of interest

A research lab for remote operations are built at NTNU in Ålesund, see figure 2.

Case: Dispersed teams
The NTNU research vessel Gunnerus is instrumented and signals are transferred to the research lab. ECDIS data as ship position, heading and speed, MRU data as pitch, roll and heave, crane data as joint angles, and engine data etc. are transferred to the NTNU research lab.

Proof of concept tests was performed in 2020 and studies of dispersed ship crew will be performed in 2021.

The aim of this case study is to investigate new ways of doing maritime operation, how use of digital twin technology can enable collaboration between shore and vessel, and how dispersed teams can optimize workflow and organisation change. Studies of performance of such teams will be executed in 2021.

Operational responses and co-simulation

The new simulation framework is based on principle of the Functional Mockup Unit (FMU) standard. Such approach enables the re-use of simulation models and models across organizations without exposing sensitive IP by protecting models and control system software inside black-box executables.

The simulation framework also includes co-simulation allowing different subsystems which form a coupled problem that is modelled and simulated in a distributed manner. Models from a variety of specialised software tools can be combined in one single system simulation. For example, a ship model, a thruster model, a DP model, a crane model, a hydraulic power model, control system can be put together in one system simulation. This framework is compatible with the Open Simulation Platform initiative.

Case: OWT
Fewer restrictions on size and height than their onshore counterparts, offshore wind turbines are becoming giants. 12 MW turbines were installed in 2019 and 14 MW turbines are ready to be tested in 2021. These giants have a rotor diameter of 222 meters and 260 metres hight to the rotor centre. Installations are moving further from shore, tapping better quality wind resources, and pushing up capacity factors. Nest generation giant turbines demand new method for installation, service, and repair.

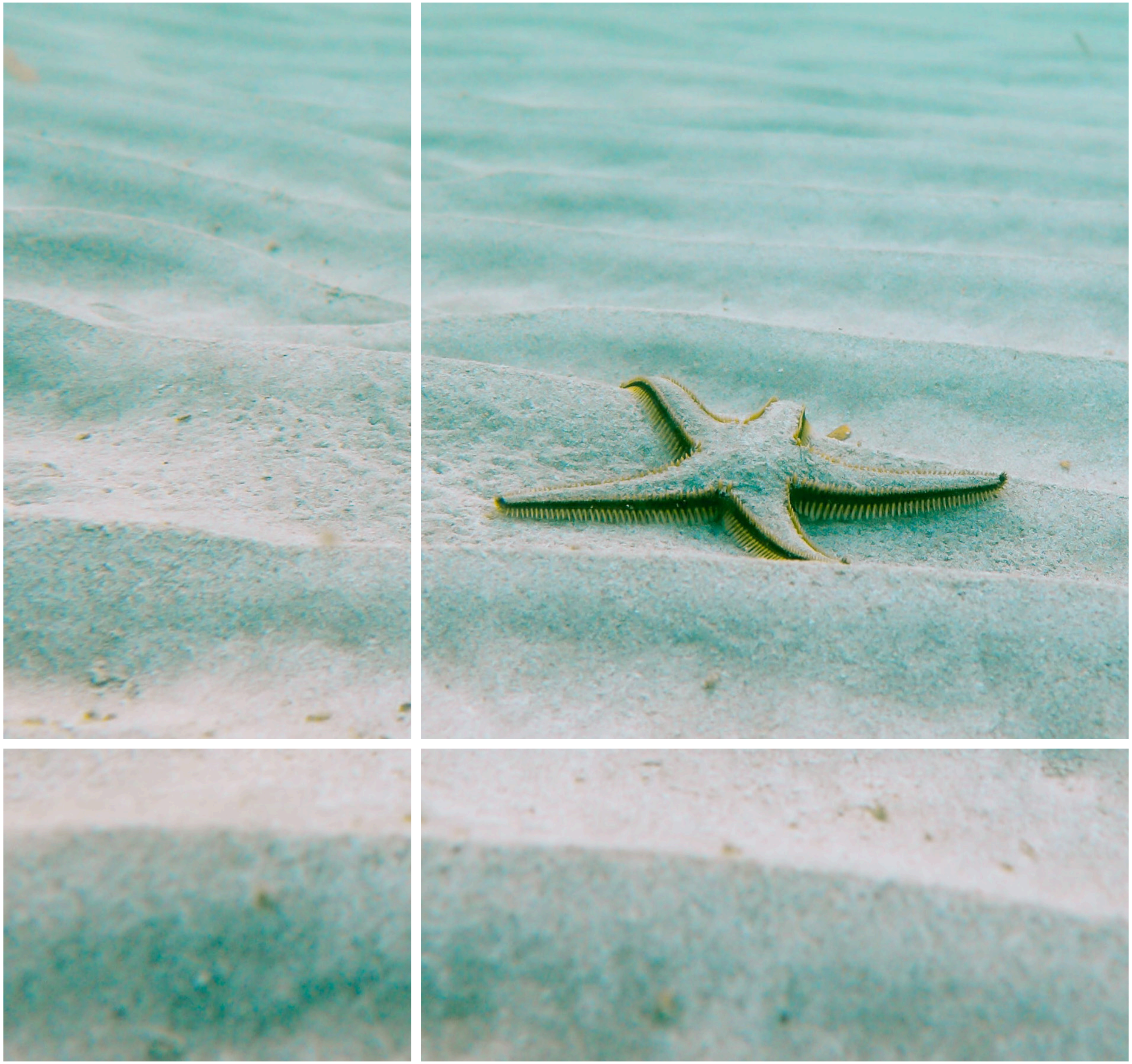
Installation of giant offshore structures are present done by huge crane vessels with needed lifting capacities and hight. Such assembly is done in sheltered areas and then towed to the wind farm for mooring. This is complex and costly operation.

SFI MOVE has been working with an innovative solution lifting the tower including nacelle and blades by wires at a lower point, see comparison in figure 3.

Figure 3.

Overall plan for the final delivery of SFI-MOVE

1. Established world leading research and innovation centre for demanding marine operations
2. System simulation workbench for real responses:
   A. Modular set of models allowing simulation of subsea operations and offshore wind installations (FMI/FMU modules)
   B. Ship behaviour & data-driven tuning of ship models
   C. Prediction of future weather responses
   D. Backbone of simulation capabilities from sales, engineering, on-board and remote operations
   E. Front-end modelling and visualisation environment including libraries
3. Methods and set-up for remote operations (based on simulation)
4. Demonstrators of technology. On-board and remote operations demonstrated for Gunnerus and an offshore vessel (case: subsea lifting/installation)



The dream job lies within offshore wind

Text : Else Britt Ervik

Photo: Kristian Rathe Gisvold

Idunn Olimb is a Senior Researcher Innovation in Equinor and feels that she is at the right place. Here she is working with sustainable energy, offshore wind, and floating wind turbines.

Main profile:
Idunn Olimb

Senior Researcher Innovation
R&T FVC Wind and Solar Technology

Equinor ASA

Throughout her life, Idunn has been interested in the environment and climate, which is clearly seen in a purpose-oriented choice of studies in maritime technology at NTNU Trondheim. The studies have led to the dream job in Equinor.

> «I grew up in Bergen, with the sea, rain, and wind easily accessible», she says. «I enjoy being on and by the ocean, and in my family bakground there are long traditions of seafaring.»

The engineer has the blue element in her blood, and she says that she loves going professionally in-depth into the projects in which she is involved at work.

A broad energy company

In Equinor, which was previously Statoil, an extensive change has taken place in line with the green change. From being only an oil company, Equinor is now a broader energy company, something which is important to keep up in the global energy change-over and to be competitive with regard to the Paris Agreement. In SFI MOVE they are an important partner, also with regards to offshore wind.

> «It has been shown that almost 80 % of the world's off-shore wind resource are located at waterdepths larger than what is practically possible for fixed bottom wind turbines. This combined with the experience Equinor has from floating platforms and marine operations, especially on the Norwegian continental shelf, makes floating wind a very interesting opportunity», Idunn explains, now approaching the core of what SFI move is all about.

There are many different participants in SFI MOVE, from akademia to industry. Through the SFI these partners collaborate and find common solutions on their challenges.

> «Collecting a broad range of partners, and exchange good experiences from both offshore activities, aqua-culture, and in time also offshore wind, is important. I believe that co-operation across the industry, so that everyone pulls in the same direction, is essential for developing good concepts and methods for the future.»

Idunn has been an employee in Equinor since 2010, when her education in marine technology in NTNU was completed. She experienced the company as an exciting place to work and was especially interested in offshore wind.

«It seemed like an inspiring place to work and I was particularly attracted to offshore wind», says the researcher, and thinks back to what created the motivation for her – at that time Statoil had recently installed Hywind Demo west of Karmøy, the world's first full-scale floating wind turbine.

In Equinor, Idunn belongs to the business area of technology and research and works today mainly with technology development of floating wind, which was her dream in the beginning.

Important to have collaboration between research and industry

> «It is always nice to come to Ålesund and experience the cluster of maritime businesses», says Idunn. «It is a short way from the akademia and research to the industry, and this proximity, I believe, contributes to an understanding of what is practical and useful for the industry.»

The former NTNU student says that several of her fellow students have ended up in the maritime cluster in Møre.

Network and professional unity at NTNU

All her life, Idunn has been motivated by acquiring knowledge, and she feels that she chose the right path in the professional direction at NTNU.

> «So far in my career I have had great use of the knowledge I gained as a student. I still open my old textbooks almost weekly. They are very relevant.»

In addition, the NTNU alumni emphasises the importance of a professional network and unity. «To have a network for professional discussions is very valuable,» she says.

Wind turbines and SFI MOVE

Idunn thinks she is very lucky being able to work with what she likes best. Regarding SFI MOVE, the engaged and all-round engineer had her first involvement with the work package *On-board decision support*. This was due to the work she had done on response forecasting, where forecasted waves and wind were applied in simulation models to improve the basis for decisions for marine operations.

> «Now I work mainly with response analyses on floating wind turbine concepts.»

She beams when talking about her projects, and based on her environmental interests, we can understand that there is great motivation working with floating wind. It is not everyone who honestly can say that they look forward to going to work every Monday morning, but for Idunn it looks like this is the case.

Research projects

Completed projects:

Project 1: OW: Low Cost Installation and Maintenance of Fixed Offshore Wind Structures
– *was completed in 2016*

Project 2: Subsea: Safe – All Year – Cost-efficient Subsea Operation
– *was completed in 2017*

Project 3: Simulation Technology and Virtual Prototyping as a Common Approach from Design to Operation – *was completed in 2017*

Project 4: Seabed Mining: Exploration of Technologies to Develop Seabed Mining as a New Business Area – *was completed in 2018*

Active projects in 2020:

Project 5: Innovative Installation of Offshore Wind Power Systems
Project 6: On-board Decision Tool
Project 7: Design for Workability
Project 8: Remote Operations/Dispersed Teams

Figure 1. Stern installation of OWT from a catamaran vessel

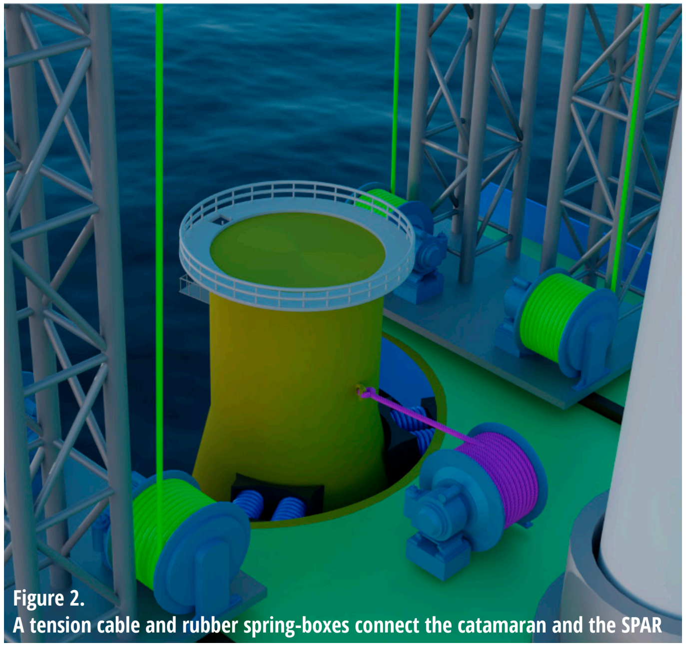


Figure 2.
A tension cable and rubber spring-boxes connect the catamaran and the SPAR

Figure 3. Alternative installation from midhsip

Project 5

Project Leader:
Karl H. Halse, NTNU Ålesund

Innovative Installation of Offshore Wind Power Systems

The installation costs of a typical offshore wind power plant, are a substantial part of the overall costs for the project (up to approx. 30 % of the total development costs). The Dogger Bank Wind Park Project is planning for several hundred offshore wind turbines to be installed in rather shallow water. Today, fixed Offshore Wind Turbines (OWT) are installed with the use of high lift cranes from jack-up platforms (or jack-up ships). This is a costly and time-consuming way of installing the turbines. During the summer of 2017, Statoil installed the world's first floating wind power park, known as Hywind Scotland. The installation was performed by assembling the parts in a sheltered Norwegian fjord, and the complete floating OWT was towed across the North Sea to its final destination outside Scotland. This is a time-consuming and costly operation, giving motivation to find a more cost-efficient way of installing floating offshore wind parks.

Offshore installation of floating OWT from a catamaran

The main challenge with the proposed concept is to reduce the relative motion between the OWT tower and the floating substructure (the SPAR buoy), see Figure 1.

During 2020, we have worked to improve the dynamic response of the concept and we have studied the operational limits.

- We have introduced a strong coupling between the floating SPAR buoy and the vessel to reduce the relative motion between these two. It consists of spring boxes with rubber friction in combination with a wire under tension to keep the connection tight, (Figure 2).
- We have established a possible crane structure design, which is modelled in FE and analysed to check for strength and flexibility of the structure during installation.
- As response criteria for the relative motion, we have adopted the criteria used for Hywind Demo; (maximum horizontal motion: +/- 20 cm and maximum vertical motion: +/- 10 cm).

