



Annual
Report
2021

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SFI MOVE

Marine Operations in Virtual Environments



SINTEF

 **NTNU**



Centre for
Research-based
Innovation



Industrial partners:



Research partners:





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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 plan and verify marine operations. Simulators are used to train crew to perform the operations.

Next-generation technology has the potential to provide virtual prototyping to pre-test marine operations including human components. On-board supports simulation systems are considering the real met-ocean situation and the ship's real behaviour will reduce the waiting on weather and thereby reduce costs. Remote support has the potential to move experts from the ship to the land-based organisation.

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)

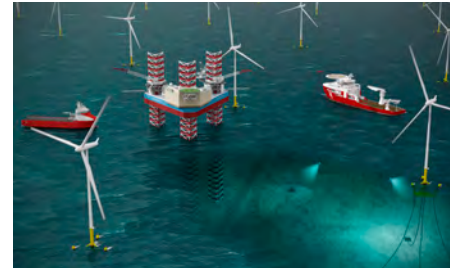
Business areas

The business areas focused on in 2021 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



Photo: Infiniturno

Director's report

Professor Hans Petter Hildre is the leader for SFI MOVE

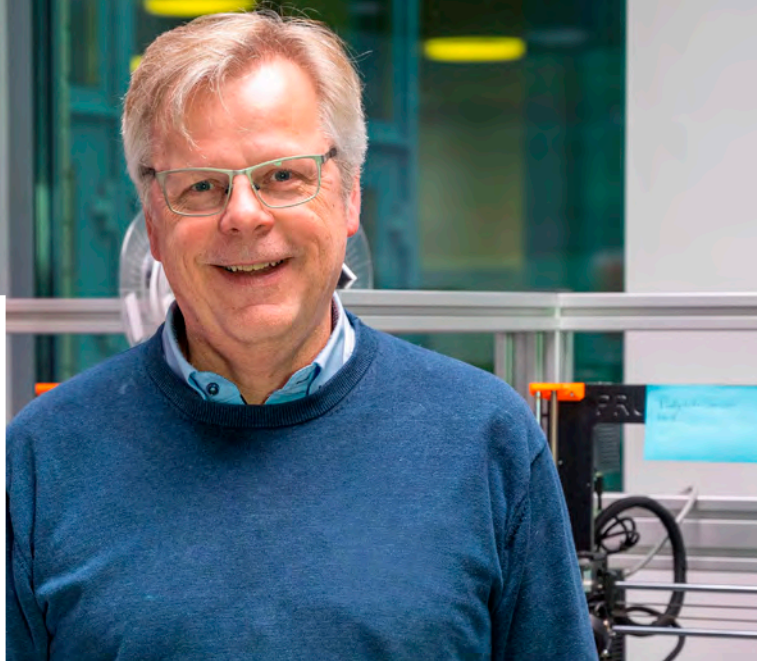


Figure 1.

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. Which vessel, load condition, wind, waves, lifted objects behaviour in air and sea etc. are assumed. The result of the simulation is that the operation can be carried out if a given wave height is not exceeded. Therefore, simulations are 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 the speed of the crane tip or the 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. 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 give 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.

Follow 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)

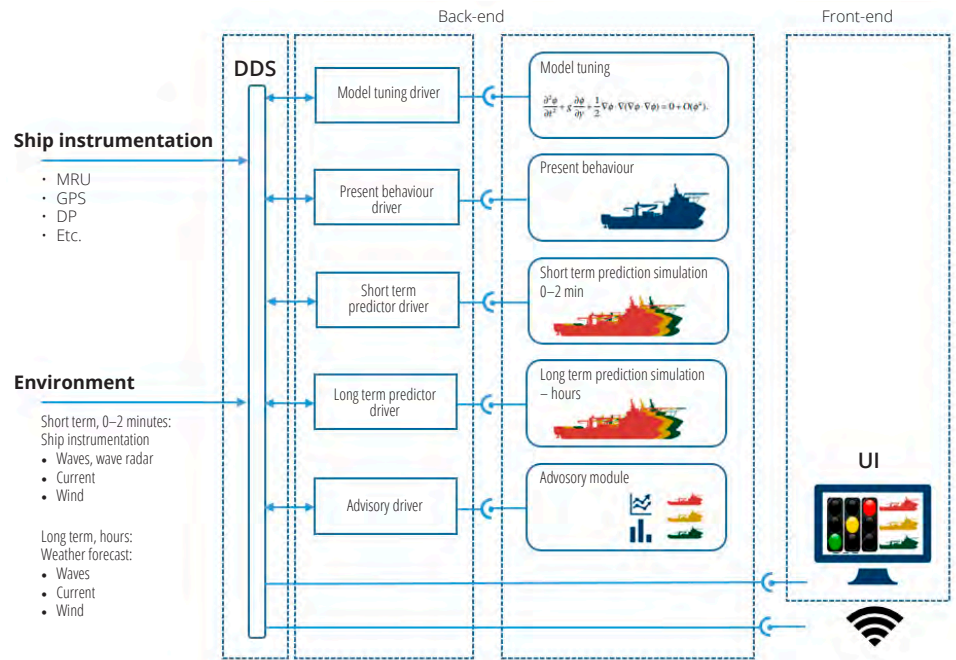
Marine operations are today designed and simulated by engineers before they are executed. The main idea of this project is to develop a framework for digital twin technology allowing onboard support simulating responses considering the actual vessel, loading condition and metocean.

Theoretical hydrodynamic vessel models used in the engineering phase are corrected using real-time measurements of vessel motion and responses (model tuning).

Vessel behaviour will then be simulated based on updated ship models. Present ship behaviour, short-term prediction (0–2 minutes) by use of wave radar, and long-term prediction (hours) by use of weather forecast will be done.

Combined with limiting criteria for operations, required weather window, safety factors etc., real-time advice on the feasibility of performing the marine operation will be given. The core of the project will be effective onboard simulation and predictive analytics tools. The simulations can then be useful to support the rigging, briefing the crew, preparation at the 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 onboard system.



Case: Subsea lifting operations

A lifting operation will be a case for this development. The driver of this case is reducing waiting on the weather (WoW) by performing the more precise simulation. The case will include rigging, lifting in the air, through the splash zone and in the water column.

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

Coefficients for splash zone behaviour will be presented in 2022. 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. Wave components in the sea state tend

to give the most significant contribution to wave forces. Both experience from offshore operations and from initial simulations show that the shielding effect from the ship hull is significant when a structure is deployed on the leeward side. Methods to take into account shielding effects were presented in 2021.



Figure 2.

Remote operation support

Marine operations are getting more technology-based. The 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 human 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-off scenarios.

A remote operations framework can be established by adding a copy of the onboard 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 the view of interest.

A research lab for remote operations (NTNU marine operation control centre, MOCC) is built at NTNU in Ålesund, see figure 1 page 6.

Case: Dispersed teams

The NTNU research vessel Gunnerus is instrumented, and signals are transferred to the research lab (MOCC).

A digital twin of the Gunnerus vessel was made in 2020 and included real-time data for example ECDIS for vessel position, heading and speed, MRU data as pitch, roll and heave, crane data as joint angles, engine data etc.

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

The aim of this case study is to investigate new ways of doing the maritime operation, how the use of digital twin technology can enable collaboration between shore and vessel, and how dispersed teams can optimize workflow and organisation change. Studies of the performance of such teams will be carried out in 2022.

Operational responses and co-simulation

The new simulation framework is based on the principle

of the Functional Mockup Unit (FMU) standard. Such an 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 a co-simulation allowing different subsystems which form a coupled problem to be 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, the control system can be put together in one system simulation. This framework is compatible with the Open Simulation Platform initiative.

Case: OWT

With fewer restrictions on size and height than their onshore counterparts, offshore wind turbines are becoming giants. 12 MW turbines were installed in 2019 and Siemens Gamesa's massive 14 MW turbines produced its first electricity in 2021. The Siemens turbine has a rotor diameter of 222 meters and 260 metres high to the rotor centre. Even bigger units are in development. Westas has announced the launch of its new offshore wind turbine at 15 MW and a Chinese company is developing a turbine at 16 MW for offshore applications. Installations are moving further from shore, tapping better quality wind resources, and pushing up capacity factors. Next generation giant turbines demand new methods for installation, service and repair.

Installation of giant offshore structures is presently done by huge crane vessels with needed lifting capacities and height. Such assembly is done in sheltered areas and then towed to the wind farm for mooring. This is a 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 the comparison in figure 2.





Arnstein Eknes

Photo: Marianne Wernesland



Per Arild Åland

Photo: DNV

Industry, man and the sea

Text: Else Britt Ervik

Main profiles:

Per Arild Åland

Business Development Manager

Arnstein Eknes

Segment Director, Special Ships

DNV

With a heart for the sea, technology and safety at sea, Per Arild Åland and Arnstein Eknes are helping to set the terms for development in the Norwegian maritime industry. They have a background in DNV, and see unique opportunities in the collaboration between academia and business in SFI MOVE.



Photo: DNV

Per Arild Åland and Arnstein Eknes both have more than 20 eventful years to look back on in the maritime, offshore industry. Det Norske Veritas (DNV) is their workplace, an important and knowledgeable partner for SFI MOVE.

– Over the years, we have both had the pleasure of trying different roles in DNV, both in Norway and internationally, says Per Arild.

He holds the title Business Development Manager, and works with market development for the industry. Arnstein, for his part, is the Segment Director for offshore and special vessels, and contributes to projects and finds effective solutions for many different players.

– A significant part of our job is to capture development trends and new elements from the industry, and take this back as input to DNV.

Early interest in technology

In the office at Høvik outside Oslo, the fjord is the nearest neighbor, and the proximity to the sea is something they both value highly. Per Arild says that for him, the interest in technology, combined with the maritime, has always been there.

– Technology, and developing robust solutions that increase safety at sea is something I am passionate about, he says.

From a childhood in Lofoten and Bodø, surrounded by the sea on all sides, the journey went further out into the world. One of his places of residence was studies in England, where his interest in the sea was decisive for his choice of a master's degree in mechanical and marine offshore.

For Arnstein, it was more coincidental that he ended up in the maritime segment. It is the interest in helping to create and seeing results that drives him.

– When I was a child, my parents told me that no matter what you do, find something that is fun, and do your best.

Growing up in Nordhordland north of Bergen, he gained an early sense of the power of nature's elements. He is fascinated by the sea, by ships and the energy image that surrounds us. When Arnstein took his master's degree at NTH in Trondheim, he used the opportunity to cultivate his interest in interdisciplinarity, and try a little different things.

– I took some courses across, but I feel I have a dream job in the maritime industry where I get to use all my knowledge.

Trust creates momentum in innovation

According to Per Arild, one of the most engaging things about the job today is to be involved in the development of new industrial segments.

– Creating even more opportunities at sea, gives motivation every single day.