Figur 4: Operational windows with stern installation (left) and midship installation (right).

- We have performed dynamic analyses with SIMA over a range of sea states, and based on the set of relative motion criteria, we have identified the limiting sea states for the offshore installation of the OWT.
- The pitch motion of the catamaran is one of the dominating factors to influence the relative motion between SPAR and OWT, and in order to overcome the effect of the pitch motion, we have proposed an alternative installation concept at the midship, (Figure 3).
- The preliminary conclusion from our initial operability analysis with the alternative concept, is that the Operational limits are significantly increased if we move the installation to the midship, (Figure 4). However, this may introduce new challenges (e.g. from static inclination or roll motion) which we have yet to explore, but the alternative installation concept is promising.

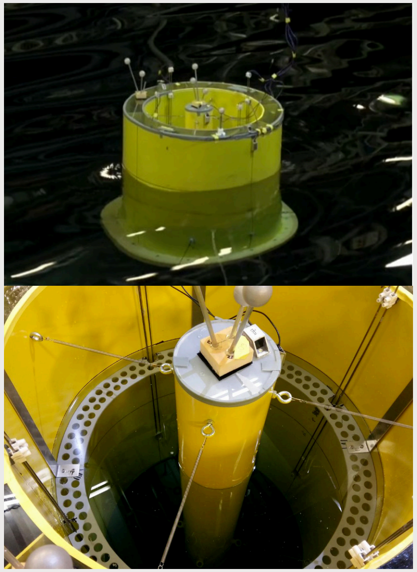
Installation of floating Offshore Wind Turbine from a floating dock (the work by PhD student Maël Moreau)

The potential code developed for the floating dock without spar was extended during 2020 to include the effects of solid and perforated annular baffles installed on the vertical walls inside the structure. Analytical and experimental results were compared, the presence of the baffle introducing a shift of the sloshing resonance to higher wave periods, and a reduction of the amplitudes of the dock's motions and free-surface elevation inside the dock. The solid baffle at small submergences damped the sloshing waves the most efficiently, reducing the resonant peak by more than 55 %. Baffles with a low perforation ratio τ=0.15 presented similar results (up to 50 % reduction) and could be a reasonable alternative to reduce the weight and cost of these damping devices.

Further work will focus on the relative motions of the spar and dock with baffle, studied with similar analytical methods, and in the light of limiting criteria for wind turbine installation provided by Equinor. Results will be compared to the model tests carried out in 2019, (Figure 5).

Forecasting of short-term wind and wave conditions for marine operation using machine learning methods (the work by associated PhD student Mengning Wu)

The associated PhD Mengning Wu has been working on forecasting of short-term wave conditions, in terms of significant wave height (Hs) and spectral peak period (Tp), using machine learning approaches and quantification of the forecasting error. In 2019, the time-series-based forecasting (TSBF) method was applied using the method of adaptive-network-based fuzzy inference system (ANFIS), which considers the past and current known values of a random parameter (for example Hs) as input and a model that is trained based on the historic hindcast data, to estimate the future values of the same parameter. In 2020, a physics-based machine learning (PBML) method using artificial neural network (ANN) was developed considering



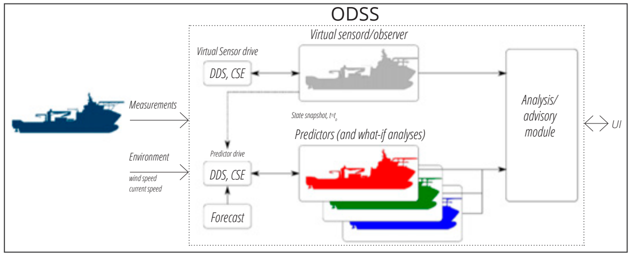
Figur 5: Floating dock with the spar of a Hywind wind turbine inside.

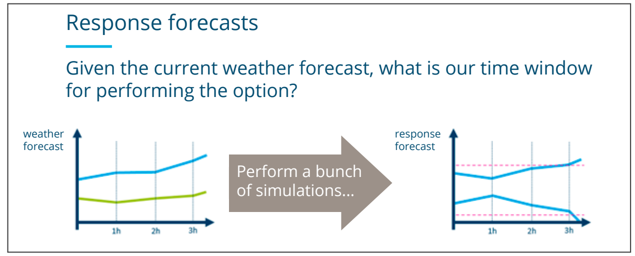
the mean wind speed and initial wave conditions as input and a model trained based on the same historic hindcast data, to estimate the future values of both Hs and Tp for wind sea and swell conditions. The ten-year (2001–2010) hindcast wind and wave data of every three hours for an offshore near the centre of North Sea were used with the first nine-year data for training and the last one-year data for validation. In general, the PBML method has a better performance than the TSBF method in terms of forecasting error and has an acceptable error for a forecasting horizon of 8 steps, effectively 24 hours.

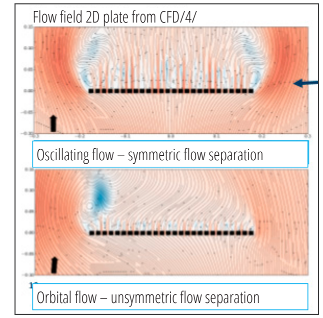
Project 6

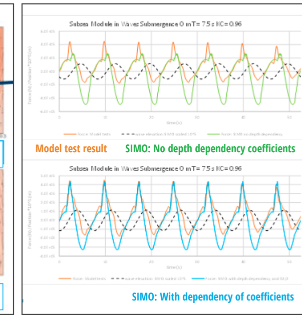
Project Leader:
Henning Borgen,
SINTEF Ålesund/SINTEF Ocean

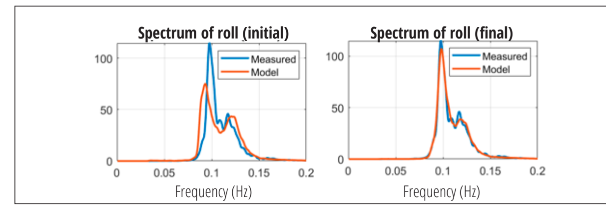
On-board Decision Tool











The On-Board decision tool (ODSS) project are developing technology on how to use operational data from ship sensors and combine these with physical based models to monitor and predict the response of vessels and their working tools (e.g. lifting equipment), and based on this information, give advice to the crew performing a marine operation on how to operate safely and efficiently. The technology developed will give an important contribution towards response-based decision making in marine operations.

In 2020 the project has continued the development of the flexible architecture for real-time onboard decision support software. There has been continuous development of the basic framework, and new functionalities are added.

This year's framework activities have focused on implementing a data storage system and an analytics module producing statistics based on the virtual sensors and predictors in the ODSS system. This year's case focused on a suction anchor in the splash zone part of a lift from the case vessel Olympic Challenger. Examples of possible results presented from the analytics module were demonstrated at the autumn conference.

In 2020, the important task of establishing a method for including vessel shielding effects on the lifted object was started. This will be an important feature to incorporate in numerical tools forming the basis of predictors to utilize the shielding the crane vessel will have on lifted objects. This year's activity has focused on investigating the suitability of several potential methods, resulting in a specification for implementation of the proposed method in 2021.

A key factor for the ship model tuning activity is the availability of wave sensor data from vessels in operation offshore. A survey of presently available technologies was therefore conducted in 2020, and radar-based methods were identified as the only available technology. Doppler radars providing synchronized (with the ship motion) time series containing information also on wave spreading are the desired sensor signal. This activity has, however, concluded that this is not available technology now, and the most promising solution for model tuning purposes is doppler radars providing wave spectra including wave spreading information.

The important ship model tuning activity continued in 2020. Based on the conclusion of the survey described above, the focus this year has been on how to utilize spectral wave information for ship model tuning purposes. Simulated data has been used, and wave measurement accuracy, resolution in frequency and direction, parameter sensitivity and error estimation have been considered in adapting the method to be based on spectral data. This work will continue in 2021, also including real sensor data from a wave radar mounted on the research vessel Gunnerus.

The activity on hydrodynamic coefficients continued in 2020, focusing on two topics. First, a series of tests studying the difference on resulting hydrodynamic coefficients in waves vs forced oscillations were analyzed. The tests show that vertical forces in waves are generally smaller than in forced oscillations, and that the difference is increasing for increasing amplitude and decreasing period. This may be due to the fact that waves create asymmetrical end vortices on plates, while forced oscillations create symmetrical vortices, and due to nonlinear free-surface effects.

The other investigated topic wrt hydrodynamic coefficients is the influence of typical module structure parts in the splash zone. Here we see that the mudmat will dominate the vertical force and shield the content until the hatch cover is wetted. Then the hatch cover will dominate the vertical force, but content and mudmat will affect the global forces during the crossing of the free surface and hence, the limiting sea state.

An additional activity was started in the ODSS project in the middle of 2020, a long term (rest of the SFI) investigation of splash zone hydrodynamics, and how this can be implemented in numerical methods. The most critical phase of marine operation occurs during splash zone crossing. Hydrodynamic forces are large, non-linear and strongly time dependent and hence defining the limiting sea-states for marine operations.

This year's activity has been creating a foundation and specification for the activities for the remainder of the SFI. Two main activities have been in focus: Collecting all work performed by SINTEF Ocean and NTNU on splash zone during SFI-MOVE up to 2020 and prior to SFI-MOVE, and the use of a Morison element model to estimate forces on conventionalized subsea structures in the wave zone. The latter activity showed that the importance of introducing depth dependency of the coefficients in the Morison element model is crucial to getting realistic slamming loads in the numerical model.

Project 7

Project Leader:
Martin Gutsch,
SINTEF Ocean/NTNU

Design for Workability

Background

Project 7, Design for workability, has provided knowledge for holistic ship design optimization. A numerical analysis tool has been developed that enables ship designers to select a combination of main dimensions and loading parameters optimizing operability of new ship designs for defined operational tasks and sea areas. A key aspect of this approach is the mission-dependent optimization of hull dimensions, including loading condition parameters, which aims for a design where natural periods of important responses such as pitch and roll are significantly different from dominating wave periods.

An earlier activity in SFI MOVE resulted in the development of a Vessel Response Tool (VRT, openly accessible on vrt.sintef.no) utilizing a large database of precalculated ship-motion characteristics (Response Amplitude Operator, RAO) consisting of 2835 parametrically varied hull sizes of a modern offshore vessel hull geometry. For vessel design benchmarking and decision-making, e.g., during a vessel selection process or for seakeeping optimization in an early ship design stage, the Operability Robustness Index (ORI)[1] was developed and shall be used along with the percentage operability for benchmarking vessel response performance in waves. A journal paper was published in 2020 providing a detailed description of the ORI and its advantages for vessel design benchmarking.

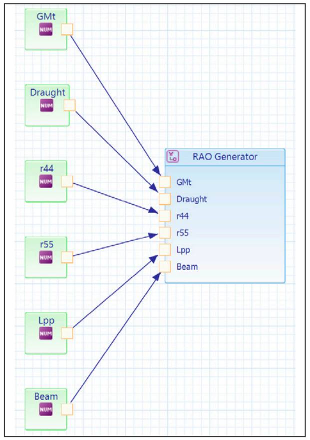


Figure 1: RAO Generator showing vessel parameters for design variation.

Based on the feedback of participating ship designers, in 2020, the VRT was integrated into a workbench allowing vessel optimization of an individual vessel design. The usability was further developed, and a prototype was presented during the SFI autumn conference.

The ability to analyze a variety of loading-condition parameters can be used for the adaptation of the vessel response model within the ODSS (in Project 6). Therefore, and due to the small size of this project, it has been decided to continue this project in 2021 as a task within Project 6.

Work activities 2020

For the VRT, a newly developed version of ShipX, built on the SIMA Workbench, was utilized as a basis for the development of a workflow which shall be usable in a simple, quick fashion.

RAO Generator

In a first stage, an RAO Generator workflow was created where a range of vessel parameters of a given input geometry can be specified (see Figure 1). So far, it is possible to vary metacentric height (GMt), draught, radius of gyration of roll and pitch. The manipulation of the geometry itself will be added at a later stage. For the calculation of the RAOs, the existing 2D Strip Theory VERES plugin is used. As an input from the KPN project Improving Performance in Real Seas (IPIRiS), a 3D potential theory tool will be made available next year, as a more accurate alternative.

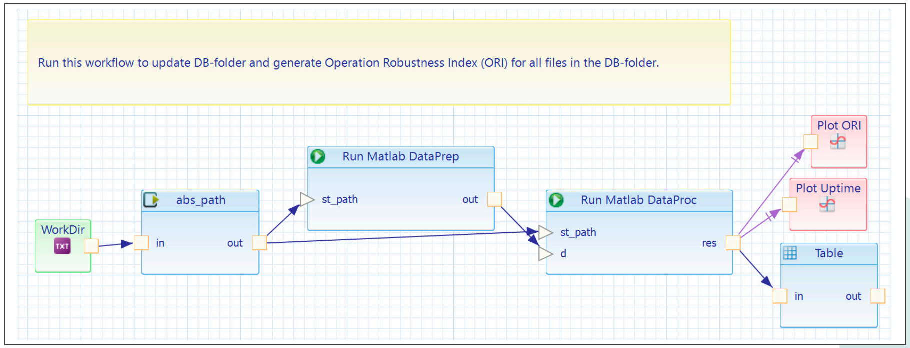


Figure 2: Postprocessor workflow for the calculation of the ORI and percentage operability (uptime).

Vessel Response Analysis

In a second stage, a postprocessor was created to assess vessel capabilities based on selected input, providing the operation scenario and limitation criteria. The postprocessor includes two calculation steps: the data preparation and the actual operability processing tool (see Figure 2).

The operability processing requires several inputs generated from the workspace (see Figure 3). Experience shows that the correct choice of environmental conditions from the operational target area is specifically important for the assessment of the vessel performance. To account for this, the workflow provides a set of wave scatter diagrams from selected sea areas and seasons. Figure 4 shows an example of the generated results for the variation in metacentric height.

Further development

The existing workflow will be further developed with the possibility to:

- Utilize a 3D RAO solver as an alternative to VERES.
- Vary hull length and beam.
- Present the ORI as a function of varying multiple input parameters.

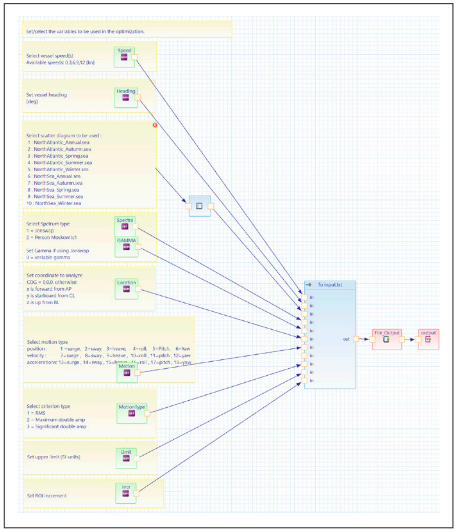


Figure 3: Preliminary input generator for operability postprocessor.

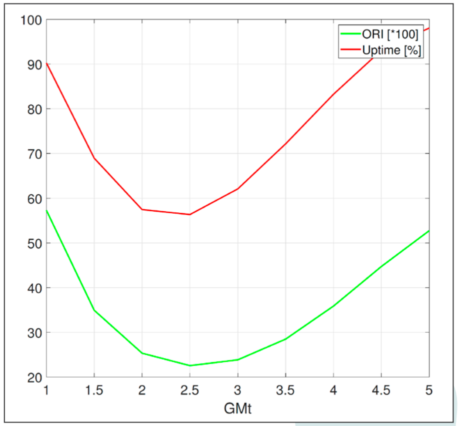


Figure 4: Example of ORI and percentage operability variation when varying the metacentric height.

[1] Gutsch, M., Steen, S., Sprenger, F. (2020). Operability robustness index as seakeeping performance criterion for offshore vessels. Ocean Engineering, 217, 107931.

Project 8

Project Leader:
Frøy Birte Bjørneseth/
Marie Haugli Larsen
NTNU Ålesund


Photo: Kongsberg Maritime

Remote Operations/ Dispersed Teams

The nature of maritime operations is changing, and we are facing a wave of digitalization in the industry. To investigate the future of demanding marine operations, the personnel working on this project are doing research into how use of digital twin technology can enable collaboration between shore and vessel, maritime cyber security, and how dispersed teams and digital transitions can optimize workflow and organizational change. In 2020 the project has continued the research within the HTO-framework (Human-Technology-Organization):

Human

Risk perception is an important factor in understanding the reaction of maritime personnel to cyber risks. Preliminary results from our qualitative study by PhD candidate Marie H. Larsen suggest that a lack of organizational framework, a feeling of secure distance and an unperceptiveness of cyber risks toward operational technology may be important factors to consider when assessing cyber risks in remote operations. This work will be integrated with an experimental study of situational awareness in the remote control center and will coincide with research within the technology dimension.

Technology

The sensor technology onboard Gunnerus has been developed further with crane sensors and live data streaming to the digital crane simulator. This was demonstrated with a video of Gunnerus and the digital twin at the autumn 2020 conference.

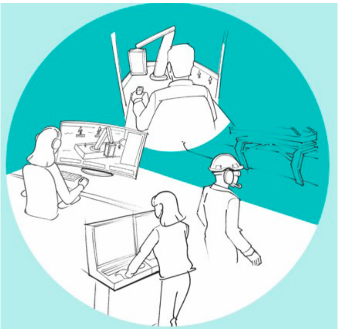
Based on insight work done in collaboration with industry partners, the proof of concept of the remote control center has matured. Results show that we should aim for development of a common tool to be used in all phases of a maritime operation. This can enable involvement of both operational and theoretical competences in distributed teams. Parts of these results were presented at the workshop at the autumn 2020 conference and will be the foundation for simulator experiments conducted in 2021/2022.

Organization

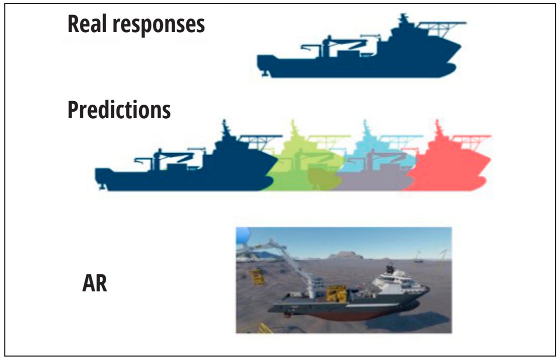
Digital transition in the maritime industry is creating new organizational models, and affect the relationship between ship, shipowner, and third-party suppliers. PhD candidate Bjarne Pareliussen presented a paper about how servitization and remote monitoring are changing the ship engineer's profession at the Nordic Working Life Conference 2020. This work will continue in collaboration with industry partners in 2021.

A paper published by Viktoriia Koilo (2020) explores new green solutions for shipping the Norwegian maritime industry has developed in recent years. The introduction of autonomous ships will help reduce accidents and the risk of oil spills. Simultaneously, it will trigger the development of new environmentally friendly vessel types that reduce the cost of transporting goods by sea. The idea is to optimize operations, from planning to execution, by better understanding the response. This is a simulation-oriented approach where models are re-used throughout the value chain. Our project aims to support the entire marine operation value chain by developing knowledge, compute tools, and methods that will be implemented in a simulator environment to pretest marine remote operations, including the human component. This work will continue with a study of how the optimization of marine remote operations can contribute to the development of new business models.

Digital twin of Gunnerus.



Cooperation during remote operations, and support from a common digital tool.



Digital twin technology.

An open simulation platform

Today, simulations are widely used in all stages in the life cycle of a vessel. However, the potential of simulations is not fully utilised as the initial cost of establishing simulation models is considerable, and re-use of models is limited. Based on a standard developed by the automotive industry we aim to establish a standard also in the maritime industry, enabling re-use of models and collaborative system simulations.

Partners in SFI MOVE, DNV GL, Kongsberg Maritime, SINTEF Ocean and NTNU, have agreed to act on this challenge together. 20 key industrial stakeholders have joined the project and the work defining a standard enabling exchange of simulation models – reducing cost and complexity related to simulations.

Through a 2-year joint industry project the Open Simulation Platform[1] is launched. A platform for co-simulation of maritime equipment, systems and entire ships. The Open Simulation Platform is a foundation for collaborative sharing of simulation models and an open industry platform for creating digital twins of products, systems and complete vessels.

The Open Simulation Platform provides the maritime industry with key tools and working processes for technical systems engineering, enabling efficient and effective construction and maintenance of digital twins for system integration, testing and verification. Building on the Functional Mockup Unit (FMU) standard, the key principles are to:

- Enable the re-use of simulation models and digital twin equipment across organizations without exposing sensitive IP by protecting models and control system software inside black-box executables.
- To establish a standard for connecting models and control systems from any simulation tool or programming language in one, large co-simulation to enable virtual system integration.
- To enable cross-organization cooperation and platform interoperability by transparency and open-source principles.

[1] https://opensimulationplatform.com/

Research cooperation

Text: Hans Petter Hildre

Ocean Space Centre – Fjord Lab Ålesund

Planning of the Ocean Space Centre has been in progress since 2008, with broad support from authorities and business life. The government has decided to continue the work of realising the Ocean Space Centre at NTNU and SINTEF. Social policy goals are to ensure value creation through competitive Norwegian maritime industries. Quality assurance confirms that the initiative is socio-economically profitable, and the project is now entering a new phase.

A new addition to the Ocean Space Centre is full-scale laboratories in the ocean space (Fjord-Lab). The Fjord Lab will have «hubs» in Trondheim, Hitra/Frøya and Ålesund. This provides unique possibilities for testing new technology right from the drawing board to completed design in the Ocean Space Centre.

The Fjord-Lab in Ålesund is an arena for the full-scale testing, design and innovation within:

- maritime technologies and operations;
- near shore navigation and ship traffic control technology and methods;
- the impact of the ocean on infrastructure along the coast;
- environmental near shore ocean observation technology and methods.

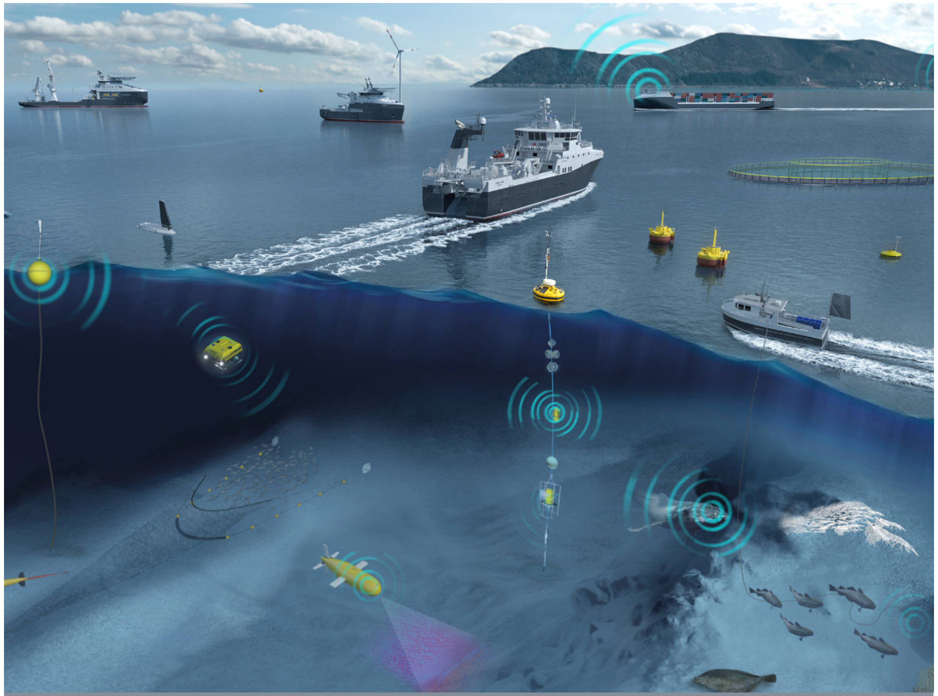


Illustration of Fjordlab Ålesund.

The laboratory for testing ships, ship equipment, fishery equipment, fish farms, wave energy and test facilities for technology for monitoring the ocean, coastal traffic and vulnerable coastal infrastructure.

Research with the objective of supporting business development is in other words an important goal for this infrastructure. At the same time, we will develop digital twins and record data over time and make these available to researchers within the ocean space.

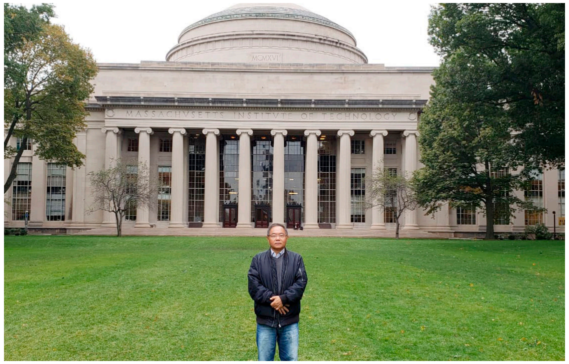
The Fjord-Lab Ålesund is in a unique marine area between Runde and Godøya and into Storfjorden including the World Heritage site Geirangerfjord. The area is in many ways a diverse miniature of the enormous ocean space Norway has control over, including exposed and more sheltered areas. The area is approved for testing of autonomous ships, as an arena for testing of energy from waves and currents, as an area for testing of fishery equipment at the seabed and has, as the only place in Norway, seabed maps with an accuracy of 1 × 1 metre.

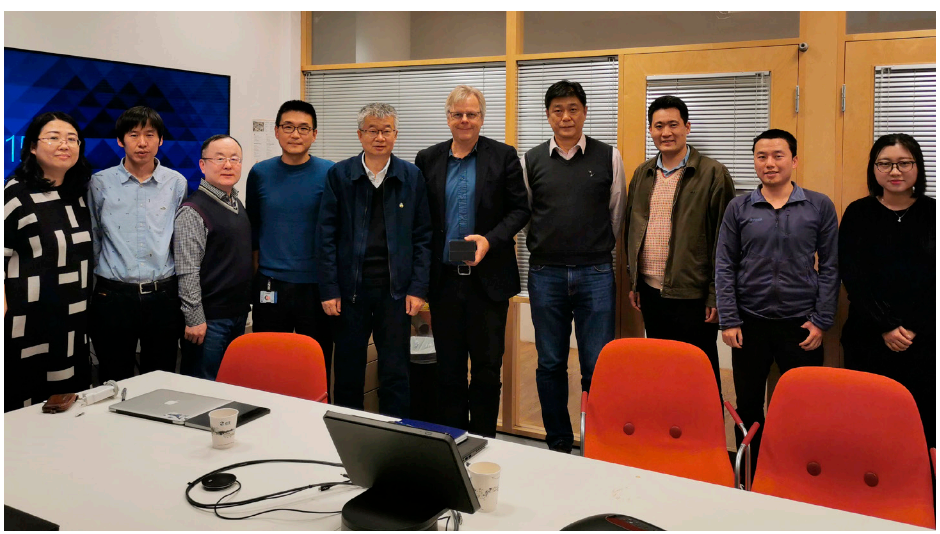
The area is thus an ideal test arena and innovation for technology in the ocean space. It is home to fisheries and to important spawning areas for herring, haddock and cod. The area is a focal point for shipping traffic, including the approach of large cruise ships to the fjords. The Norwegian Coastal Administration (Kystverket) is developing full radar coverage for monitoring the area.

We see that this comprehensive instrumentation of one of nature's very exciting areas creates enthusiasm and inspiration for both businesses and researchers to make use of the area as a large R & D laboratory.

International cooperation

Text: Henrique M. Gaspar/ Houxiang Zhang





University of São Paulo (USP – Brazil)

2020 was an atypical year for international collaboration: since March 2020 travel has not been recommended due to the pandemic. Despite this, the partners managed to keep the momentum that was established in the previous years, and plenty of good research is being done. As an example, PhD candidate Ícaro Fonseca (NTNU) did a 3-month research stay at the University of São Paulo (USP – Brazil) from Nov 19 until Feb 2020. His research developed an online digital twin platform for scale model experiments (https://shiplab.github.io/dt_cv/basin_demo.html), and the paper has just been submitted to a level 2 journal. Ícaro's research managed to connect diverse common interests between NTNU (via Assoc. Prof. Henrique Gaspar) and USP (via Prof. Kazuo Nishimoto and Prof. Eduardo Tanuri). Currently two MSc students are engaged in this project, one from each institution, as well as two Brazilian post-docs.