Both the two DNV employees see the opportunities it provides to gather a network of inspiring people from business and academia. Through the collaboration in SFI MOVE, contacts are made between many talented companies.

– Norwegian maritime industry is a world leader in areas such as subsea technology, zero-emission technology and information technology, says Arnstein.

He believes that one of the things that makes it easier to cooperate in Norway, and bring innovation, is the high degree of trust we have in each other.

Gigantic possibilities in simulation

By taking a deep dive into other topics that SFI MOVE has addressed in recent years, maritime simulation is something that engages the two civil engineers.

– Heavy weather and high waves are common in the Norwegian Sea for large parts of the year, says Per Arild. – With simulation, for example, you can make it a little clearer how long you can continue with an operation.

With a lot of movement, it is difficult for those on board to know where the boundaries go for what is possible, and where the uncertainties lie.

– Simulation is about reducing the danger and being able to plan, Arnstein adds. – Like the backing alarm in a car, you know what happens if you continue to back up.

Although technology offers opportunities, they know that the human factor plays a role. They have seen how important it is for humans to trust the simulator and be comfortable using it. The captain on the bridge must make the decisions, and must be responsible for the choices afterwards.

– When you experience pressure and chaos, there are many factors that come into play for a simulation to work optimally, Per Arild explains.

A rapid technological development

Per Arild and Arnstein have followed the digital development closely, and observed how programming and simulation have changed from being an analysis activity behind a desk, to a practical tool. They think back to their study time a few decades ago, where it took hours or days to see the results of a programming. Today we are talking nanoseconds.

– The possibilities with simulation are gigantic, says Arnstein – It is almost unbelievable that the technology can be used as decision support here and now, on board a ship, when you think about how it was before.

In addition to ships, wind power must be on the radar ahead. Per Arild is very clear about this. There will definitely be more and larger floating wind turbines in the coming years.

– The offshore wind industry is in rapid development, and here SFI MOVE can really contribute with competence in research, elucidation, development and simulation.

Exciting continuation

Both engineers emphasize that it is commendable of NTNU to have completed the project so broadly. The SFI has been completed at a time of challenges in the industries. Restructuring and closures are taking place for oil, gas, the wind industries. Nevertheless the Universities have managed to keep it going, and are successful in holding thematics that are relevant for the industry, where dozens of representatives attend each gathering.

– Business feels that this is useful, says Arnstein. – They need people who can co-operate and share knowledge, and we get that in this forum.

Per Arild experiences that DNV is given an opportunity to contribute with expertise and share competence. They see that they are included in forming some of the development of NTNU, such that the students will be as relevant as possible for the working life they shall go out into.

– It is exciting to be a part of the continuation here, he concludes. – To put sharp heads from the research environment and industry together is very necessary to achieve far-reaching goals.



Research projects



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*

Project 7: Design for Workability – *was completed in 2020*

Ongoing projects in 2021:

Project 5: Innovative Installation of Offshore Wind Power Systems

Project 6: On-board Decision Tool

Project 8: Remote Operations/Dispersed Teams





Figure 1. Stern installation of OWT from a catamaran vessel

Project 5

Project Leader:
Karl H. Halse, NTNU Ålesund

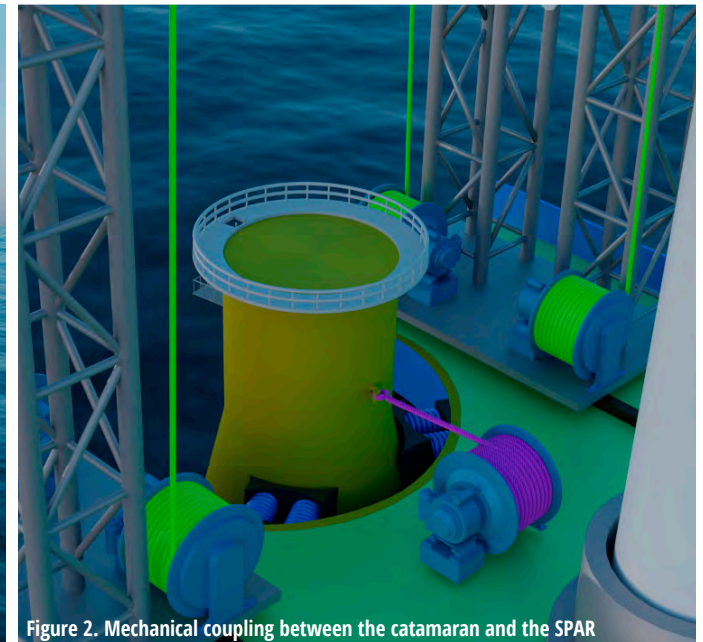


Figure 2. Mechanical coupling between the catamaran and the SPAR



Alternative installation from midship

Innovative Installation of Offshore Wind Power Systems

The offshore wind market continues to increase along with the requirement of energy decarbonization. The Dogger Bank Wind Park Project is planning for several hundred offshore wind turbines to be installed in rather shallow water. Recently, also two areas in the Norwegian sector have been identified and opened for production of wind power. For Sørlige Nordsjø II (40–70 m) the conditions favour bottom-fixed installations, whereas for Utsira Nord (220–280 m), production of wind power must be carried out on floating installations. With this, the industrialization of wind energy production enters Norwegian sector as well. It is worth noting, that 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). Today, fixed Offshore Wind Turbines (OWT) are usually installed with the use of high lift cranes from jack-up platforms (or jack-up ships), which is a costly and time-consuming approach of installing the turbines. On the other hand, the development of floating wind turbines has gained more attention since Statoil installed the world's first floating wind power park, known as Hywind Scotland, during the summer of 2017. The installation in Hywind Scotland 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. However, this operation is also quite time-consuming and costly, giving us a strong motivation to explore a more cost-efficient way of installing floating offshore wind parks. To this end, two alternative approaches have been proposed in SFI MOVE:

1. Installation of floating OWT from a floating installation vessel
2. Installation of floating OWT from a floating dock

Offshore installation of floating OWT from a catamaran

During 2021, we have worked to improve the dynamic response of the concept (see Figure 1) by improving the numerical modelling of the mechanical system as well as the hydrodynamic models. We have also attempted to introduce a workbench to analyse the dynamic system in a modularized and high-fidelity fashion by using co-simulation with the FMI standard.

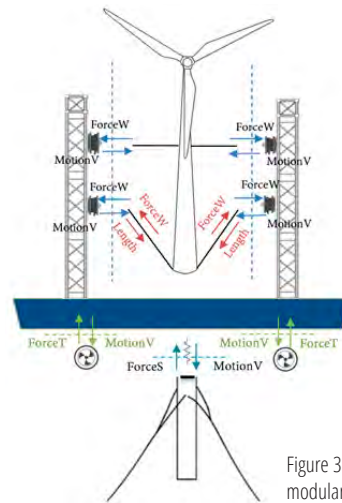


Figure 3. Interfaces in modularization.

Improved numerical modelling of the response prediction

- A mechanical coupling (with fenders and pretensioned wires) was introduced between the floating SPAR buoy and the vessel, to reduce the relative motions. We have varied the spring stiffness of the fender and the pretension in the wires to study the effect on the system response (Figure 2).
- The mass properties, the hydrodynamic damping and mooring system for the SPAR have been updated.
- A finite element model of the jacket-like crane structure was simulated in a dynamic analysis and the response of the crane top was compared to the response from simulations where the crane was assumed to be a part of the rigid vessel body.
- A comparative study with an alternative installation vessel (a SWATH) was initiated. The preliminary conclusion is that the vessel provides less motion than the catamaran and consequently that it is possible to reduce the relative motion between the vessel and the SPAR.

Analysis issues (FMI vs full analysis)

- We have developed a preliminary modularization solution for the FMI-based co-simulation of the whole

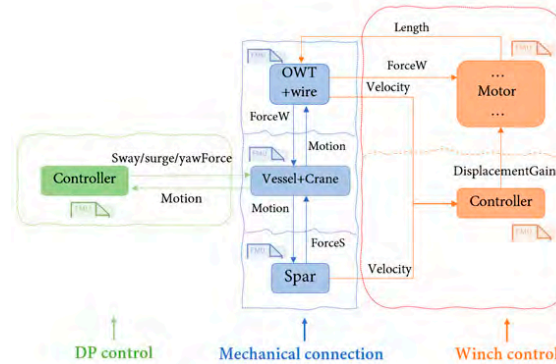


Figure 4. FMUs based on proposed modularization.

- system, (Figure 3). Separate FMUs are made for the OWT, vessel, and SPAR based on OrcaFlex. Secondary controlled winches are packaged as FMUs in 20-sim for the lifting and stabilization. In addition, controllers involving simplified control algorithms are made as FMUs for winch control and DP control, respectively.
- We have adopted Vico platform developed by NTNU in Ålesund for the test of co-simulation performance. All the FMUs (Figure 4) are parameterized and connected with each other based on system structure and parameterization (SSP) standard. The results have been compared with the relevant monolithic simulation. However, there are still accuracy and efficiency issues left for the future discussion.

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

Model tests have been carried out to understand the behaviour of a floating dock in waves. The sloshing induced motions of a floating wind turbine's SPAR inside the cylindrical floating dock were investigated for both regular and irregular incident waves (see Figure 5), focusing on the first lateral sloshing mode. The reduction of the lowest natural sloshing frequency was a notable consequence of

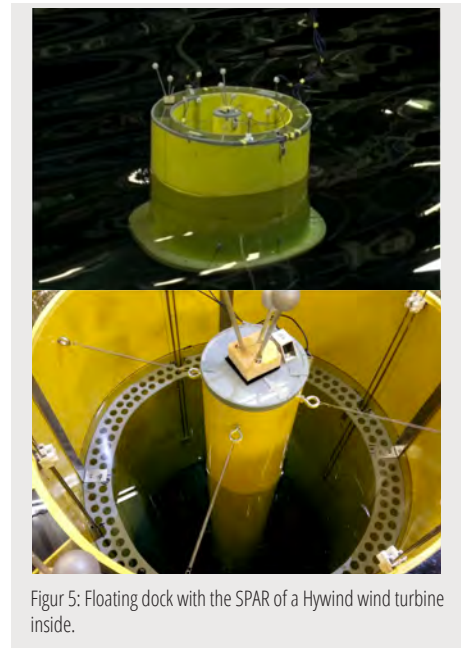


Figure 5: Floating dock with the SPAR of a Hywind wind turbine inside.

adding the SPAR inside the dock. Analytical results were compared to experimental results with a fair agreement, revealing a significant sensitivity of the amplitude of the motions to the moment of inertia in pitch of the dock, and to few other parameters related to the mass distributions and the geometries of both the SPAR and the dock.

Various damping devices have been tested with encouraging results. Perforated baffles have shown to be efficient damping devices, for both the internal wave elevation and the SPAR's motions, which could help to reach the required criteria for the assembly of floating wind turbines in site at operational weather conditions. Further investigations on the mooring system, or on the opening allowing the introduction of the SPAR inside the dock, would be a logical continuation of the feasibility study of the project.



Project 6

Project Leader:
Henning Borgen,
SINTEF Ålesund/SINTEF Ocean



DATA
ANALYSIS



On-board Decision Tool

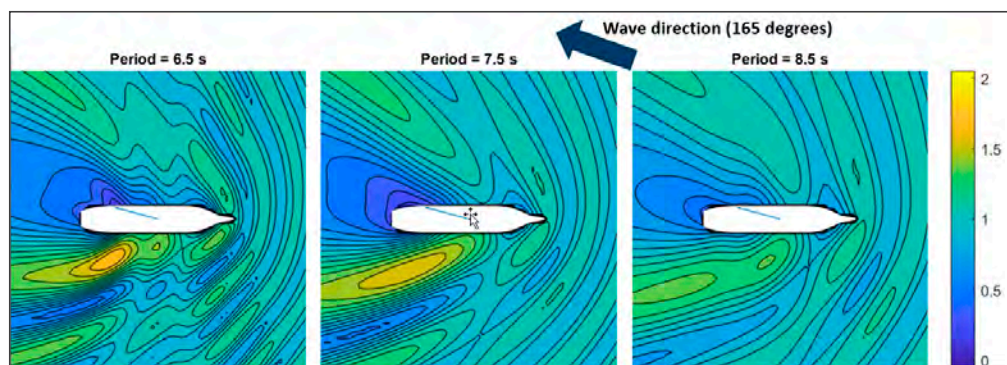


Figure 1. Wave height amplification factor due to shielding effect.

The On-board Decision Tool (ODSS) project is developing methods and technology on how to use operational data from ship sensors and combine these with physics-based models to monitor and predict the response of the vessel and its 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 important task of establishing a method for including vessel shielding effects on a lifted object was started. During 2021 a prototype version of this method has been implemented in the simulation tool SIMO. The new method and implementation were presented at the 2021 autumn conference, using the Johan Sverdrup ITS installation as case study, where the ITS (the lifted object) consisted of a number of slender elements. It was demonstrated that the shielding effect significantly reduce the tension in the main wire as compared to previous analysis which did not take this effect into account. In addition to taking the shielding effect into account, the new method uses a new and more efficient calculation method, and for the mentioned ITS installation analysis the total simulation time was reduced by approximately 50% compared to the previous analysis. This will be

an important feature to incorporate in numerical tools forming the basis of predictors to utilize the shielding effect the crane vessel will have on lifted objects.

In previous years the model tuning method and software were tested with data from model tests and simulations. For 2021 it was planned to test the method for model tuning with "real" data from field measurements. For this purpose, a system for wave measurement with radar was rented from Miros and installed on board the ship RV Gunnerus. Of particular interest was to see what accuracy could be obtained with spectral data from a radar system. Due to limited accessibility of Gunnerus, time for the on-board experiments could not be booked until November 2021. Two days were booked. Since the weather was calm during these days, the vessel had to seek as far as Frohavet to find waves of useable magnitude. Due to long travel distance and some technical problems with the Miros system, the captured amount of data was less than expected. Further measurements are planned in 2022, and hence applying the data for tuning is postponed to 2022.

In addition to the present and future data for RV Gunnerus, measurements of waves and motions from OSV Normand Vision has been provided by Havfram AS. This is good news for the project. Data covering one month of continuous

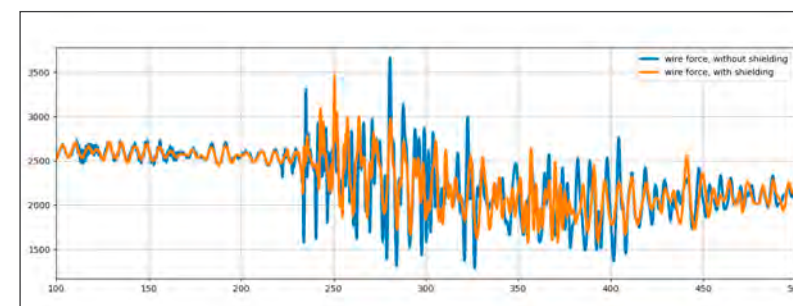


Figure 2. Comparing tension in main wire during installation analysis, with and without shielding effect.

logging was received from Havfram in November. The amount of data is large and as it represents a vessel of different type and size than Gunnerus, it adds several variations to the tuning study. In the remaining part of 2021, the data has been screened and analysed to find continuous error-free parts suited for model tuning. This work is described in a separate report.

The ship model tuning procedure has several applications, both in system design and operation analysis. In the context of ODSS, it is seen as a kind of "virtual sensor" that provides up-to-date estimates of important ship parameters like damping coefficients, stiffness coefficients, the position of the center of gravity, and so on. Other parts of the decision support system can then benefit from freshly updated values for these parameters, for example to improve the accuracy of response predictions.

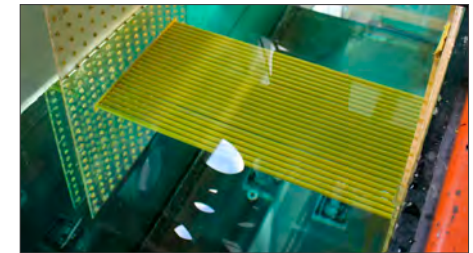
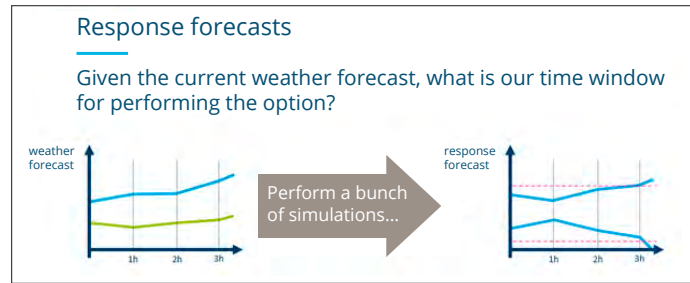
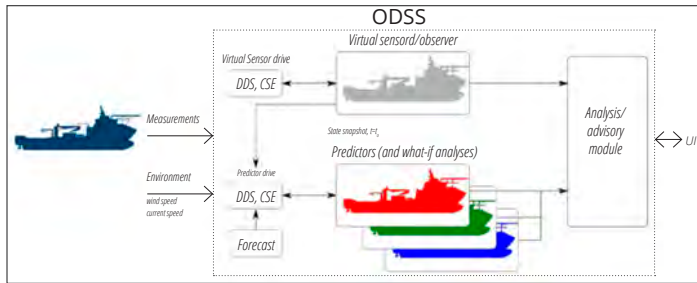


Figure 3. Laboratory test of a hatch cover.

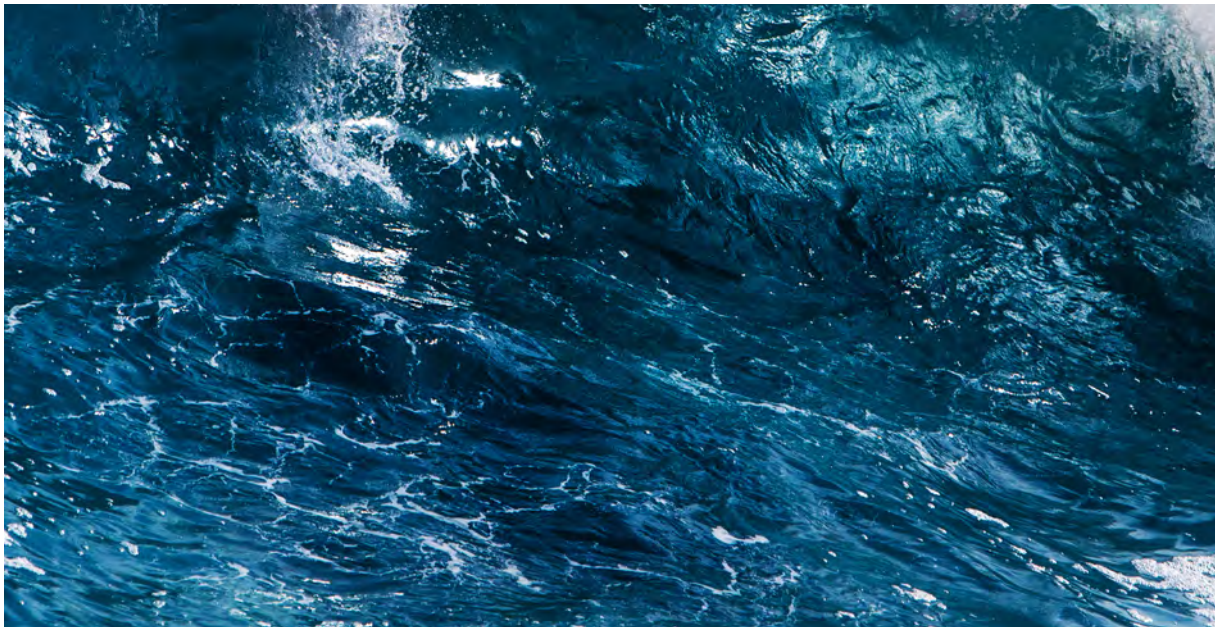
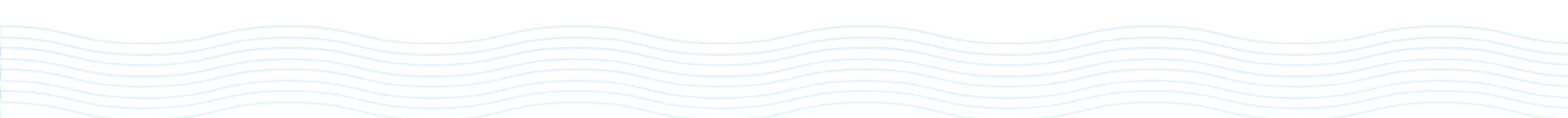
At the 2021 autumn conference this application was demonstrated with a simulated case study; While a light subsea construction vessel is waiting to perform its operations, data about its motions are collected (e.g. with an MRU), including the waves that induce them (e.g. with a wave radar). The measured motions are compared to the ones predicted by the ODSS system model for the same sea state, and discrepancies in some of the motion spectra were observed. The model tuning procedure was therefore activated to adjust certain key parameters so that the model produces data that are more in line with the actual measurements. The tuned model is then used for decision support, to predict vessel responses for an upcoming operation. The result (in this particular and, admittedly, contrived example) is that the predicted responses are smaller than with the original model parameters, pointing to a potential expansion of the weather window for the operation.

The activity on hydrodynamic coefficients continued in 2021, focusing on how the subsea equipment inside a module with protection roof and mudmat influence on the hydrodynamic coefficients. The main findings are that for the generalized modules tested, damping is generally the dominating hydrodynamic force. However, the presence of content inside the module will generally increase the importance of added mass compared with a

module consisting of only roof and mudmat. Estimation of coefficients by summation of the coefficients for the individual structure parts was also studied. It is seen that the damping will generally be overestimated when estimated as the sum of the damping for the individual elements, compared with model test results of the entire module. If the module consists of both mudmat and roof, with and without internal content, estimation of added mass by summation is good. On the other hand, for structures without a roof or a mudmat, estimation by summation will underestimate the added mass.