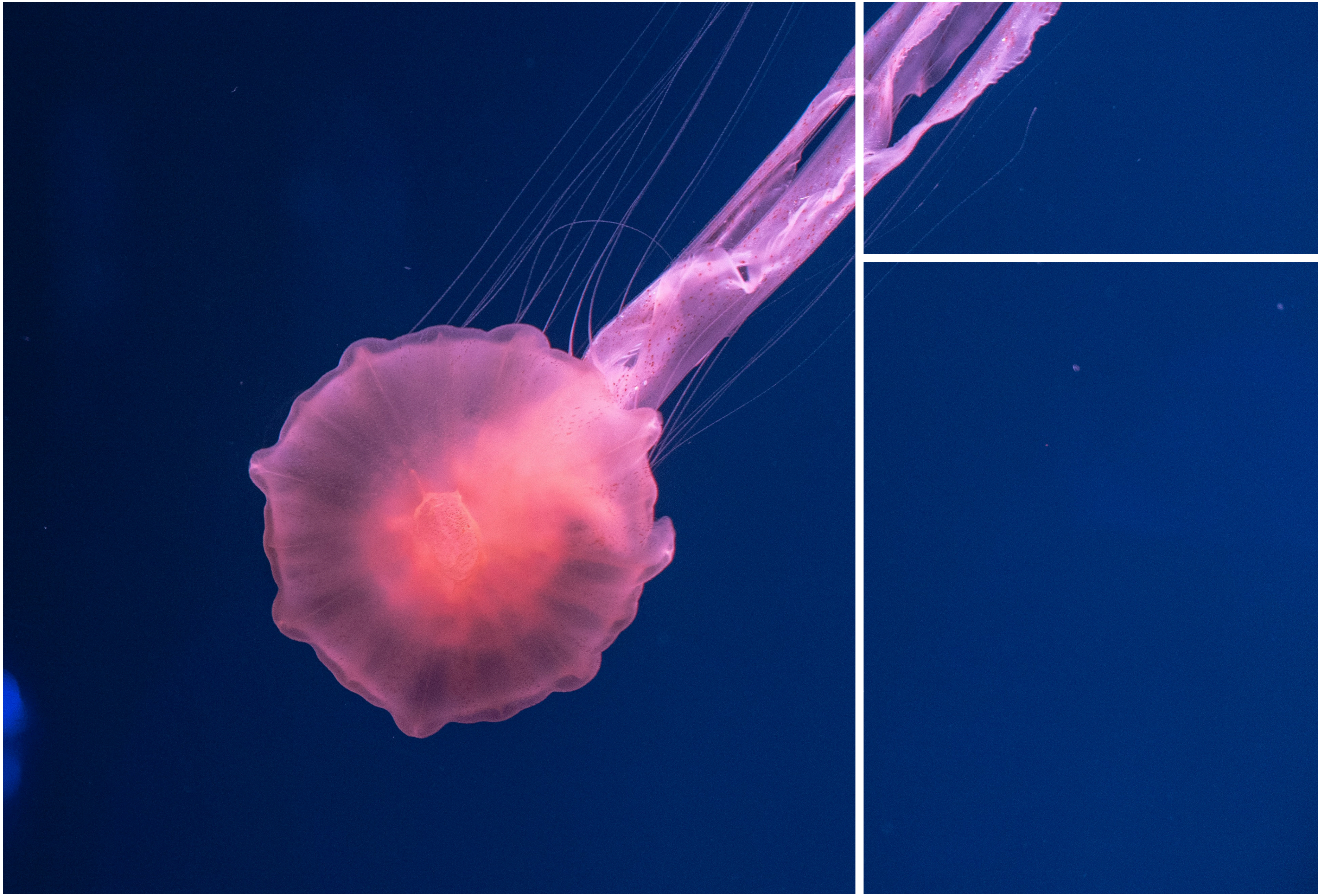
On the Brazilian side, post-doc Daniel P. Vieira (USP) did a research stay at NTNU in 2019, combining with a short stay at MIT afterwards. The paper on Salt-Cave simulation, collaboration between NTNU, USP and MIT is currently under review.

The connection between SFI-MOVE and Intpart Subsea continues to be strong, as the last project was renewed for three more years, and more exchange is expected between the institutions as soon as the travel ban is lifted.

Harbin University (China)

Prof. Guihua Xia, the Vice President of Harbin Engineering University (HRBEU), together with several professors, visited NTNU Trondheim campus and Aalesund campus.

In Aalesund, IHB team introduced our research activity on SFI MOVE project. Harbin engineering University presented their research on maritime applications. Both groups find NTNU and HRBEN have common research interests on demanding operations and marine digitalization. The discussion is general, open and transparent.



Recruitment

Due to late start of the SFI MOVE we had a minor delay in hiring PhD students from the start. We are very pleased with the number and quality of applications, but would like to see that there were more women among them.

PhD candidates and Postdocs					
PhD candidates with funding from SFI MOVE					
Name	Start	End	Project	Nationality	Gender M/F
Martin Friedwart Gutsch	2015	2020	Vessel performance	German	M
Fredrik Mentzoni	2015	2019	Numerical models and tools	Norwegian	M
Zhengru Ren	2016	2018	On-board systems	Chinese	M
Amrit Shankar Verma	2016	2019	Numerical models and tools	Indian	M
Robert Skulstad	2016	2020	Integrated simulator environment	Norwegian	M
Maël Moreau	2017	2020	Numerical models and tools	French	M
Jiafeng Xu	2015	2018	Integrated simulator environment	Chinese	M
Xu Han	2018	2021	On-board systems	Chinese	M
Behfar Ataei	2019	2022	Integrated simulator environment	Iranian	M
Marie Haugli Larsen	2019	2023	Integrated simulator environment	Norwegian	F
Gowtham Radhakrishnan	2019	2022	Numerical models and tools	Indian	M
Sunghun Hong	2020	2023	Integrated simulator environment	South Korea	M
PhD candidates with funding from other sources					
Tor Huse Knudsen	2014	2018	Numerical models and tools	Norwegian	M
Svenn Are T. Værnø	2014	2017	Numerical models and tools	Norwegian	M
Senthuran Ravinthrakumar	2016	2019	Numerical models and tools	Norwegian	M
Øyvind Rabliås	2017	2021	Numerical models and tools	Norwegian	M
Tore Relling	2017	2020	Integrated simulator environment	Norwegian	M
Rami Zghyer	2017	2021	Integrated simulator environment	Jordanian	M
Raheleh Kari	2018	2021	Integrated simulator environment	Iranian	F
Bjarne Pareliussen	2019	2022	Integrated simulator environment	Norwegian	M
Postdocs with funding from SFI MOVE					
Mia Abrahamsen-Prsic	2016	2019	Subsea: Safe All Year	Croatian	F
Zhiyu Jiang	2016	2018	Offshore Wind: Innovative Inst.	Chinese	M
Mats Jørgen Thorsen	2016	2018	Mining	Norwegian	M
Niranjan Reddy Challabotla	2016	2018	Mining	Indian	M
Zhengru Ren	2019	2021	On-board systems	Chinese	M
Ting Liu	2020	2021	Integrated simulator environment	Chinese	F

Martin Gutsch

Photo: Thor Nielsen

Title

Performance Indicators for vessels performing challenging marine operations.

Research topics

The ongoing exploration of the maritime environment and the effort to use the sea as a source of energy in the context of increasing financial constraints leads to increasing global demands for more economical and weather independent services within marine operations. Although, ships and on-board equipment are designed to operate in harsh environmental conditions, the current practice is often to terminate an operation when a rigid and often conservative weather limitation is reached, usually specified in terms of the significant wave height as the exclusive criterion. Since the offshore industry is aiming for all year-round safe operations, a strong interest among ship designers, owners, and operators arises for operation-based design optimization and for task specific criteria aiming the full exploitation of the vessel-specific operational performance.

The main objective of the PhD work is to address the question what makes an offshore vessel perform better, especially in harsh environmental conditions. The identification of rational performance criteria for vessels fulfilling selected operational tasks shall provide knowledge for a better understanding of factors contributing to a successfully completed offshore work task and shall deliver tools to estimate ship specific operational limitations usable for a vessel selection and design optimization process.

Industrial goals

The use of rational performance criteria shall provide a methodology and tools to evaluate operational performance using vessel- and task specific limitations beyond a general H_S-limit. This addresses a primary concern of the offshore industry to increase operability and approach the objective of safe all year-round operations. The work shall provide strategies for the application of performance measures in order to support the vessel design process, the assessment of vessel performance in operations, and the selection of the suitable vessel for a specific task.

Scientific questions

- What is a good offshore vessel and why are some vessel performing better than others?
- What are vessel specific factors contributing to operational performance?
- What are performance indices to measure and quantify vessel specific operational potential?
- How can newly established performance indices be validated?

Innovations

The knowledge of operational performance criteria shall provide

- Guidance for vessel design with increased operability, cost-efficiency, and safety.
- Knowledge for the performance assessment of a vessel design in relation to a specific operational task and environmental condition aiming the selection of the most suitable vessel for a predefined task.
- Tools to identify task specific weaknesses for a given ship design and/or the planning of an operation providing guidance for improvements (e.g. the Vessel Response Tool accessible on vrt.sintef.no).
- Information for further development of on-board support systems.

Cooperating companies

Ocean Installer
Equinor

Supervisor: Sverre Steen
Co-supervisors: Florian Sprenger, Trygve Kristiansen

Robert Skulstad

Photo: Kristin Støylen

Title
Data based ship motion prediction in offshore operations

Research topics
- Ship motion prediction
- Time series prediction models and input selection

Industrial goals
- Decision support/controller feedback for autonomous vessels
- Fault detection

Scientific questions
- How can data from sensors on ships be combine to provide long-term prediction of ship motion?

Innovations
- Methods for long-term ship motion prediction leading to improved guidance and navigation of vessels and increased safety at sea

Cooperating company
OSC AS

Supervisor: Houxiang Zhang (IHB, NTNU)
Co-supervisors: Thor I. Fossen (ITK, NTNU) and Bjørnar Vik (Kongsberg)

Mäel Moreau

Photo: Thor Nielsen

Title

Hydrodynamic study of roll motion of offshore vessels in operation.

Research topics

The roll damping is crucial for the vessel performance. Since the damping is dominated by viscous loads due to flow separation from bilge keels or other appendages, state-of-the art industry codes based on potential flow theory cannot predict this, and rely on empirical methods. Empirical methods have been developed for conventional type of hulls with bilge keels for several decades, and good empirical methods (e.g. Ikeda 1976 to 1978) exist. 2D roll damping coefficients for mid-ship sections are found (in still water), and applied in a strip-wise manner along the ship. However, for other variations of the hull form than the conventional, Ikeda's formulas are not applicable. This applies particularly to novel designs of vessels used in offshore operations that deviate strongly from conventional hull.

Further, how to apply the formulas (roll damping coefficients) in a stochastic sea is not well-established, even for conventional hulls.

A main research task will be to design a method to predict roll damping (coefficients) for non-standard hull types, while another will be to investigate the applicability of the (still water) hydrodynamic coefficients when the ship is freely floating in waves. A 2D type of study will be conducted, including experiments and numerical work.

Industrial goals

- Provide a better understanding of the physics, and reliable estimations of the roll motion of offshore ships in operation
- Provide a better prediction of the roll response to irregular waves in view of defining an appropriate weather window

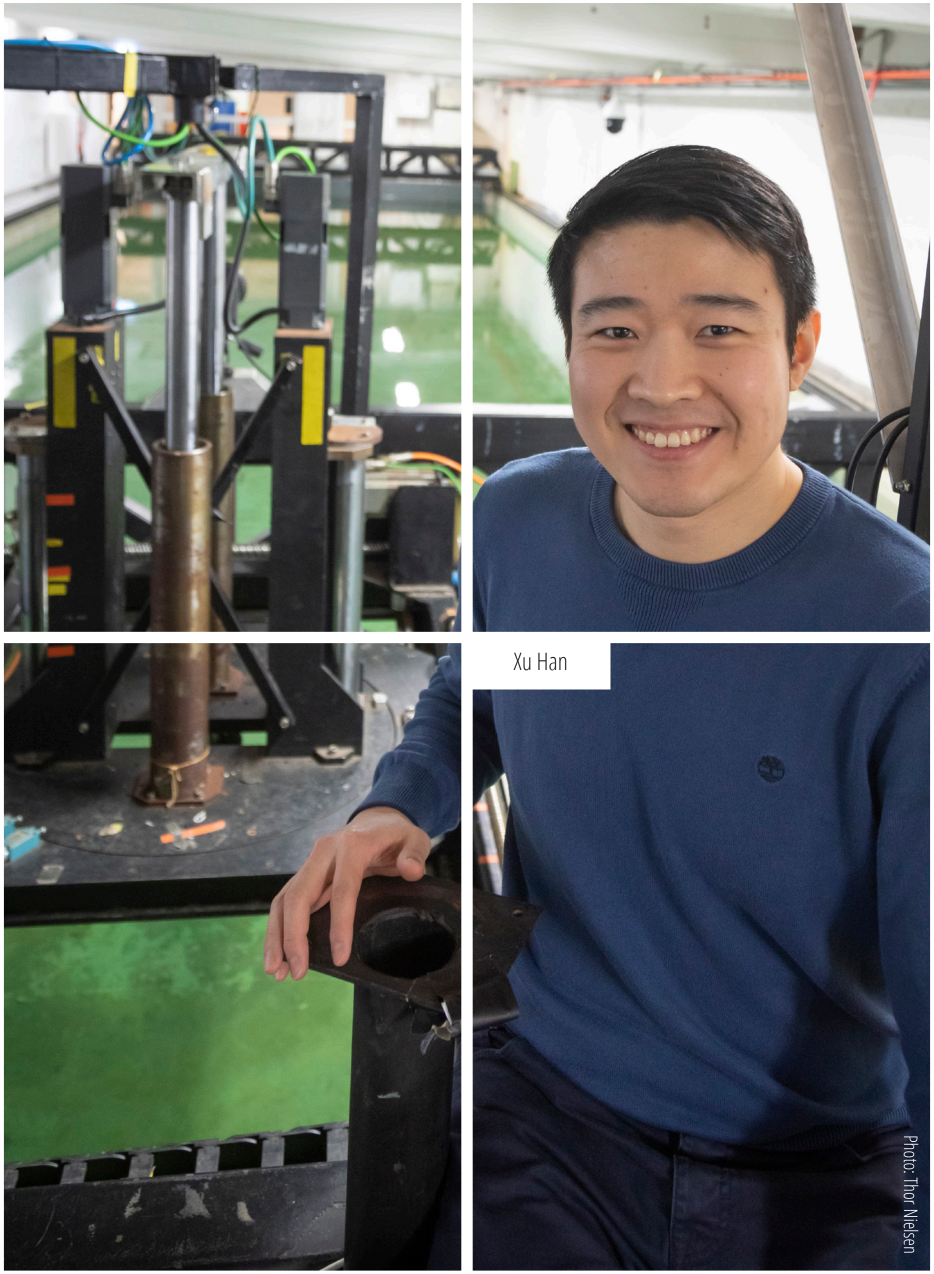
Scientific questions

- How to predict the roll damping accurately for unconventional hulls
- How to extend the equation of motion in still water to irregular sea states

Innovations

Propose a method of estimating the hydrodynamic coefficients that is adapted for the study of the roll motion of offshore vessels.