The activity on splash zone hydrodynamics, focusing on estimation of slamming loads on perforated structures such as hatch covers, was further pursued in 2021 by low-cost 3D numerical simulations following the 2D numerical and experimental work of PhD student Fredrik Mentzoni. These 3D simulations provided depth-dependent added mass and slamming coefficients used in time domain models to estimate the slamming load during the water entry phase of a subsea module during a lifting operation. The work on splash zone hydrodynamics will continue in 2022 focusing on developing methods and analysis procedures. Numerical simulations will be combined with simplified and easy controllable laboratory tests in the Marine Cybernetics Laboratory (MC-Lab) in Trondheim.

From 2021 the work previously reported as *Project 7: Design for Workability* was embedded into the ODSS project as a new work package named "Vessel condition adapted response model". The aim of this work task is to enable ship designers and operators to optimize ship motion characteristics and thus seakeeping performance for selected operational tasks and sea areas. The key aspect of this approach is the mission-dependent optimization of hull dimensions, including loading condition parameters, aiming for a design where natural periods of important responses such as pitch and roll are significantly different from the dominating wave periods. The approach of mission dependent seakeeping optimization can also be used in an on-board decision support setting and will allow to pre-tune expected vessel response behaviour and to better utilize vessel performance for the actual offshore work task. In 2021 the work focused on the further development of an easy-to-use tool for parametric seakeeping studies. The seakeeping optimization tool makes use of existing seakeeping codes and will be made available for project partners as part of an update of the new ShipX/SIMA workbench in spring 2022.





Project 8

Project Leader:
Marie Haugli Larsen
NTNU Ålesund



Photo: Kongsberg Maritime

Remote Operations/ Dispersed Teams

Introduction

In this project, we are working on how use of digital twin technology can enable collaboration between shore and vessel, development of cyber security solutions, and how dispersed teams and digital transitions in remote operations can optimize workflow and organizational change. We see that the technological development taking place in the maritime industry is creating opportunities for optimization and increased safety in marine operations.

Project activities 2021

The project activities are focused on research within the HTO-framework (Human-Technology-Organization). According to the work plan of 2021, the focus has been on collecting empirical data from experiments and dialogue with industry partners. Amongst other things, we have tested the technology and front-end design in our remote operation center, worked on development of cyber security solutions, and executed investigations for developing new business models for remote operations. A promotion video of the digital twin and remote operation center was made and presented at the autumn conference (link to video: <https://app.frame.io/presentations/1d92c604-3a8a-4a63-95ad-7eb42bacd9c6>).

Human

Our concept of a remote operation center and plans for testing was presented at the spring conference. Then experiments were conducted to test useability and communication solutions in the simulator setup. The experiments were in real time with use of our digital twin, R/V Gunnerus and nautical students. Results show that more integration of sensor data can enhance useability, and it can be beneficial with more interactional systems for communication. This was presented at the autumn conference.

PhD candidate Marie H. Larsen is doing research on maritime cyber risk perception, and in her first paper she is stating that there is a need for developing risk mitigation measures to consider maritime cyber security issues.

This work will continue with development of a maritime cyber security course, which can contribute to the operational safety of future remote operations.

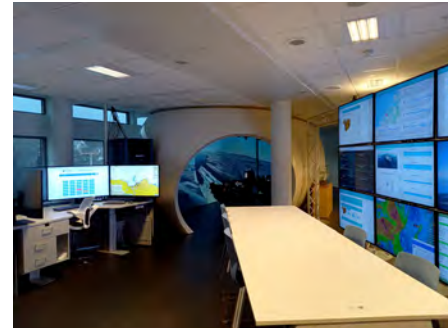
Technology

The work with transferring and visualization of sensor data from R/V Gunnerus to the remote operation center was completed. The system performance and visualization of live sensor data was tested in the experiments presented above. Results show that the system performance is sufficient to run scenarios in real time, but occasionally loss of signals due to topography and 4G coverage must be expected. The visualization of sensor data gives information about the environment and ship performance, but further development of operator-specific dashboards and change of placement can be beneficial. Further tests will be conducted in 2022.

Organization

The digital transition in the maritime industry creates new organizational models and affects the relationship between the ship, shipowner, and third-party suppliers. These new relationships require development of new business models. Associate professor Viktoriia Koilo is using a business case of remote ROV-operations to look at structural changes and future competence requirements. The main idea of the study is to investigate from the whole value chain perspective how the next generation of digital services is affecting the business value. The preliminary results were presented at the autumn conference, together with a SWOT-analysis.

PhD candidate Bjarne Parelius is looking at how interorganizational relations can be changed when organizations go through digital transitions. Professional expertise is created and shared across organizational boundaries and the involved organizations find new ways of performing operations and work processes. This creates new opportunities for both the individual company but also for the industry.



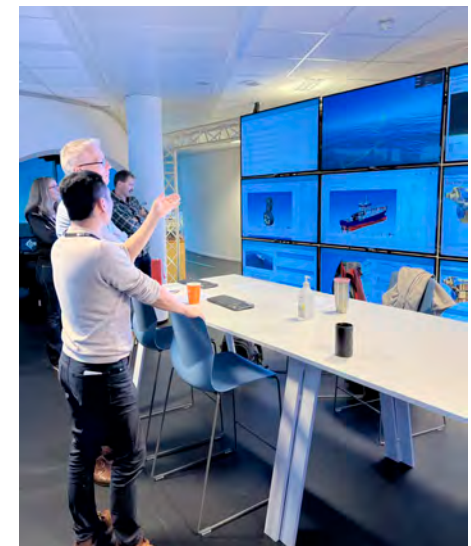
Remote operation center at NTNU in Aalesund.



Digital twin setup in simulator dome.



Live support from the remote operation center.



Use of sensor data for decision support and predictions.

Plans ahead

In 2022, we will work further with:

- Scenarios for testing remote operations with dispersed teams and digital twins.
- Experiments in simulator lab and on R/V Gunnerus.
- Recommendations for further development and improvements of our "remote operation centre".

- Results from the case study about business models and remote operations.
- Development of cyber security course at management level.

Research cooperation

Text: Hans Petter Hildre



Ocean Space Centre, Trondheim

Photo: Sindreeta Romp

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 maritime ecosystem for co-simulation enabling re-use of models and collaborative system simulations.

Partners in SFI MOVE, DNV, 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.

The Open Simulation Platform¹ 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.

Ocean Space Centre – Fjord Lab Ålesund

The centre will become the national knowledge centre for ocean space technology. The purpose of the Ocean Space Centre (OSC) is to secure Norway's position as a leading ocean nation and contribute to the green shift in Norwegian ocean industries.

The centre will:

- educate future specialists within the field of ocean space technology
- ensure that industry and authorities enjoy access to leading expertise and infrastructure
- contribute to effective utilisation of national expertise and increased knowledge through collaboration with Norwegian and foreign institutions and companies

- actively contribute to increased innovation in ocean space technology
- contribute to the restructuring and development of ocean industries

OSC includes several laboratories and will be built on the site where the Marine Technical Centre is located today. Construction will start in the summer of 2022.

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.

¹<https://opensimulationplatform.com/>

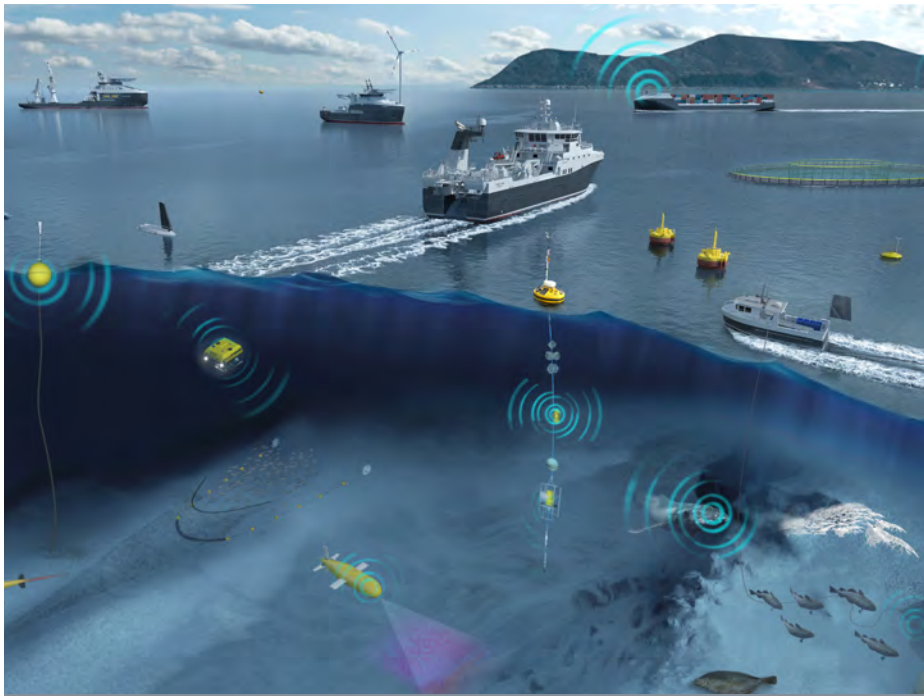


Illustration of Fjordlab Ålesund

International cooperation

SFI MOVE has established partnerships with the University of Sao Paulo (USP) in Brazil and the Harbin Engineering University (HRBEU) in China.

Due to Covid 19, all visits and conferences have been canceled and activities postponed until 2022.

The goal is to establish an international conference in demanding marine operations. This work has also been postponed, but planning is ongoing.



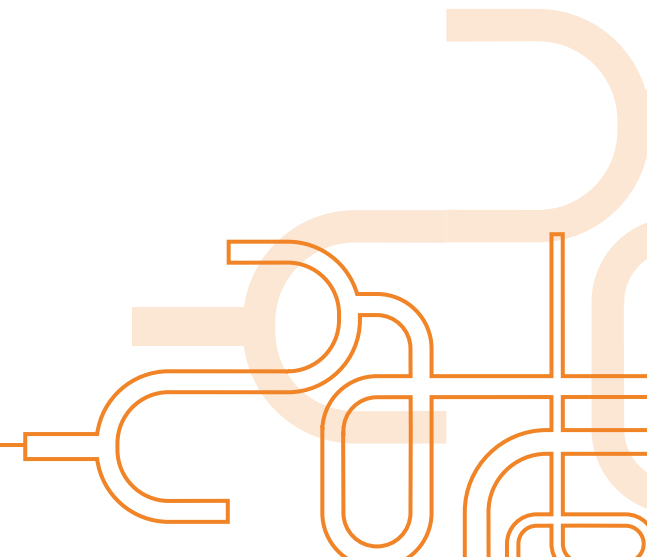
The Fjord-Lab in Ålesund is an arena for the full-scale testing, design and innovation within:

- 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

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.

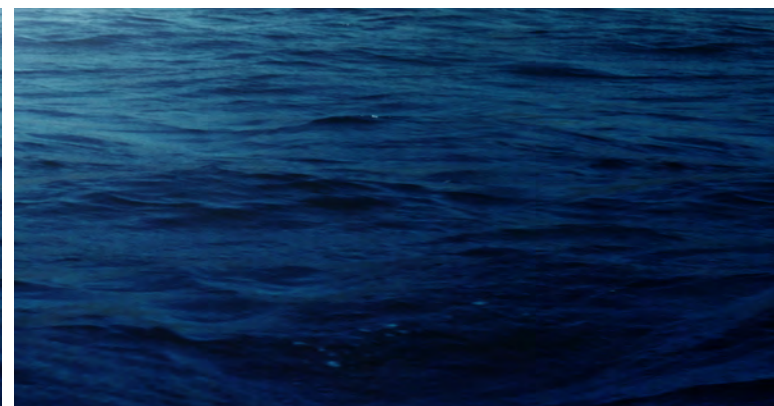
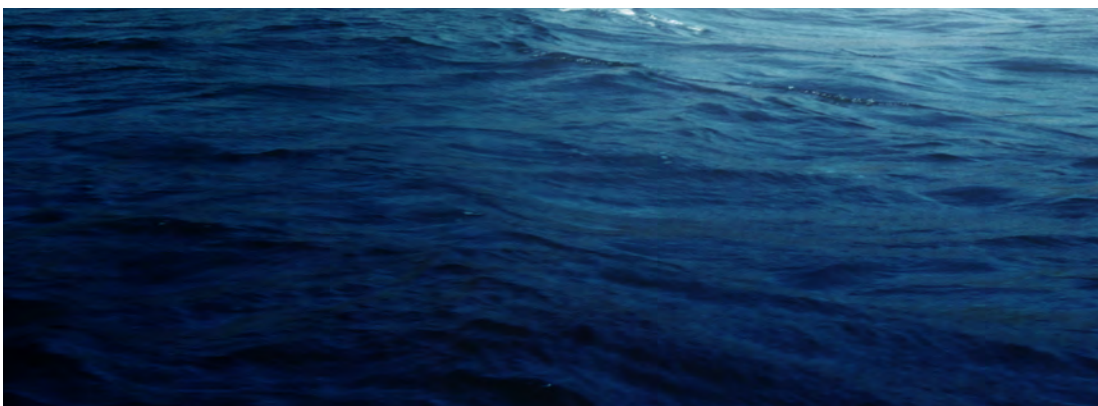
The Fjord-Lab Ålesund is in a unique marine area between Runde and Godøya and into Storfjorden including the World Heritage site Geirangerfjord. The area is in many ways a diverse miniature of the enormous ocean space Norway has control over, including exposed and more sheltered areas. The area is approved 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.

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.



Key Researchers		
Name	Institution	Main research area
Karl Henning Halse	NTNU Ålesund	RA4 Integrated simulator environment
Houxiang Zhang	NTNU Ålesund	RA4 Integrated simulator environment
Henrique Gaspar	NTNU Ålesund	RA4 Integrated simulator environment
Marie Haugli Larsen	NTNU Ålesund	RA4 Integrated simulator environment
Viktorii Koilo	NTNU Ålesund	RA4 Integrated simulator environment
Finn Tore Holmeset	NTNU Ålesund	RA4 Integrated simulator environment
Frøy Birte Bjørnseth	NTNU Ålesund	RA4 Integrated simulator environment
Svein Sævik	NTNU	RA2 Numerical models and tools
Zhen Gao	NTNU	RA2 Numerical models and tools
Trygve Kristiansen	NTNU	RA2 Numerical models and tools
Sverre Steen	NTNU	RA2 Numerical models and tools
Roger Skjetne	NTNU	RA3 On-board systems
Bernt Johan Leira	NTNU	RA3 On-board systems
Henning Borgen	SINTEF Ocean/SINTEF Ålesund	RA3 On-board systems
Egil Giertsen	SINTEF Ocean	RA3 On-board systems
Halvor Lie	SINTEF Ocean	RA3 On-board systems
Lars Tandle Kyllingstad	SINTEF Ocean	RA3 On-board systems
Karl Erik Kaasen	SINTEF Ocean	RA3 On-board systems
Stian Skjong	SINTEF Ocean	RA3 On-board systems
Øyvind Ygre Rogne	SINTEF Ocean	RA3 On-board systems
Frøydis Solaas	SINTEF Ocean	RA1 Vessel performance

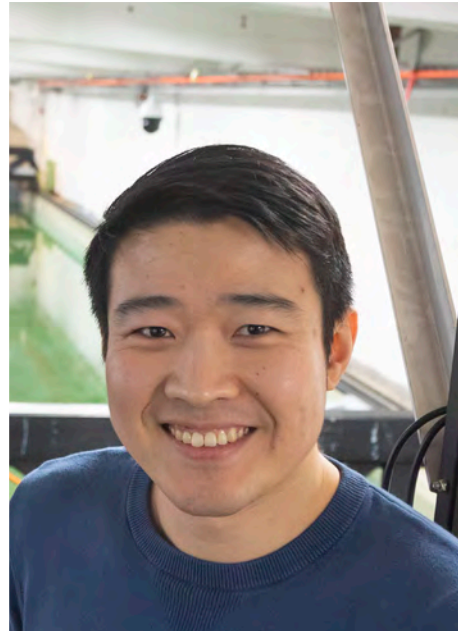
Personnel



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					
Name	Start	End	Project	Nationality	Gender M/F
PhD candidates with funding from SFI MOVE					
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	Norsk	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
Mengning Wu	2020	2021	Integrated simulator environment	Chinese	F
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	2022	Integrated simulator environment	Chinese	F
Mohammad Mahdi Abaei	2021	2021	On-board systems	Iranian	M
Robert Skulstad	2021	2023	Integrated simulator environment	Norwegian	M
Postdocs with funding from other sources					
Shuai Yuan	2020	2021	Integrated simulator environment	Chinese	M



Xu Han



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

**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

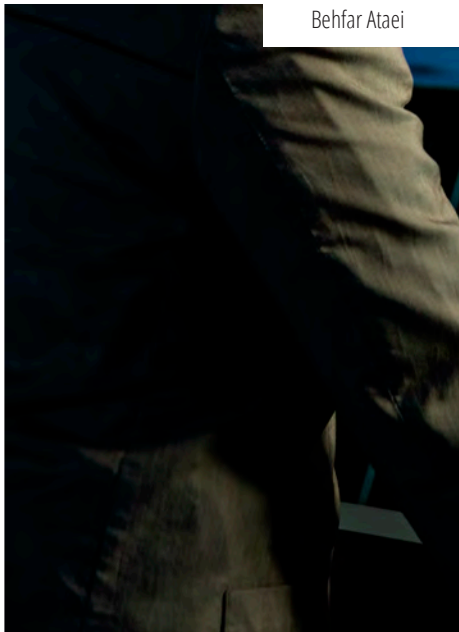
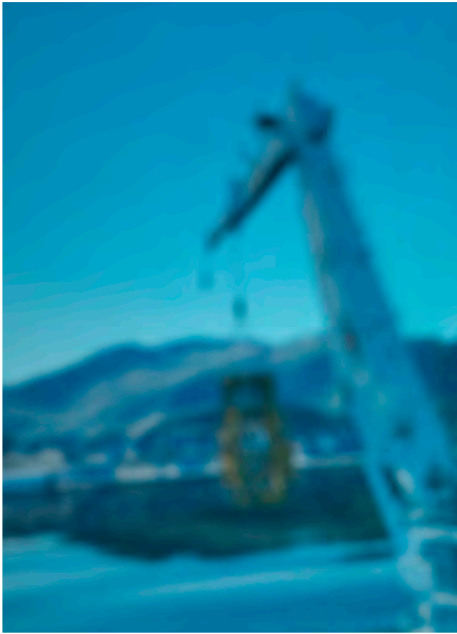


Photo: Tony Hall



Marie Haugli Larsen

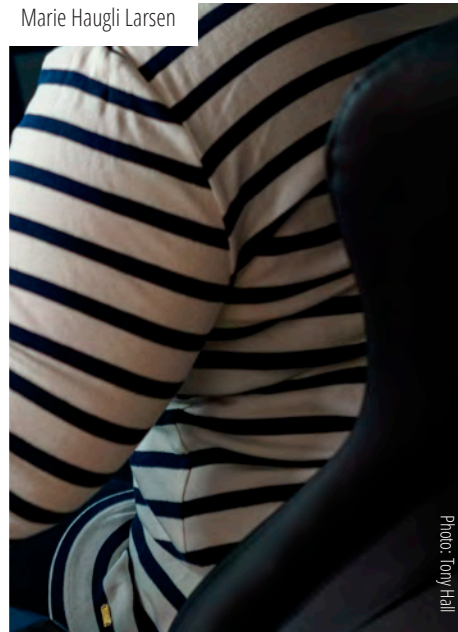


Photo: Tony Hall

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.

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 probabilistic & 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



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

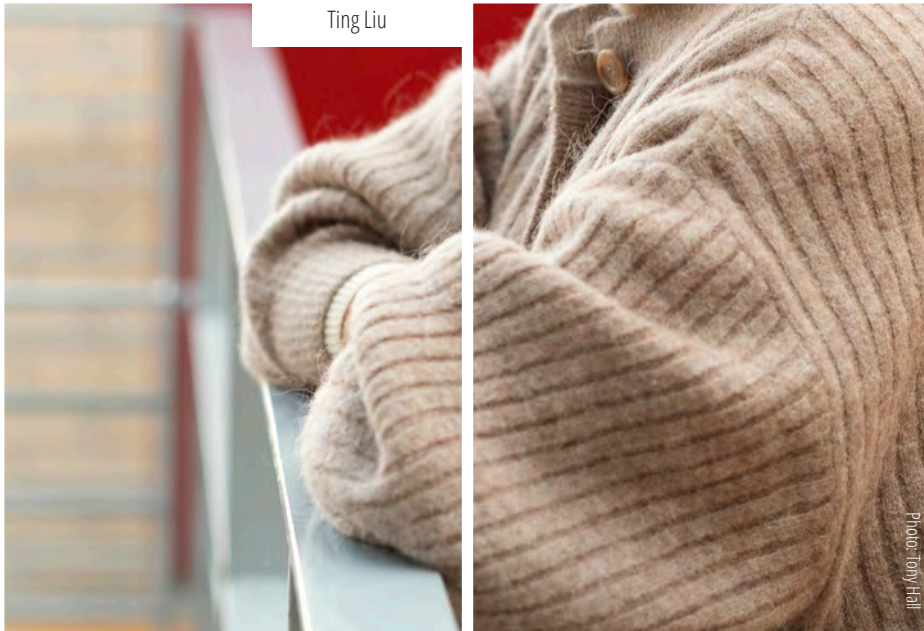
SINTEF Ocean

Supervisor: Roger Skjetne (IMT, NTNU)





Ting Liu



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



Mohammad Mahdi Abaei

Title

A Data-Driven Approach for Evaluating Safety of Offshore Installation in Splash Zone.