Supervisor: Trygve Kristiansen
Co-supervisor: Babak Ommani



Xu Han

Photo: Thor Nielsen

Title
Vessel Motion Prediction Based on Adaptive Numerical Model with Measurement Data

Research topics
- Modification of numerical model based on real-time onboard measurements and weather information
- Short-term and long-term vessel motion prediction
- Reliability of approach utilizing response-based operational criteria approach for marine operations

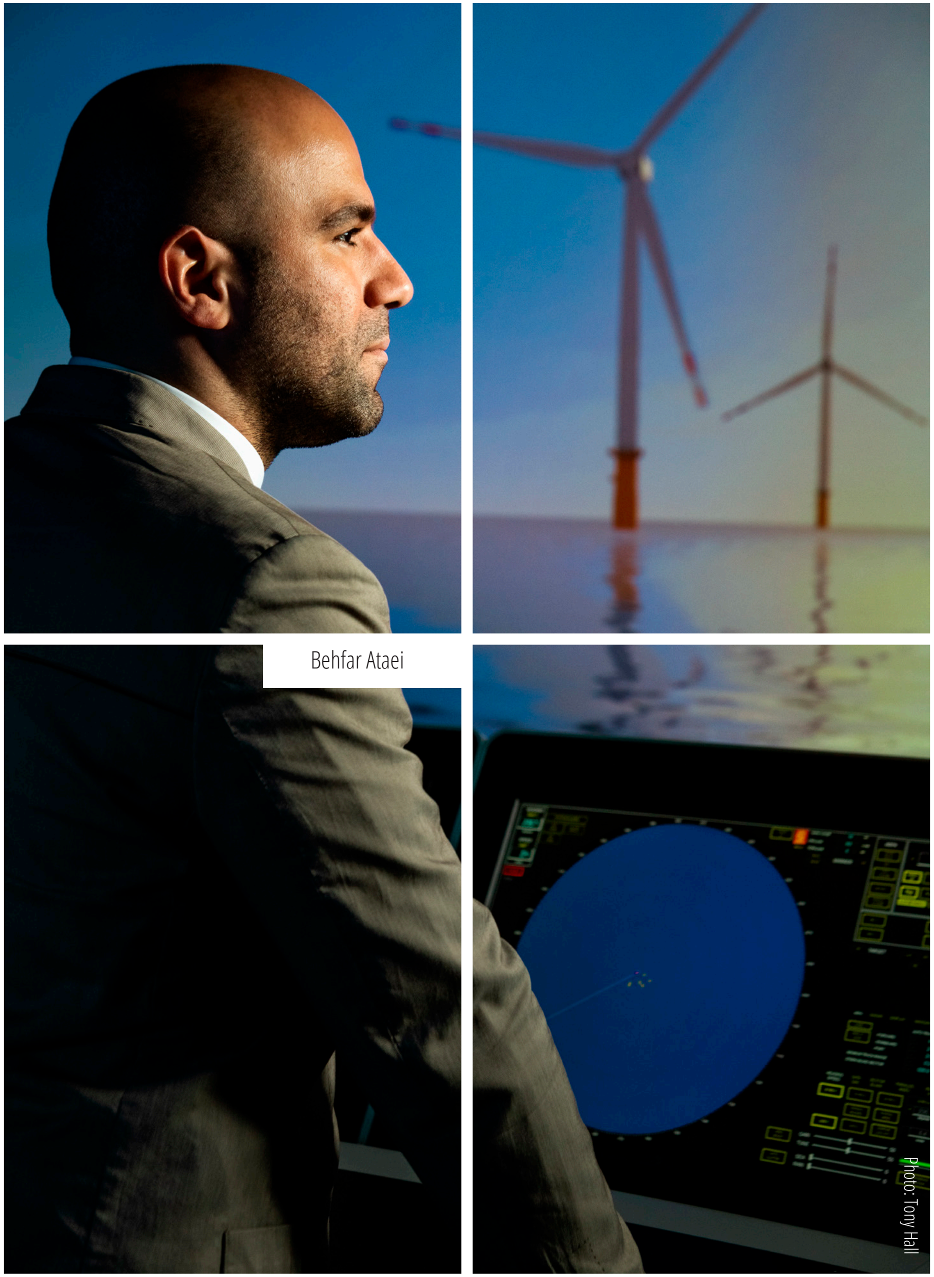
Industrial goals
- More accurate response-based approach for marine operations, to improve safety and operational limit
- Robust onboard decision support system for marine operations

Scientific questions
How to modify model based on measurements, considering uncertainties and frequently shifted operating phases

Innovations
Methods for vessel motion prediction leading to improved safety and operability for marine operations

Cooperating company
SINTEF, Ocean Installer

Supervisor: Bernt Johan Leira (NTNU)
Co-supervisors: Svein Sævik (NTNU), Lars Tandle Kyllingstad (SINTEF), Stian Skjong (SINTEF)



Behfar Ataei

Photo: Tony Hall

Title
Virtual Prototyping of Installation of Offshore Power Systems

Short project description
The industries, houses, and transportation equipment are producing extensive amounts of emissions, therefore, they are threatening the living species by polluting the planet. To reduce emissions and protect the environment, it is required to utilize cleaner sources of energy such as wind. Wind turbines are designed to convert wind energy into electricity and can be located onshore and offshore. The wind velocity is higher and more stable at the sea and it increases the production potential of Offshore Wind Turbines (OWTs) while project costs are considerably higher than the inland structures.

Installation of offshore wind turbines is a challenging operation and that is mainly due to complexities in the environment such as waves, winds, and currents. Besides, there are multiple structures involved in these operations such as OWT assembly, lifting vessel, floating spar, etc. (depending on the installation arrangement). The response of each of these structures to the environment and interaction between them is cumbersome which increases the complexities in the operation. In the current research, the main focus will be on understanding the underlying physics and the way the competitive advantage of this technology can be increased.

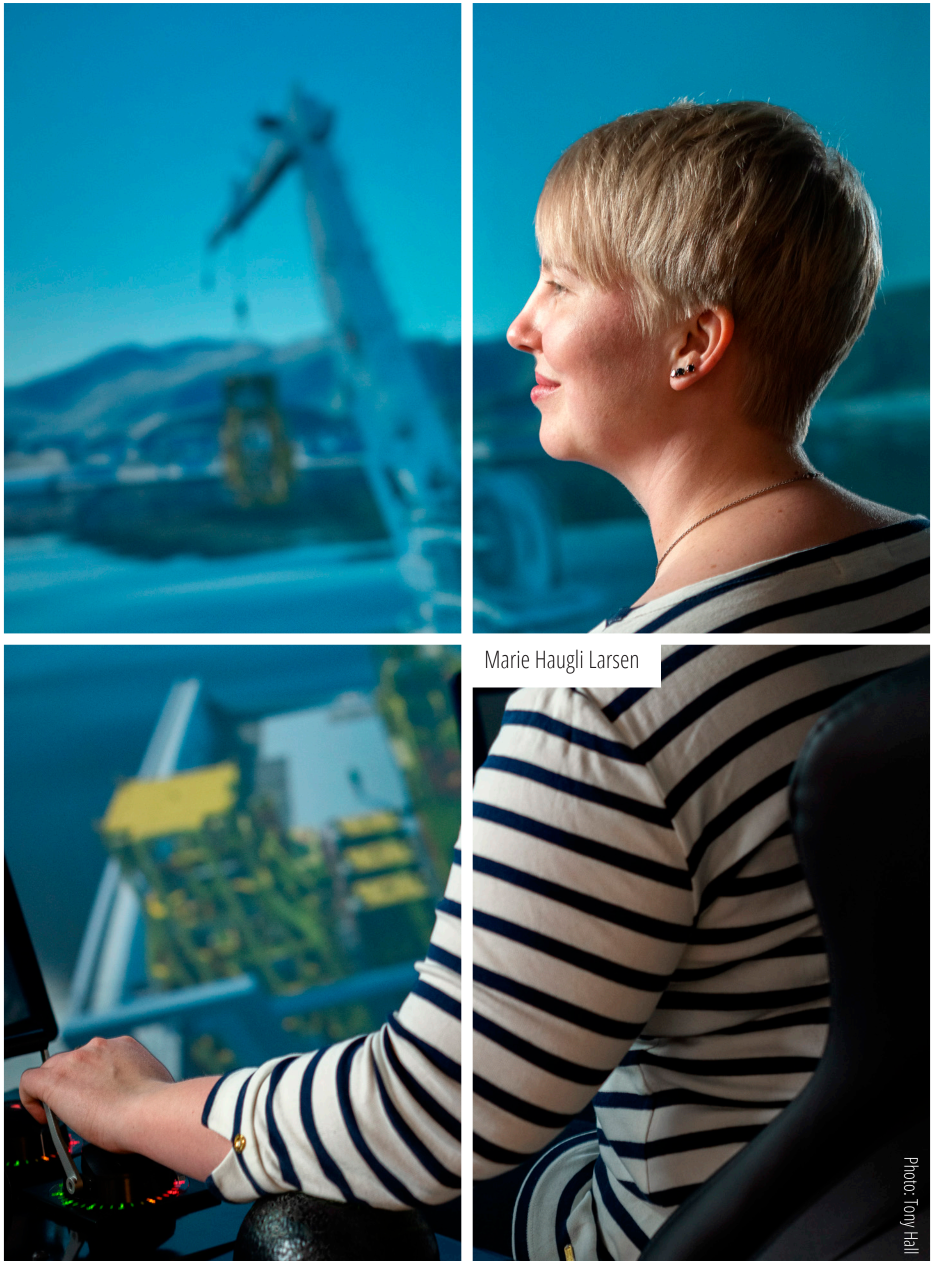
Industrial goals
1. Knowledge transfer from offshore oil and gas industry and implement in OWT installations.
2. Development of innovative concepts for OWT installation operation to increase efficiency.
3. Development of a unified virtual prototyping environment following Functional Mock-up Interface standard.

Scientific questions
1. What are the main physical phenomena governing OWT installations?
2. How these phenomena can be defined numerically that is possible to integrate into different simulation environments?

Innovations
Conventional installation methods in this field are not efficient and there is a demand for innovative installation concepts. The development of a unified simulation environment increases the flexibility of the operation while reduces error.

Cooperating company
Technip FMC

Supervisor: Karl Henning Halse
Co-supervisor: Zhengru Ren



Marie Haugli Larsen

Photo: Tony Hall

Title

Perception of cyber risks in offshore operations.

Short project description

In today's maritime operations there is an increasing reliance on digitalization, integration, automation and networked-based systems. The increase of technology and connectivity makes operations at sea vulnerable to cyber-attacks.

Risk perception plays a vital role in identifying cyber risks and achieving risk awareness. Research into this side of cyber security in the maritime domain is limited, but it can be valuable to identify and understand seafarers' cyber risk perception. By understanding cyber risk perception, we can create targeted education, develop policy to improve behavioral compliance, and design technical solutions more effectively. This study will therefore focus on achieving in-depth understanding of cyber risk perception in the maritime domain.

Industrial goals

Achieve better understanding of deck officers cyber risk perception, in order to give the maritime industry recommendations on cyber policies, operational cyber training and the development of dispersed bridge crew.

Scientific questions

1. How can perception of maritime cyber risks be understood in the context of offshore operations?
2. How does the deck officer perceive cyber risks in offshore operations?
3. In what way can knowledge about deck officer's perception of cyber risks contribute to the development of dispersed bridge crews?

Innovations

A new model of cyber risk perception in offshore operations, and recommendations for how this can be used in the development of training programs, policies and dispersed bridge crews.

Main supervisor: Frøy Birte Bjørneseth
Co-supervisors: Runar Ostnes, Sokratis Katsikas, Mass Soldal Lund

Gowtham Radhakrishnan

Photo: Thor Nielsen

Title
Onboard decision support systems based on mathematical and data-driven models for predicting vessel response during marine operations in realistic conditions.

Research topics
- Pursuing integration of realistic metocean conditions (corrected forecasts/observations) to mathematical models for predicting the operational behaviour of vessels in real environment, both in short range and long range.
- Achieving optimal real time response evaluation through blending vessel's sensor measurements into models.
- Using state-of-the-art data-based algorithms for estimating vessel's futuristic response from historical data.

Industrial goals
- Rapid and dependable predictive simulations on board for studying vessel's operational characteristics both in real time and in future.
- Identification of critical situation beforehand for certain acute operations.
- Deducing essential intelligence from the support systems for making pivotal and flexible decisions.