Research topics

In this study, a physics-based learning approach is introduced to create an intelligent prediction model for estimating peak loads in lifting wires with addressing two advantages: less simulation time while still including uncertainties associated with sea randomness features.

A robust Bayesian Gaussian Regression model is introduced to incorporate the uncertainty and predict peak loads for various marine environmental conditions. A real case study is considered to demonstrate the application of the proposed model. The peak values for the Dynamic Amplification Factor were estimated despite a few numerical simulations.

The results proved good agreement with the real-time data obtained from physical simulation for predicting peak loads in lifting cable.

Industrial goals

Installing large floating objects in offshore operation is a challenging and failure-prone task, especially in the splash zone due to extreme lifting loads on wire and the payloads.

For a safe operation, in the real operation the industry essentially needs to predict the peak loads on the installation system and create an in-advance decision-making scenario for the operating vessel before starting the real operation on site.

To this end, the industry must be supported with an in advance predictive tool that can help to evaluate more accurately the extreme loads on lifting wires. Thus, the main goal is developing advent computer tools for uncertainty reduction and more reliable decision-making, with less time consuming numerical models and quick safety certification on the operation.

Scientific questions

In this study, a particular focus is taken toward lowering lifting objects in the splash zone and predicting the uncertainty of the critical peak loads. To this end, a coupled hydrodynamic simulation and Machine Learning model is

applied to develop a comprehensive data-driven approach for monitoring lifting wire loads during the installation phase.

The present model examined this subsea structure to evaluate the operation's installation efficiency and protect the lifting object and wire responses from experiencing large loads during lowering in the splash zone.

By applying the present predictive model, it is possible to apply the regressed model with less simulation time that followed the physics of the operation in return. Thus, effectively estimating design limits for lifting wire.

Innovations

The present study can provide reliable information about the real-time installation condition and, consequently, improve the prediction accuracy of the lifting system before starting the operation.

Therefore, the model can be adopted as a pre-monitoring decision support system to improve the safety of complex marine operations and increase low-risk operation confidence by providing safety mitigation suggestions.

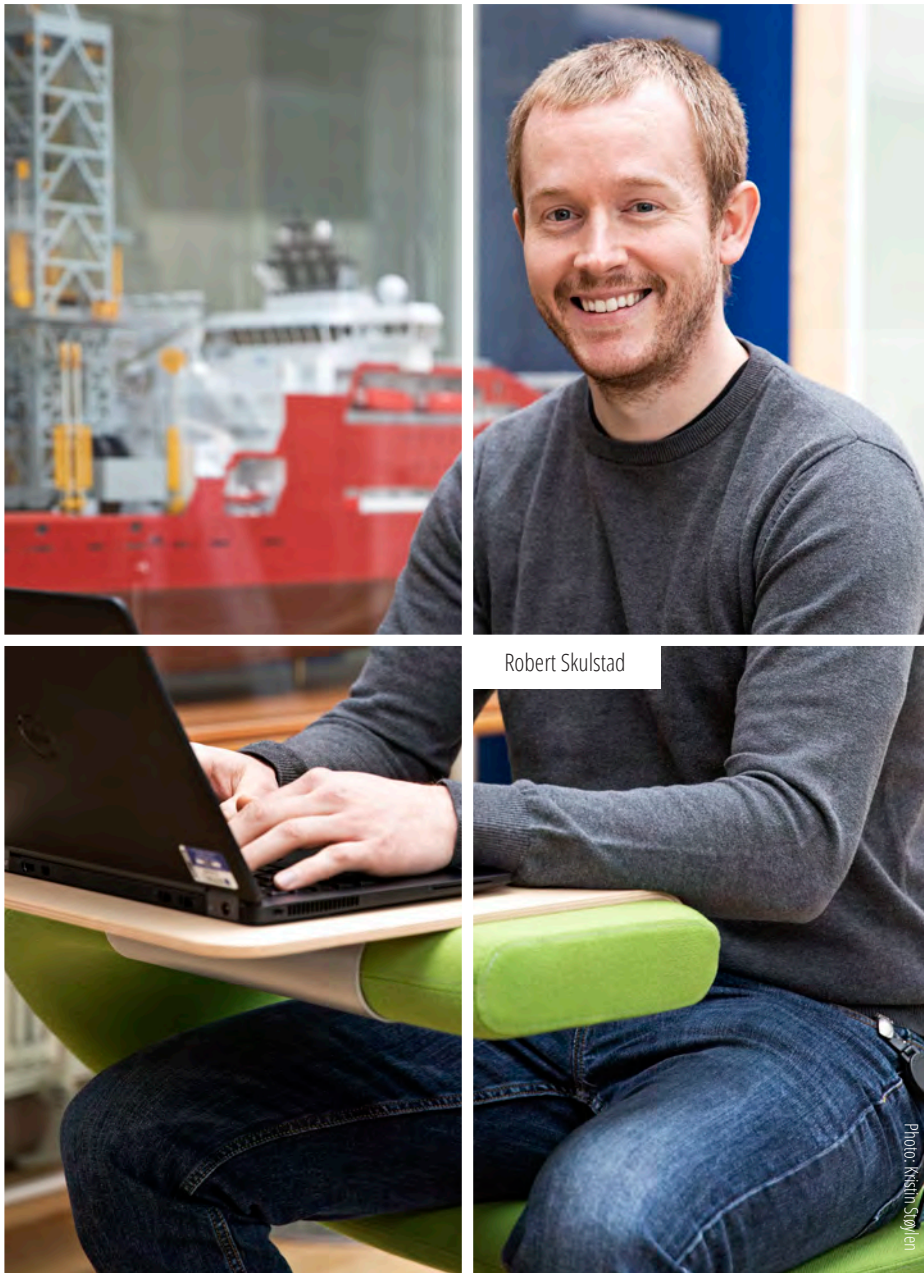
A physics-based learning approach based on the Bayesian Gaussian Regression model to support an intelligent prediction help in estimating extreme loads in lifting wires. In addition, the present model will be helpful for future studies with the concern of health condition monitoring and digitalization in remote sensing, although the focus of this study was the installation of large objects in the splash zone.

Cooperating company

DNV

Supervisor: Bernt Johan Leira (NTNU)

Co-supervisor: Svein Sævik (NTNU)



Title

Hybrid modelling for ship motion prediction

Research topics

- Hybrid modelling, using physics-based models as well as data-based models, to describe and predict ship motion
- Time series prediction models and input selection

Industrial goals

- Decision support for manned and unmanned ships

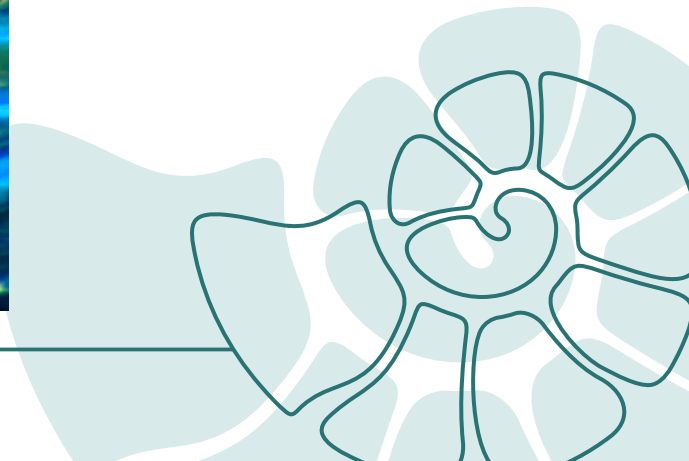
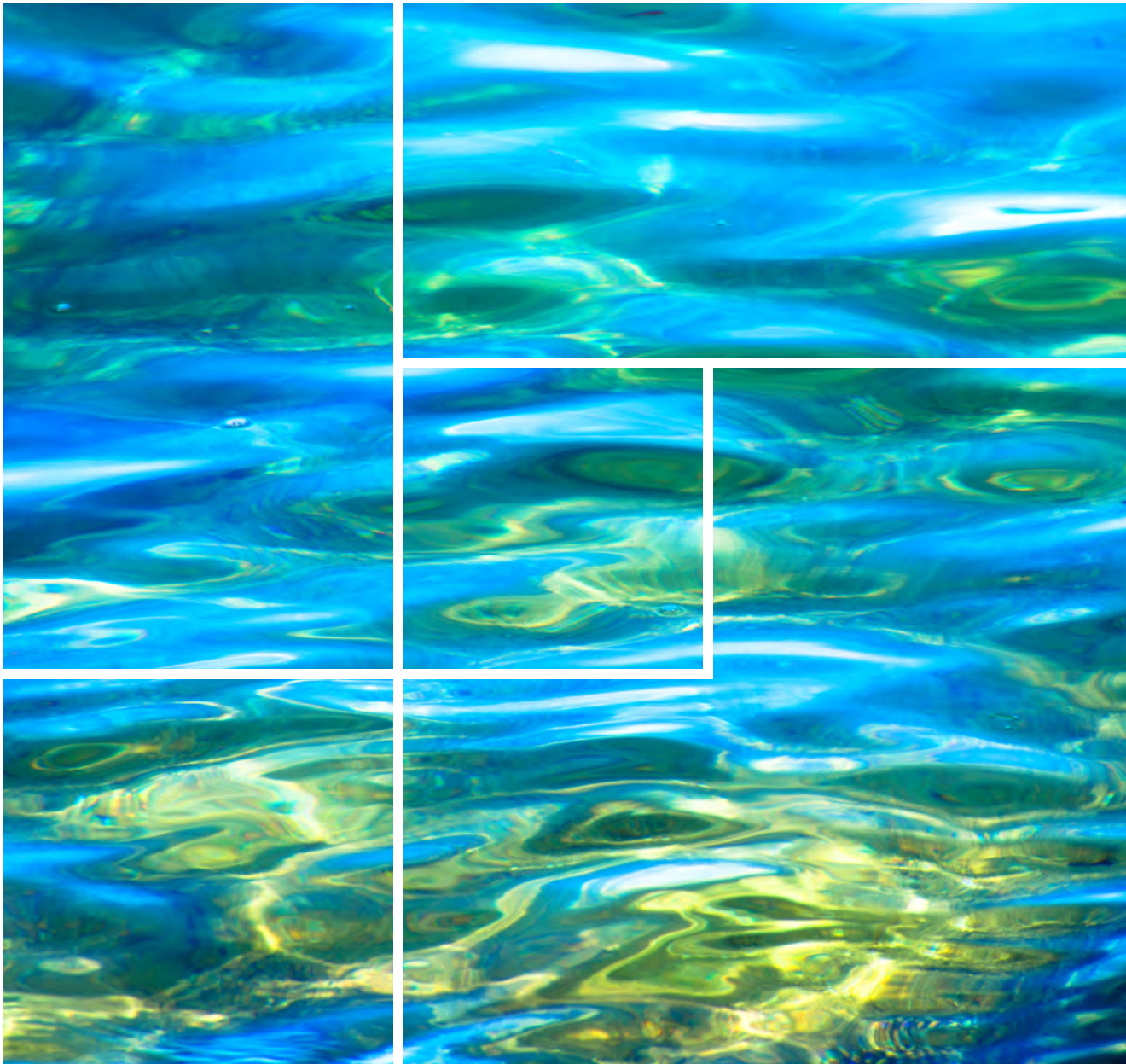
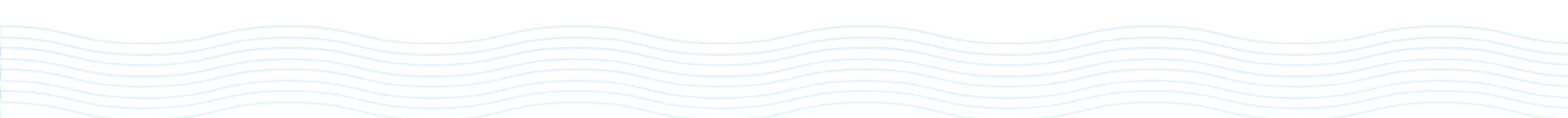
Scientific questions

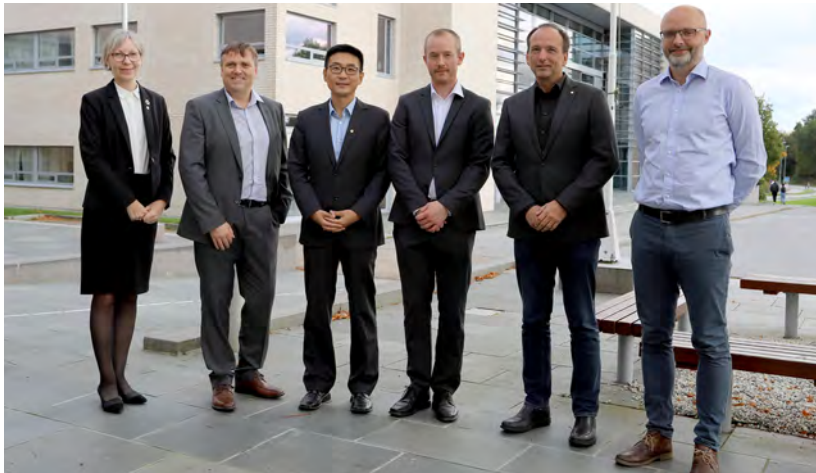
- How can data from sensors on ships be combined in hybrid models to provide accurate predictions of ship motion?

Innovations

- Methods for prediction of ship motion leading to improved efficiency and increased safety at sea

Supervisor: Houxiang Zhang and Hans Petter Hildre (IHB, NTNU)





One of the SFI MOVE PhD students, Robert Skulstad, defended his PhD thesis on Sep. 27th, 2021, at the Norwegian University of Science and Technology (NTNU), Faculty of Engineering, Department of Ocean Operations and Civil Engineering.

Robert Skulstad submitted the following academic thesis as a part of the doctoral work:
«Data-Based Modelling of Ships for Motion Prediction and Control Allocation».

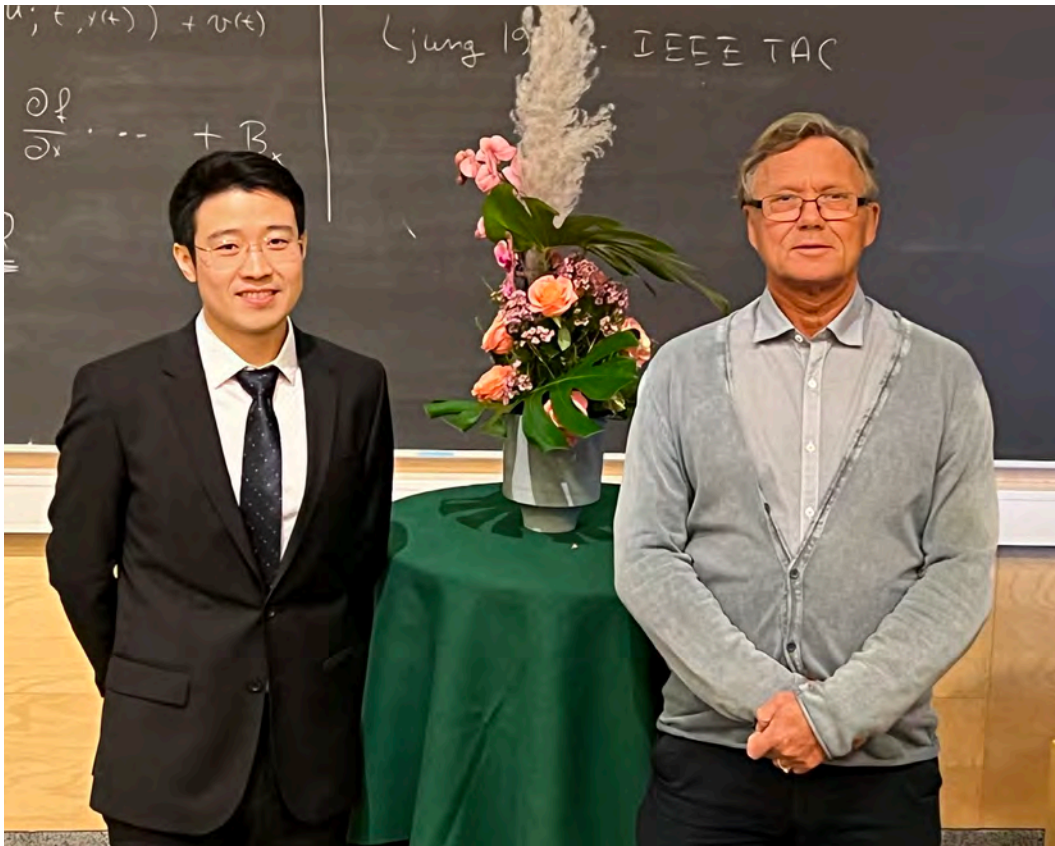
The Faculty appointed the following Assessment Committee to assess the thesis:

- Professor Shuhong Chai, University of Tasmania, Australia (1. opponent)
- Chief Operating Officer Jann Peter Strand, Sperre Compressors, Norway (2. opponent)
- Associate Professor Ann Rigmor Nerheim, NTNU

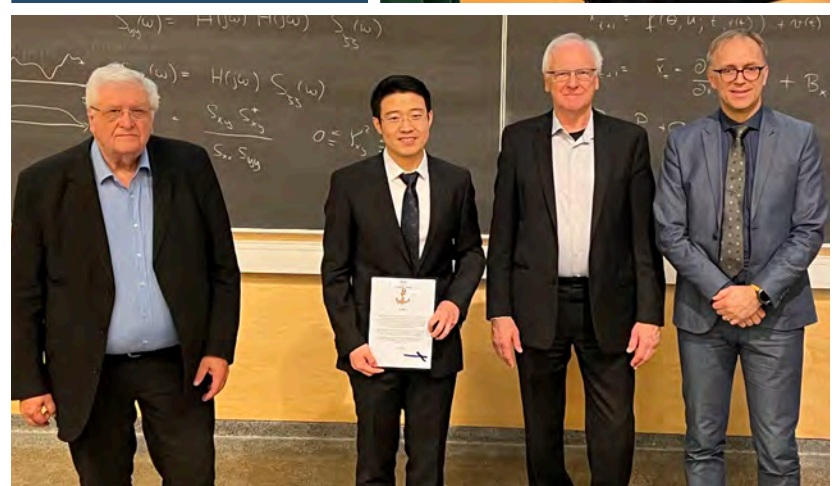
Associate Professor Ann Rigmor Nerheim, Department of Ocean Operations and Civil Engineering, was appointed Administrator of the Committee. The Committee recommended that the thesis was worthy of being publicly defended for the PhD degree.

The doctoral work was carried out at the Department of Ocean Operations and Civil Engineering. The trial lecture took place on September 27th, 2021 at 10:15 at NTNU in Ålesund, on the following prescribed subject: "Provide an overview of different methods and approaches for data-driven modelling, clarify and give a structured presentation of the main terms Neural Network (NN), Machine Learning (ML), Artificial Intelligence (AI) and Deep Learning (DL) etc. Describe the differences between these various methodologies and demonstrate their application in maritime engineering problems".

The public defence of the thesis took place on September 27th, 2021 at 13:15 at NTNU in Ålesund. Professor Houxiang Zhang, Department of Ocean Operations and Civil Engineering, was the candidate's main supervisor. Professor Thor I. Fossen, Department of Engineering Cybernetics, and Principal Engineer Bjørnar Vik, Kongsberg Maritime were the candidate's co-supervisors.



Defens of Thesis Xu Han



The SFI MOVE PhD student, Xu Han, defended his PhD thesis on November 19, 2021, at the Norwegian University of Science and Technology (NTNU), Faculty of Engineering, Department of Marine Technology.

Xu Han submitted the following academic thesis as a part of the doctoral work:
"Onboard Tuning and Uncertainty Estimation of Vessel Seakeeping Model Parameters"

The Faculty appointed the following Assessment Committee for the thesis:

- Professor Mogens Blanke, DTU, Denmark
- Professor Emeritus Ove T. Gudmestad, University of Stavanger
- Associate Professor Karl Henning Halse, NTNU

Associate Professor Karl Henning Halse, Department of Ocean Operations and Civil Engineering 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 November 19, 2021 at 10:15 at NTNU in Trondheim, on the following prescribed subject: "On the role of wave tank testing for vessel design and operational performance".

The public defense of the thesis took place on November 19, 2021 at 13:15 at NTNU in Trondheim. Professor Bernt J. Leira, Department of Marine Technology was

the candidate's main supervisor. Professor Svein Sævik, Department of Marine Technology, Dr. Stian Skjong and Dr. Lars Tandle Kyllingstad, both at SINTEF Ocean, were the candidate's co-supervisors.

Communication and dissemination activities

DISSEMINATION



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

The project has arranged following main conferences/ workshops in 2021:

- Spring conference, at Teams 31.05.21
- Workshop, at Teams 01.06.21
- Autumn conference, at Zoom 29.11.21

The SFI MOVE-program is now starting on the final phase. There are 1 ½ years left and there is now a focus on completing sub-projects. We are also working on what we can achieve after the project is finished.

The program has the following objectives for the final delivery:

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)

Publication highlights



We want to highlight three of the publications from 2021, one related to project 5 (Innovative Installation of Wind Power Systems), one related to project 6 (On-board Decision Tool) and one related to project 8 (Remote Operations/Dispersed Teams).