Scientific questions
- Quantification of uncertainties inherent in weather forecasts using probabilitistic & oceanographic methods; Application of satellite and insitu observations for yielding reliable environmental forecasts.
- Utilisation of cloud based data storage, data transfer & computing.

Innovations
- Employment of cutting edge machine learning, deep learning, bigdata, IoT & cloud architectures in vessel response prediction.

Supervisor: Bernt Johan Leira (NTNU)
Co-supervisors: Svein Sævik (NTNU), Zhen Gao (NTNU)

Sunghun Hong

Photo: Tony Hall

Title
Global dynamic analysis of on-site offshore installation of floating offshore wind turbines.

Research topics
With increasing global demand for clean energy resources, floating offshore wind energy has been considered one of the main alternatives to fossil-based resources. Towing assembled wind turbine and floating foundation units from the quay to the operation site is currently the primary installation method for floating offshore wind turbines. 'On-site offshore installation' was proposed as an alternative method for geographical challenges that required deep water depth. The main goal of the PhD program is the global dynamic analysis of offshore installation of floating offshore wind turbines with the specific scopes as follows:

- Numerical modelling and global dynamic analysis of the multibody system (floating installation vessel, lifted offshore wind turbine, and floating foundation) during the offshore heavy lifting operation.
- Development of coupling methods to mitigate the relative motion between the lifted wind turbine and the floating foundation for mating preparation.
- Suggesting limiting criteria and guidelines for estimating the operable weather window.

Industrial goals
- Reduce the cost of installing floating offshore wind turbines using new methods.
- Increase operational efficiency by establishing appropriate limiting criteria and guidelines for the weather window estimation.

Scientific questions
- What are the critical responses in the on-site offshore installation of floating offshore wind turbines?
- What are the mitigation measures to reduce the global dynamic responses of the multibody system?
- What are the thresholds and limiting criteria for weather window estimates for floating offshore wind turbines installation?

Innovations
- Methods for the on-site offshore installation of floating offshore wind turbines.

Supervisor:
Karl Henning Halse

Co-supervisor:
Torodd Skjerve Nord

Mia Abrahamsen Prsic

Photo: Thor Nielsen

Title
Hydrodynamic loads on submerged complex structures under the influence of waves and currents.

Research topics
The main goal of the postdoctoral research is to provide deeper understanding of the hydrodynamic forces exerted on the subsea modules during the structures' deployment. Due to the complexity of the structures, it is generally too demanding to model the realistic subsea modules, either experimentally or numerically. However, it is possible to represent the dominant parts of the structures by selected generalised elements, such as porous plates and cylindrical structures representing simplified module cross-sections.

Such elements are systematically examined, in different combinations, increasing the complexity, to explore the governing physical effects relevant for the hydrodynamic loads. Modelling is performed for the generalised structures subjected to the forced oscillations, representing the waves exerted on the fully submerged subsea modules.

The experimental results offer a systematic overview over the hydrodynamic coefficients for the various basic elements and their combinations, and are performed for a broad span of sea states that a real subsea module can experience.

CFD simulations complement the experiments by providing an insight in the details of the flow around the structures and the interactions in the flow field. Numerically simplified CFD models allow quick and efficient calculations of more complex structure combinations, and can thus be recommended for the practical, industrial use. They are compared to the detailed, three-dimensional turbulence CFD models to understand the limitations and advantages of various simplified approaches.

Industrial goals
Increasingly complex marine operations require safe and robust planning and all-year accessibility, relying on accurate calculations of the hydrodynamic loads. The goal of our project is to contribute to the current rational methods and recommended practice by systematic understanding of the hydrodynamic forces on various elements and flow interactions in the structures, providing guidelines for reliable use of the experimental and the numerical procedures.

Scientific questions
- What types of generalised, basic structures can be used to represent the dominant parts of the large, complex, three-dimensional subsea modules? How accurate are such representations?
- What are the main physical parameters and effects influencing the hydrodynamic forces on such basic structures and their combinations?
- When can the specific basic elements be observed as the individual contributors to the hydrodynamic forces of the complex modules, and when are the interactions between the various structural elements important?
- How precise and how applicable are various types of CFD calculations, varying from the detailed to the numerically simplified, fast models, when applied for the modelling of the basic structures and various combinations, subjected to the oscillatory flow?

Cooperating company
SINTEF Ocean

Supervisor: Prof. Trygve Kristiansen

Zhengru Ren

Photo: Thor Nielsen

Title
Onboard decision support system.

Research topics
- Multiple IMUs sensor fusion.
- Vessel and payload motion prediction.
- Onsite sea state estimation based on vessel responses.
- Cooperative control of floating heave lifting.

Industrial goals
- Design onboard decision support and decision making algorithms to enhance the safety and efficiency in various marine operations.
- Design control strategies to the offshore wind turbine preassembly installation scenario.

Scientific questions
- Realize high-fidelity vessel motion monitoring, including twist and bending, by sensor fusion of multiple IMUs placed on the vessel and integrate it into onboard design support system.
- Improve the robustness of onboard sea state estimation methods.

Innovations
- Smart onboard decision system
- Multiple IMU sensor fusion
- L1 optimization

Cooperating company
SINTEF Ocean

Supervisor: Roger Skjetne (IMT, NTNU)

Ting Liu

Photo: Tony Hall

Title

Optimization of low-height lifting system for installation of offshore wind turbines (OWT) by using floating vessel.

Research topics

- Hydro-aero-dynamic response prediction of the installation system
- Prediction of extreme response for the installation and estimation of the reliability of the system
- Optimization of the installation concept and prescription of the response-based criteria

Industrial goals

- Provide new and accurate response estimation model for installation of offshore wind turbines
- Contribute to the development of the response-based criteria and improved regulations

Scientific questions

- How to improve the design concept of this low-height lifting system while ensure both economy and safety
- How to enhance the numerical models to provide a more realistic prediction for the dynamic responses of the installation system.

Innovations

- Novel methods for OWT installation leading to cost-reducing as well as improved safety and operability.

Cooperating company

SINTEF Ocean

Supervisor:

Karl Henning Halse

Co-supervisor:

Bernt Johan Leira

Defens of Thesis

Amrit Shankar Verma

One of the SFI MOVE phd students, Amrit Verma, defended his phd thesis on Jan. 9 at the Department of Marine Technology, Faculty of Engineering.

Amrit Shankar Verma has submitted the following academic thesis as a part of the doctoral work at the Norwegian University of Science and Technology (NTNU), Department of Marine Technology.

«Modelling, Analysis and Response-Based Operability Assessment of Offshore Wind Turbine Blade Installation with Emphasis on Impact Damages».

The Faculty appointed the following Assessment Committee to assess the thesis:

- Professor Jonas Ringsberg, Chalmers University of Technology, Sweeden (1. opponent)
- Professor Mostapha Tarfaoui, ENSTA Bretagne, France (2. opponent)
- Senior Principal Engineer Jon Taby, FiReCo AS, Norway (3. opponent)
- Professor Jørgen Amdahl, NTNU

Professor Jørgen Amdahl, Department of Marine Technology, was appointed Administrator of the Committee.

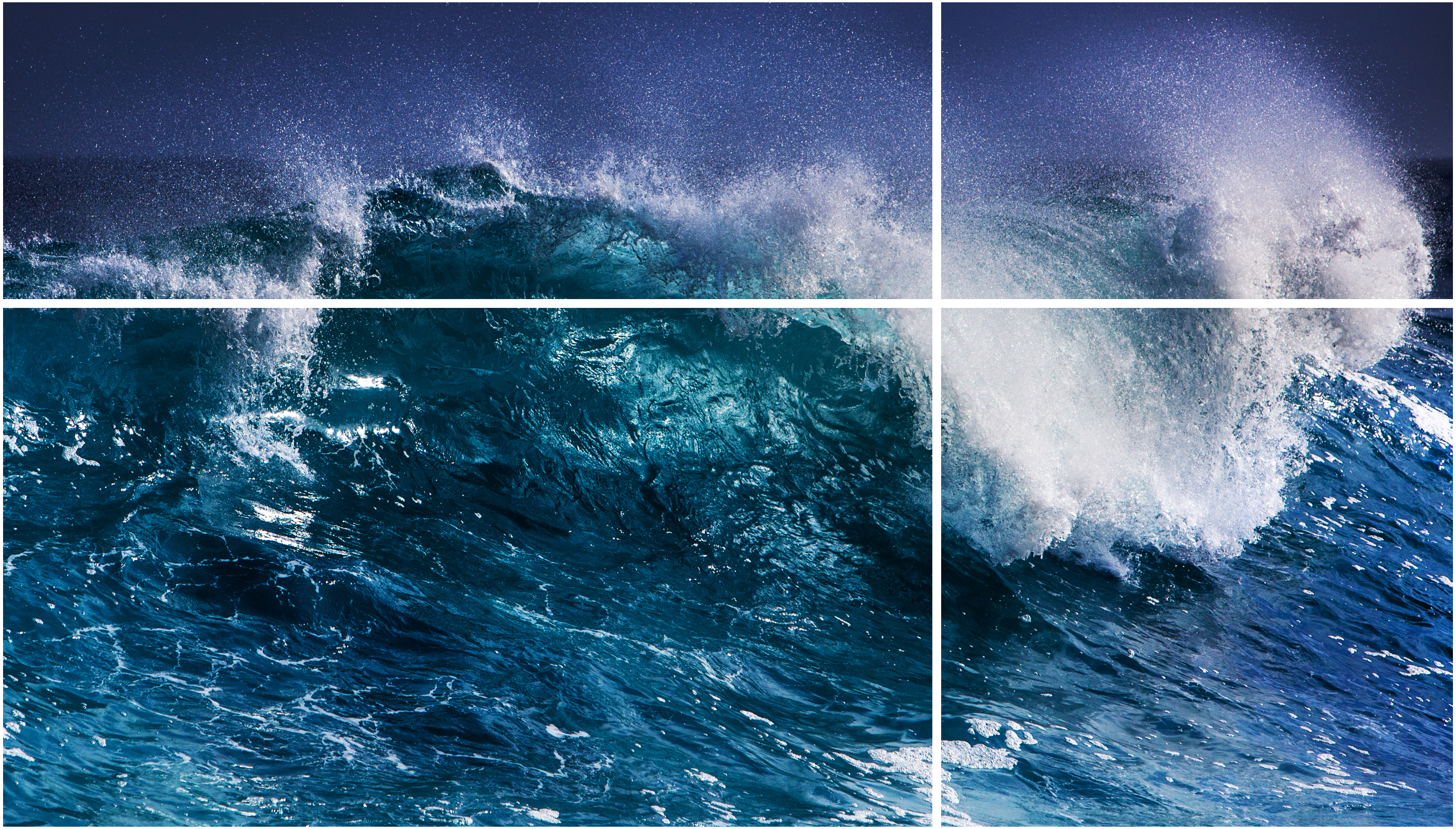
The Committee recommended that the thesis was worthy of being publicly defended for the PhD degree.

The doctoral work was carried out at the Department of Marine Technology.

The trial lecture took place on January 9th, 2020 at 10:15 in Auditorium T2, Marine technological Centre, Tyholt on the following prescribed subject:
"Analysis and design of offshore wind turbines subjected to ship collisions".

The public defence of the thesis took place on January 9th, 2020 at 13:15 in Auditorium T2, Marine technological Centre, Tyholt.

Professor Zhen Gao, Department of Marine Technology, was the candidate's main supervisor. Associate Professor Nils Petter Vedvik, Department of Mechanical and Industrial Engineering was the candidate's co-supervisor.



Communication and dissemination activities

The project has arranged following main conferences/ workshops in 2020:

- Spring conference/Workshop, at Teams 26.05.20
- Autumn conference, at Teams 25.11.20
- Workshop, at Teams 25–26.11.20

Digital Twin
Digital transformation is a hot topic at present. Digital Twin integrates sensor technology, IIoT, analytics, simulation technology, artificial intelligence, BigData, and satellite communication.

A digital twin is a virtual model of a physical component or system which includes TLC information needed throughout the value chain. Digital Twin integrates artificial intelligence/machine learning and analytics to living simulation models that continuously learns and updates itself from multiple data sources to provide real-time working conditions. These learning systems learn from themselves in operation, as well as input from experts, and are used to optimize design, manufacturing, operations and service.

The SFI MOVE home page is frequently updated, see www.ntnu.edu/move

Publication highligts

We want to highlight two of the publications from 2020, one related to project 5 (Innovative Installation of Offshore Wind Power Systems) and one related to project 6 (On-Board Decision Tool).

Low-height lifting system for offshore wind turbine installation: Modelling and hydrodynamic response analysis using the commercial simulation tool SIMA
Proceedings of the ASME 2020 39th International Conference on Ocean, Offshore and Arctic Engineering OMAE 2020 June 28–July 3, 2020, Fort Lauderdale, FL, USA.

In this work, presented at the 39th International Conference on Ocean, Offshore & Arctic Engineering (OMAE 2020), one of the main concerns related to the installation of offshore wind turbines (OWTs) in floating foundations was addressed. The specific issue approached revolves around controlling the relative distance between the Spar platform foundation and the OWT during the installation process, while the OWT is deployed from the installation vessel to the floating foundation. Several factors play an important role in increasing the complexity of such operation. Initially, the dimension of modern OWT requires big installation vessels equipped with big and high-capacity lifting structures. Another issue is related to controlling the relative movement between the 3 different bodies involved in the installation. Additionally, high precision is required during the mating phase of the installation, where the OWT makes contact and is attached to the Spar foundation. In order to address these issues, a low-height lifting system for OWT installation from a catamaran vessel was proposed.

The main goal of the proposed concept is to match the required installation criteria regarding relative movement between the different bodies while avoiding the use of prohibitively tall lifting structures. The low-height lifting system lifting the OWTs from its base, while constant tension tugger wires attached to the OWT mid-section are used to ensure the balance of the tower and avoid the inverted pendulum problem. The dimensions and physical arrangement of the proposed concept were presented, and a series of hydrodynamic analyses using the software suite SIMA were conducted to study the dynamic response of the proposed system under different weather conditions and different operational layouts. The low-height lifting system is controlled by an active heave compensation system responsible for controlling the safe deployment of the OWT over the Spar foundation. The control system formulation was presented and its impact in reducing the relative movement between the bodies was assessed. In this study, the proposed concept was proven feasible from a hydrodynamic point of view and can now be pushed forward for further studies regarding other aspects of the operation, such as impact and structural loads and mechanical design of components.

A Sensitivity Study of Vessel Hydrodynamic Model Parameters
ASME 2020 39th International Conference on Ocean, Offshore and Arctic Engineering, August 3–7, 2020, Virtual, Online conference.

Xu has been working on the application of operational sensor data, as a means of realizing the digital twin concept for maritime operations, then also serving as a basis for On-board decision support systems. The basic idea is to apply measured data as a basis for updating the vessel response model in such a way that the inherent uncertainties of vessel performance are captured. A case study was presented to identify the most sensitive parameters in the vessel hydrodynamic model with respect to the vessel motion performance. The need for the digital twin to be adaptive to various operational conditions and also the importance of selecting the correct parameters for tuning was demonstrated. The work represents a significant step forward with respect to developing a rational basis for designing on-board decision support systems. Fundamental research is ongoing with respect to investigating different strategies for updating the vessel model.

Publications

2020

Cheng, Xu; Li, Guoyuan; Skulstad, Robert; Chen, Shengyong; Hildre, Hans Petter; Zhang, Houxiang.
A Neural Network-Based Sensitivity Analysis Approach for Data-Driven Modeling of Ship Motion. *IEEE Journal of Oceanic Engineering* 2020;Volum 45.(2) s.451-461
NTNU

Fonseca, Icaro Aragao; Gaspar, Henrique Murilo.
Fundamentals Of Digital Twins Applied To A Plastic Toy Boat And A Ship Scale Model. I: *Proceedings of the 34th International ECMS -Conference on Modelling and Simulation – ECMS 2020.* ECMS European Council for Modelling and Simulation 2020 ISBN 978-3-937436-68-5.
s.207-213
NTNU

Gutsch, Martin.
Design for Workability: Scenarios for parametric design optimization. SFI-MOVE Spring Conference 2020; 2020-05-26 - 2020-05-26
OCEAN NTNU

Gutsch, Martin.
Vessel Design Optimization Tool Development Status. SFIMOVE Autumn Conference 2020; 2020-11-25 -2020-11-25
OCEAN

Gutsch, Martin; Steen, Sverre; Sprenger, Florian.
Operability robustness index as seakeeping performance criterion for offshore vessels. *Ocean Engineering* 2020 ;Volum 217.
OCEAN NTNU

Han, Xu; Leira, Bernt Johan; Sævik, Svein.
Tuning of vessel seakeeping model parameters based on motion and wave measurements. SFI MOVE Autumn Conference 2020; 2020-11-25 -2020-11-26
NTNU

Han, Xu; Sævik, Svein; Leira, Bernt Johan.
A Sensitivity Study of Vessel Hydrodynamic Model Parameters. 39th International Conference on Ocean, Offshore & Arctic Engineering; 2020-08-03 - 2020-08-07
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Han, Xu; Sævik, Svein; Leira, Bernt Johan.
A Sensitivity Study of Vessel Hydrodynamic Model Parameters. I: *ASME 2020 39th International Conference on Ocean, Offshore and Arctic Engineering - Volume 1: Offshore Technology.* The American Society of Mechanical Engineers (ASME) 2020 ISBN 978-0-7918-8431-7.
NTNU

Jiang, Zhiyu; Yttervik, Rune; Gao, Zhen; Sandvik, Peter Christian.
Design, Modelling and Analysis of a Large Floating Dock for Spar Floating Wind Turbine Installation. *Marine Structures* 2020 ;Volum 72.
OCEAN NTNU UIA

Koilo, Viktoriia.
Energy efficiency and green solutions in sustainable development: evidence from the Norwegian maritime industry. *Problems and Perspectives in Management 2020*; Volum 18.(4) s.289-302
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Kyllingstad, Lars Tandle; Skjong, Stian.
On-board decision support framework functionality developed in 2020. SFI MOVE Autumn Conference 2020; 2020-11-25 - 2020-11-26
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Visual Attention Assessment for Expert-in-the-loop Training in a Maritime Operation Simulator. I*EEE Transactions on Industrial Informatics* 2020;Volum 16.(1) s.522-531
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Mentzoni, Fredrik; Kristiansen, Trygve.
Two-dimensional experimental and numerical investigations of parallel perforated plates in oscillating and orbital flows. *Applied Ocean Research* 2020 ;Volum 97. s.1-20
NTNU

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Two-dimensional experimental and numerical investigations of perforated plates in oscillating flow, orbital flow and incident waves. *Applied Ocean Research* 2020 ;Volum 97. s.1-22
NTNU

Moan, Torgeir; Gao, Zhen; Bachynski, Erin Elizabeth; Rasekhi Nejad, Amir.
Recent Advances in Integrated Response Analsysis of Floating Wind Turbines in a Reliability Perspective. *Journal of Offshore Mechanics and Arctic Engineering* 2020 ;Volum 142.(5)
NTNU

Monteiro, Thiago Gabriel; Gaspar, Henrique Murilo; Zhang, Houxiang; Skourup, Charlotte.
A MODEL FOR FORECASTING MENTAL FATIGUE IN MARITIME OPERATIONS. I: *Proceedings of the 34th International ECMS - Conference on Modelling and Simulation - ECMS 2020.* ECMS European Council for Modelling and Simulation 2020 ISBN 978-3-937436-68-5. s.221-227
NTNU

Monteiro, Thiago Gabriel; Li, Guoyuan; Skourup, Charlotte; Zhang, Houxiang.
Investigating an Integrated Sensor Fusion System for Mental Fatigue Assessment for Demanding Maritime Operations. *Sensors* 2020 ;Volum 20.(9)
NTNU

Monteiro, Thiago Gabriel; Skourup, Charlotte; Zhang, Houxiang.
Optimizing CNN Hyperparameters for Mental Fatigue Assessment in Demanding Maritime Operations. *IEEE Access* 2020 ;Volum 8. s.40402-40412
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Pareliussen, Bjarne.
Digital transitions in the maritime organizations: Changing the Game by Power by the Hour and Remote Monitoring. Nordic Working Life Conference 2020; 2020-09-28 - 2020-09-29
NTNU

Ren, Zhengru; Skjetne, Roger; Jiang, Zhiyu; Gao, Zhen.
Active Single-Blade Installation Using Tugger Line Tension Control and Optimal Control Allocation. *International Journal of Offshore and Polar Engineering* 2020; Volum 30.(2) s.220-227
NTNU UIA

Ren, Zhengru; Zhao, Bo; Nguyen, Dong Trong.
Finite-time Backstepping of a Nonlinear System in Strict-feedback Form: Proved by Bernoulli Inequality. *IEEE Access* 2020 ;Volum 8. s.47768-47775
NTNU

Skjetne, Roger; Ren, Zhengru.
A survey on modeling and control of thruster-assisted position mooring systems. *Marine Structures* 2020; Volum 74.
NTNU

Skulstad, Robert; Li, Guoyuan; Fossen, Thor I.; Vik, Bjørnar; Zhang, Houxiang.
A Hybrid Approach to Motion Prediction for Ship Docking – Integration of a Neural Network Model into the Ship Dynamic Model. *IEEE Transactions on Instrumentation and Measurement* 2020 ;Volum 70.
NTNU

Solaas, Frøydis.
Lecture on Hydrodynamic coefficients for subsea structures during installation operations Main findings. SFI-MOVE Spring Conference 2020; 2020-05-26 - 2020-05-26
OCEAN

Solaas, Frøydis; Mentzoni, Fredrik; Abrahamsen-Prsic, Mia; Kristiansen, Trygve.
An Experimental and Numerical Study of Added Mass and Damping for Side-by-Side Plates in Oscillating Flow. 2020 ;Volum 143.(1)
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Verma, Amrit Shankar; Jiang, Zhiyu; Gao, Zhen; Vedvik, Nils Petter.
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Verma, Amrit Shankar; Jiang, Zhiyu; Ren, Zhengru; Gao, Zhen; Vedvik, Nils Petter.
Effects of Wind-Wave Misalignment on a Wind Turbine Blade Mating Process: Impact Velocities, Blade Root Damages and Structural Safety Assessment. *Journal of Marine Science and Application* 2020 ;Volum 19. s.218-233
NTNU UIA

Vieira, Daniel; Nishimoto, Kazuo; Ferrari de Oliveira, Felipe; Gaspar, Henrique Murilo.
Simulation Of The Conceptual Design Of Offshore Salt Caves For CO2 Storage. I: *Proceedings of the 34th International ECMS - Conference on Modelling and Simulation - ECMS 2020. ECMS European Council for Modelling and Simulation* 2020 ISBN 978-3-937436-68-5. s.214-220
NTNU

Vågnes, David; Monteiro, Thiago Gabriel; Halse, Karl Henning; Hildre, Hans Petter.
Low-height lifting system for offshore wind turbine installation: Modelling and hydrodynamic response analysis using the commercial simulation tool SIMA. 39th International Conference on Ocean, Offshore & Arctic Engineering (OMAE 2020); 2020-08-03 - 2020-08-07
NTNU

Wu, Mengning; Stefanakos, Christos; Gao, Zhen.
Multi-step-ahead forecasting of wave conditions based on a physics-based machine learning (PBML) model for marine operations. *Journal of Marine Science and Engineering* 2020 ;Volum 8.(12) s.1-24
OCEAN NTNU

Xu, Jiafeng; Ataei, Behfar; Halse, Karl Henning; Hildre, Hans Petter; Mikalsen, Egil Tennfjord.
Virtual prototyping of a low-height lifting system for offshore wind turbine installation. 39th International Conference on Ocean, Offshore & Arctic Engineering (OMAE 2020); 2020-08-03 - 2020-08-07
NTNU

Master's degrees

Name	Sex M/F	Topic
Jens Nikolai Alfsen	M	Dynamic optimal path-planning for autonomous harbor maneuvering
Caroline Sophie Røhm Fleischer	F	Optimal path-planning on a bio-inspired neural network landscape model for autonomous surface vessels
Hongyu Zhou	M	Autonomous guidance, stepwise path planning, and path-following control with anti-collision for autonomous marine robots
Elias Gauslaa	M	Navigation, guidance, and control for autonomous autodocking of ships
Jakob Stensvik Jensen	M	Dynamic optimal path-planning for autonomous harbor maneuvering
Andrea Therese Rognstad	F	Numerical Study for Single Blade Installation of an Offshore Wind Turbine – Comparing a Jack-up and a Semi-submersible Crane Vessel in Intermediate Water Depths
Ingeranne Strøm Nakstad	F	Numerical Study for Single Blade Installation of an Offshore Wind Turbine – Comparing a Jack-up and a Semi-submersible Crane Vessel in Intermediate Water Depths
Thijs van Essen	M	Motion-Compenstated Gripper Frame on a DP Vessel
Piet H Bastiaanssen	M	Modelling the Dynamic Behaviour of a Rotor Nacelle Assembly during the Installation using a Floating Vessel
Karoline Vottestad	F	Hydrodynamic Loads on Subsea Protection Structures
Marius Robsahm	M	Experimental Study of Splash Zone Wave Loads on a Combined Configuration of a Porous Plate and a Circular Cylinder
Jon Kristian Voster	M	Experimental and Numerical Investigations of Hydrodynamic Loads on Perforated Plates Subjected to Irregular Forced Oscillations

Accounts

Project 1: Low Cost Offshore Wind Installation and Maintenance – was completeted in 2016

Project 2: Subsea: Safe – All Year – Cost-efficient Subsea Operation – was completed in 2017

Project 3: Simulation Technology and Virtual Prototyping as a Common Approach from Design to Operation – was completed in 2017

Project 4: Seabed Mining: Exploration of Technologies to Develop Seabed Mining as a New Business Area – was completed in 2018

(All figures in 1000 NOK)

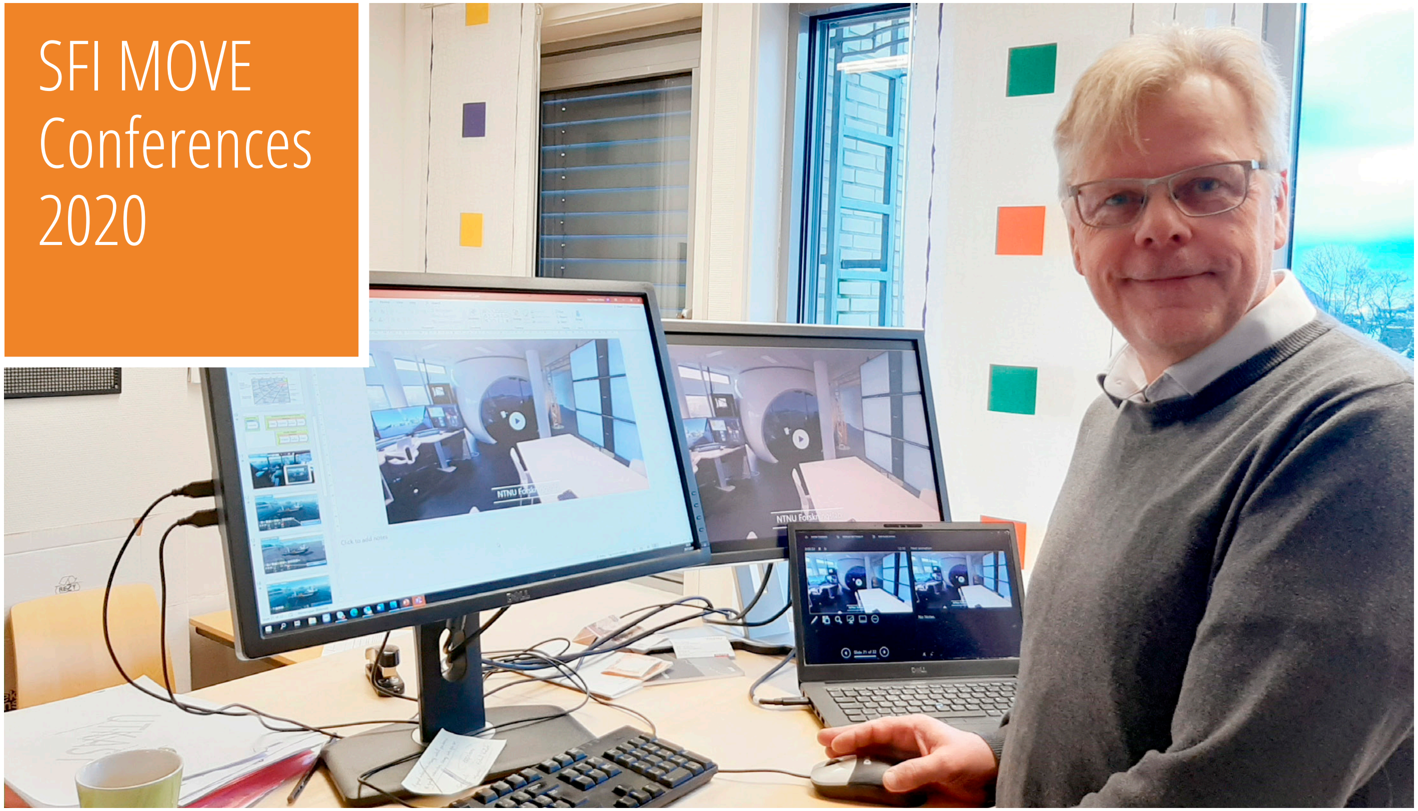
Funding		Project 5	Project 6	Project 7	Project 8	Lab/Dissemination	Management	Total
The Research Council		**2 812**	**5 256**	**118**	**398**	**207**	**1 176**	**9 967**
The Host Institution, NTNU in Ålesund		**401**	**-**	**-**	**1 505**	**-**	**-**	**1 906**
Research partners:		**954**	**3 133**	**73**	**-**	**-**	**-**	**4 160**
	NTNU	954	1 883	-	-	-	-	2 837
	SINTEF	-	1 250	73	-	-	-	1 323
Enterprise partners:		**995**	**1 865**	**162**	**1 447**	**1310**	**-**	**5 779**
Total		**5 162**	**10 254**	**353**	**3 350**	**1 517**	**1 176**	**21 812**

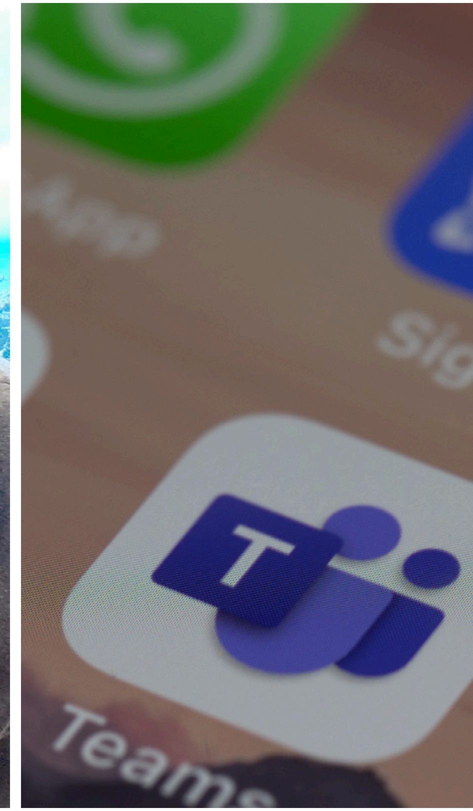
Costs		Project 5	Project 6	Project 7	Project 8	Lab/Dissemination	Management	Total
The Host Institution, NTNU in Ålesund		**3 891**	**-**	**-**	**2 443**	**1 517**	**1 177**	**9 028**
Research partners:		**954**	**9 661**	**291**	**-**	**-**	**-1**	**10 905**
	NTNU	954	4 670	-	-	-	-1	5 623
	SINTEF	-	4 991	291	-	-	-	5 282
Enterprise partners:		**317**	**593**	**62**	**907**	**-**	**-**	**1 879**
Public partners		**-**	**-**	**-**	**-**	**-**	**-**	**-**
Equipment		**-**	**-**	**-**	**-**	**-**	**-**	**-**
Total		**5 162**	**10 254**	**353**	**3 350**	**1 517**	**1 176**	**21 812**

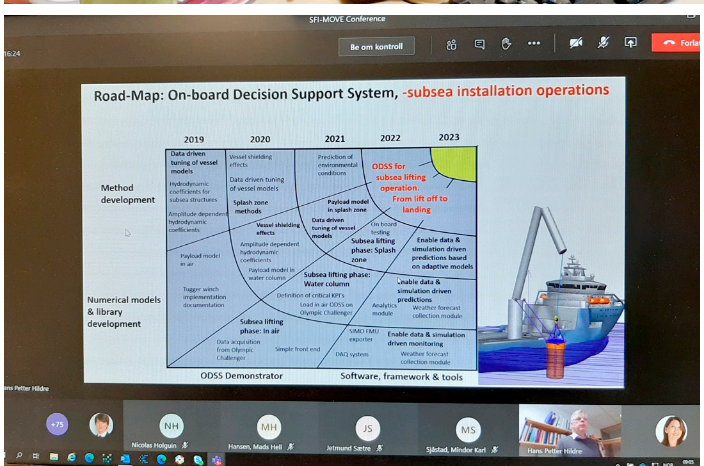
Name of active projects in 2020:

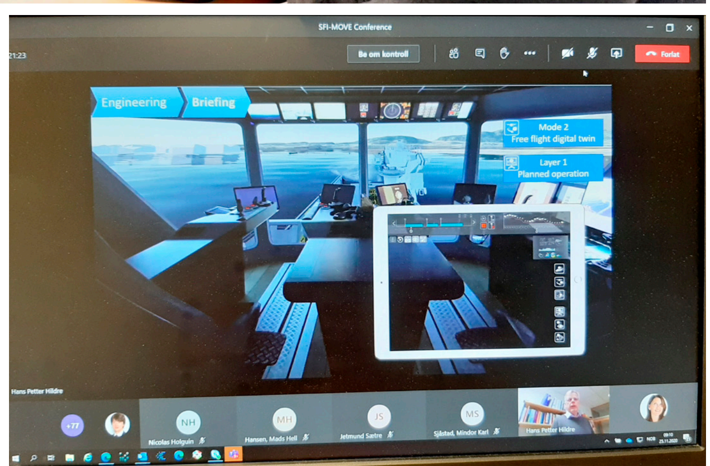
Project 5: Innovative Installation of Offshore Wind Power Systems
Project 6: On-board Decision Tool
Project 7: Design for Workability
Project 8: Remote Operations/Dispersed Teams
RA 5: Lab/Dissemination
RA 6: Management

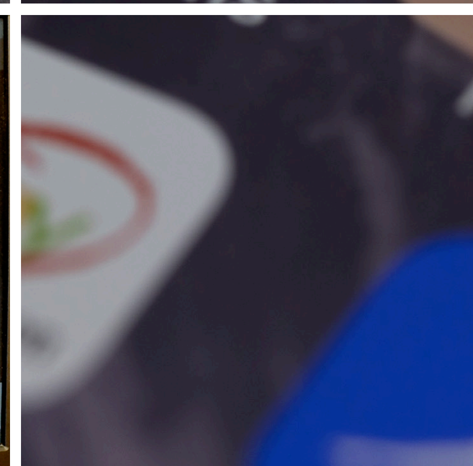
SFI MOVE Conferences 2020











Due to the corona pandemic, both conferences in 2020 were carried out digitally on Teams. It is not ideal that one cannot meet face to face, partly because one misses out on the informal meeting point with other conference participants. Now that is said, it has also been seen that digital conferences do have an upside. We have never had so many participants in our conferences as we had at this year's Teams' conferences.

Here is the program for this years conferences:

Spring Conference, May 26

09.00 Introduction, Hans Petter Hildre
- Vision and strategy
- SFI-MOVE Annaual Reprot 2019,
- Ongoing projects
- Ongoing PhD/PD
- Use of the Gunnerus vessel in research

09.15 Installation of offshore wind (P5),
Karl Henning Halse
- The idea
- Team
- Simulation of installation process

09.30 On-board decision tool (P6),
Henning Borgen
- The idea
- Team
- Ongoing work

09.45 Hydrodynamic coefficients
- Team
- Motivation for the work
- Model test description
- Important topics and findings
    - Estimation of coefficients based on data for individual structure parts
    - Semi analytical method for estimation of coefficients for perforated plates
    - Importance of damping
    - Importance of content inside the module
    - Effect of distance to the free surface
    - Is it correct to use results from forces oscillation tests for structures in waves?
- Ongoing and further work
- List of deliveries

10.30 Dispersed teams
– remote operations (P8), Frøy Birte Bjørneset
- The idea – remote operation
- Team
- Remote operations center
- Cyber security
- Business view

10.45 Ship responses (P7),
Marin Gutsch
- The idea
- Team
- Parametric design study

12.00–15.00 Workshop/Group discussion (Parallel sessions)

1. Workshop Offshore Wind Installation
- Introduction by Karl Henning Halse
- Input from Equinor, HighWind Tampen
- Discussion

2. On-Board Decision support and Ship responses
- Introduction by Henning Borgen
- Experiences with calculation of hydrodynamic coefficients using CFD, Subsea7
- Discussion

3. Dispersed Teams (ship crew)
- Introduction by Frøy Birte Bjørneset
- Discussion

Autumn Conference, November 25–26

Conference November 25

09.00 Introduction, Hans Petter Hildre

09.15 On-board Decision Tool, subsea installation case
- Introduction and status for the 2020 project activities; Henning Borgen
    - Ship model tuning and collection of weather data for this purpose
    - Shielding effects
    - Hydrodynamic coefficients
    - Splash zone modelling
    - Vessel Design Optimization Demo; Martin Gutsch
- Vessel seakeeping model tuning based on vessel motion measurements and wave information; Xu Han
- Demonstration of ODSS framework functionality developed in 2020; Lars T. Kyllingstad, Stian Skjong

10.45 Innstallation of Wind Power Systems
- Offshore Installation from a floating vessel, Karl Henning Halse
    - Evaluation of vessel motion, David Vågnes
    - Evaluation of strength/flexibility of the crane structure, Behfar Ataei
- Floating dock – Overview of model tests and status for analytical method, Mael Moreau

11.45 Remote Operations
- Demonstration (Gunnerus), Hans Petter Hildre

12.30 Lunch brake

Workshop, November 25

13.30–15.30 On-board Decision Tool
(Henning Borgen)

Workshop, November 26

09.00–11.00 Installation of Wind Power Systems (Karl Henning Halse)

12.00–16.00 Remote Operations
(physical meeting with invitations)

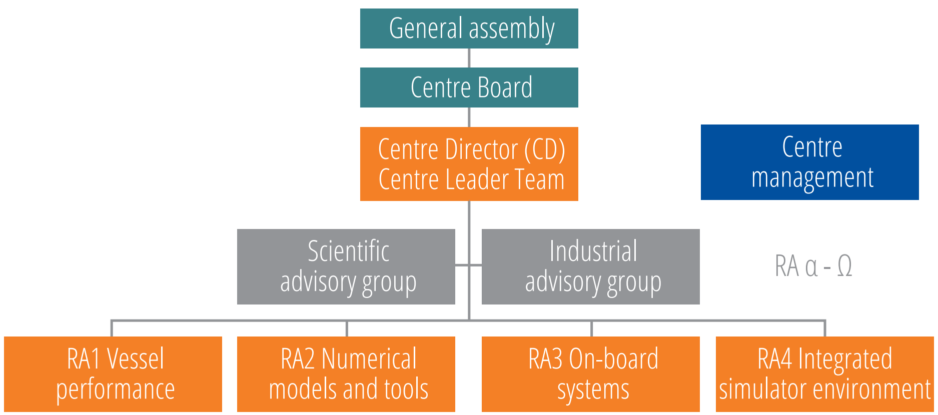
Research organisation

The following research partners were involved in 2020:

- NTNU in Ålesund (former Ålesund University College)
- NTNU
- SINTEF Ocean

Ålesund University became a part of NTNU in 2016, and MARINTEK and SINTEF Fisheries and Aqua-culture became SINTEF Ocean in 2017. We are very pleased for the restructuring of the research partners in few and strong organisations.

The project is organised as shown in the figure.



Organisation chart

The project leaders are:

Project	Project Leader
Innovative Installation of Offshore Wind Power Systems	Karl Henning Halse, NTNU
On-board Decision Tool	Henning Borgen, SINTEF Ocean
Design for Workability	Martin Gutsch, SINTEF Ocean/NTNU
Remote Operations/Dispersed Teams	Frøy Birte Bjørneseth/ Marie Haugli Larsen, NTNU

The Board of the Centre had the following Members in 2020:
Rafael Rossi, Chairman (TechnipFMC)
Arnt Olufsen, (Equinor)
Tore Ulstein (Ulstein Group)
Sverre Torben (Kongsberg, former Rolls Royce Marine)
Hans Petter Hildre (NTNU in Ålesund)
Sverre Steen (NTNU)
Harald Stenersen (Havila)
Arne Fredheim (SINTEF Ocean)
Runar Stave (Olympic)

Centre Director:
Hans Petter Hildre, Professor, Head of Department of Ocean Operations and Civil Engineering, NTNU in Ålesund

Administrative key personnel:
Magnhild Kopperstad Wolff, Finance & Administrative Coordinator, SFI MOVE, Adviser at Department of Ocean Operations and Civil Engineering, NTNU in Ålesund

Industrial partners:
Two of our partners, Statkraft and Cranemaster, decided to withdraw from SFI MOVE from January 2017. A third partner, EMAS-AMC, closed the business in February 2017. In addition, Farstad decided to withdraw from the project from January 2020. On the other hand SFI MOVE got two new partners in 2019, Subsea 7 and TechnipFMC.

The industrial partners in the project in 2020 were:
Olympic Shipping
Havila Shipping
Kongsberg (former Rolls-Royce Marine)
Ulstein International
ÅKP/GCE Blue Maritime
OSC
Vard
NTNU Ocean Training
Equinor
Ocean Installer
DNV-GL
Subsea 7
TechnipFMC

Brosundet, Ålesund. Foto: Børge Sandnes.