Project 5 **Sunhun Hong, David Vågnes, Karl Henning Halse and Torodd Skjerve Nord:**

Mechanical Coupling Effect on the Horizontal Response of Floating Offshore Wind Turbine Installation Using a Catamaran with a Low Height Lifting System, Proc 31st Int Ocean Polar Eng Conf, ISOPE, 2021

This paper proposes improvements to the previously presented installation method for installation of floating offshore wind turbines at the operation site using a catamaran. The study shows results on the effect of reducing relative horizontal motions by introducing a mechanical coupling system on the installation method. In the absence of mechanical coupling, the proposed installation method was found to be impractical due to excessive relative horizontal motions between the floating

wind substructure and the lifted wind turbine from the catamaran. Numerical analysis results confirmed that the relative horizontal motions of the two floating bodies might be effectively reduced when a mechanical coupling using fenders and wires is applied. The results of this study suggest that the practicality of the floating wind turbine onsite installation method presented in this paper can be further improved through continuous R&D on the mechanical coupling system.

Project 6 **Xu Han, Bernt J. Leira and Svein Sævik:**

Vessel hydrodynamic model tuning by Discrete Bayesian updating using simulated onboard sensor data. Ocean Engineering 2021, Volume 220. NTNU

The paper presents a procedure for updating the vessel hydrodynamic model based on vessel response measurements, as a contribution towards realising the concept of response-based marine operations. A probabilistic approach was undertaken for updating the important model parameters. Realising that the vessel response includes non-linear effects, a discrete Bayesian

model updating scheme was applied, enabling the update of both parameter values and their confidence level, quantitatively. This represents an important step towards reliability-based marine operations and the reduction of inherent conservatism in the practice of today. The model can be continuously applied throughout the whole lifetime of the vessel, assisting in monitoring, inspection, management, life extension, etc., in accordance with the digital twin concept. A case study demonstrated that the model tuning approach is robust, and stable with respect to signal noise.

Project 8 **Victoriia Koilo:**

Developing new business models: Logic of network value or cross-industry approach. Problems and Perspectives in Management 2021. Volum 19.(2) s 291–307. NTNU

Digital transition in the maritime industry is creating new organizational models and affecting the value chain relationships. Associate professor, Viktoriia Koilo, is investigating key drivers for creating new business models for more remote and autonomous operations, and

conditions for effective implementation of such models.

There are still many uncertainties, especially when it comes to creating value. Furthermore, it is somewhat more difficult to find business models for autonomous ships. One main problem is maintenance. Today, it is cheaper to have people on board than the investments needed to ensure that technical systems do not need supervision during the work. However, more expensive fuel and stronger regulation of emissions can change this. The trend is the same with lower staffing, more automation, as well as new forms of operation and maintenance in today's shipping. In addition, autonomous operation opens for more flexible transport systems at sea, in that more and smaller ships can be used. It can provide better economy plus weight savings that reduce emissions of environmental and greenhouse gases. Thus, today's business models need to change.

There are several external and internal factors that continually drive the development of new business models. Considering the current tendency of the green restructuring and technological development, along with internal factors such as the interfaces in relationships with different industries, it is important to talk about value creation not only from a supply chain perspective, but it should also be considered from a network value point of view. It was proven that the level of innovativeness, growing competency, reduction of asymmetry of information, strengthening of the relationship within the whole supply chain is vitally important for value creation. Therefore, it is needed necessary to develop models, calculation, and simulator tools that gives many test solutions and alternatives within a short time. But for this to be efficient enough, it requires reliable coordination, strong value chain relationships, and other links between companies and industries.



Publications

2021

Erstad, Erlend; Larsen, Marie Haugli.

Cyber Security i praksis - Maritim Cyber Risikostyring. Rederikonferansen21; 2021-09-22 - 2021-09-22
NTNU UIT

Han, Xu; Leira, Bernt Johan; Sævik, Svein.

Vessel hydrodynamic model tuning by Discrete Bayesian updating using simulated onboard sensor data. Ocean Engineering 2021 ;Volum 220.
NTNU

Han, Xu; Leira, Bernt Johan; Sævik, Svein; Kaasen, Karl Erik.

Validation of vessel seakeeping model tuning algorithm based on measurements at model scale. Marine Structures 2021 ;Volum 80.
NTNU OCEAN

Han, Xu; Leira, Bernt Johan; Sævik, Svein; Ren, Zhengru.

Onboard tuning of vessel seakeeping model parameters and sea state characteristics. Marine Structures 2021 ;Volum 78.
NTNU

Han, Xu; Ren, Zhengru; Leira, Bernt Johan; Sævik, Svein.

Adaptive identification of lowpass filter cutoff frequency for online vessel model tuning. Ocean Engineering 2021; Volum 236.
NTNU

Han, Xu; Sævik, Svein; Leira, Bernt Johan.

Tuning of vessel parameters including sea state dependent roll damping. Ocean Engineering 2021; Volum 233.
NTNU

Hong, Sunghun; Vågnes, David; Halse, Karl Henning; Nord, Torodd Skjerve.

Mechanical Coupling Effect on the Horizontal Response of Floating Offshore Wind Turbine Installation Using a Catamaran with a Low Height Lifting System. I: Proceedings of the Thirty-first (2021) International Ocean and Polar Engineering Conference, Rhodes, Greece, June 20–25, 2021. International Society of Offshore & Polar Engineers 2021 ISBN 978-1-880653-82-1. s.628-633
NTNU

Koilo, Viktoriaa.

Business model development by implementing remote operations. SFIMOVE spring conference; 2021-05-31
NTNU

Koilo, Viktoriaa.

Developing new business models: Logic of network value or cross-industry approach. Problems and Perspectives in Management 2021 ;Volum 19.(2) s.291-307
NTNU

Koilo, Viktoriaa.

Evaluation of R&D activities in the maritime industry: Managing sustainability transitions through business model. Problems and Perspectives in Management 2021 ;Volum 19.(3) s.230-246
NTNU

Larsen, Marie Haugli.

Use of Digital Twin Technology in Remote Operations. SFI-Move autumn conference 2021; 2021-11-29 - 2021-11-29
NTNU

Larsen, Marie Haugli; Holmeset, Finn Tore.

The concept of a remote operation center. SFI-Move spring conference 2021; 2021-05-31 - 2021-06-01
NTNU

Larsen, Marie Haugli; Lund, Mass Soldal.

Cyber Risk Perception in the Maritime Domain: A Systematic Literature Review. IEEE Access 202 ; Volum 9. s.144895-144905
NTNU BI FORSV

Stang, Emilie B.; Vatlø, Henrik N.; Utslottøy, Pål.

Cybersikkerheit i maritim industri. Ålesund: NTNU Open 2021 65 s.
NTNU

Mao, Runze; Li, Guoyuan; Hildre, Hans Petter; Zhang, Houxiang.

A Survey of Eye Tracking in Automobile and Aviation Studies: Implications for Eye-Tracking Studies in Marine Operations. IEEE Transactions on Human-Machine Systems 2021 ;Volum 51.(2) s.87-98
NTNU

Pareliussen, Bjarne.

Working across organizations in a dispersed team. SFI MOVE Spring conference; 2021-05-31 - 2021-06-01
NTNU

Pareliussen, Bjarne; Æsøy, Vilmar; Giskeødegård, Marte Fanneløb.

Professions, work, and digitalization: Technology as means to connective professionalism. Journal of Professions and Organization 2021 s.1-15
NTNU

Radhakrishnan, Gowtham.

Digital twins in decision support systems for offshore vessels. SFI MOVE Spring Conference_2021; 2021-05-31 - 2021-06-01
NTNU

Ren, Zhengru; Han, Xu; Verma, Amrit Shankar; Dirdal, Johann Alexander; Skjetne, Roger.

Sea state estimation based on vessel motion responses: Improved smoothness and robustness using Bezier surface and L1 optimization. Marine Structures 2021 ;Volum 76.
NTNU

Ren, Zhengru; Skjetne, Roger; Verma, Amrit Shankar; Jiang, Zhiyu; Gao, Zhen; Halse, Karl Henning.

Active heave compensation of floating wind turbine installation using a catamaran construction vessel. Marine Structures 2021 ;Volum 75.
UIA NTNU

Ren, Zhengru; Verma, Amrit Shankar; Ataei, Behfar; Halse, Karl Henning; Hildre, Hans Petter.

Model-free anti-swing control of complex-shaped payload with offshore floating cranes and a large number of lift wires. Ocean Engineering 2021;Volum 228.
NTNU OCEAN

Ren, Zhengru; Verma, Amrit Shankar; Li, Ye; Teuwen, Julie J.E.; Jiang, Zhiyu.

Offshore wind turbine operations and maintenance: A state-of-the-art review. Renewable & Sustainable Energy Reviews 2021 ;Volum 144.
UIA NTNU OCEAN

Skulstad, Robert.

Data-Based Modelling of Ships for Motion Prediction and Control Allocation. Ålesund: NTNU 2021 (ISBN 978-82-326-6605-8) 139 s.
NTNU

Skulstad, Robert; Li, Guoyuan; Fossen, Thor I.; Wang, Tongtong; Zhang, Houxiang.

A Co-operative Hybrid Model For Ship Motion Prediction. Modeling, Identification and Control 2021 ;Volum 42.(1) s.17-26
NTNU

Slåttnum, Sindre Sagsveen.

Data-driven sea state estimation for a DP vessel based on distributed inertial measurement units. Norges teknisk-naturvitenskapelige universitet 2021 60 s.
NTNU

Wang, Chunlin; Li, Guoyuan; Skulstad, Robert; Cheng, Xu; Osen, Ottar Laurits; Zhang, Houxiang.

A sensitivity quantification approach to significance analysis of thrusters in dynamic positioning operations.. Ocean Engineering 2021 ;Volum 223.
NTNU

Wu, Mengning; Gao, Zhen.

Methodology for developing a response-based correction factor (alpha-factor) for allowable sea state assessment of marine operations considering weather forecast uncertainty. Marine Structures 2021 ;Volum 79.(103050)
NTNU

Xu, Kun; Larsen, Kjell; Shao, Yanlin; Zhang, Min; Gao, Zhen; Moan, Torgeir.

Design and comparative analysis of alternative mooring systems for floating wind turbines in shallow water with emphasis on ultimate limit state design. Ocean Engineering 2021 ;Volum 219.
NTNU



Master's degrees

Name	Sex M/F	Topic
Øywind Trones	M	Situational awareness in RLWI operations
Sindre Sagsveen Slåttum	M	Data-driven sea state estimation for a DP vessel based on distributed inertial measurement units
Bjørn Wilhelm Jæger	M	Numerical Study on Offshore Wind Turbine Blade Installation by Utilizing a Floating Vessel
Laura Slootweg	F	Single blade installation with a floating monohull crane vessel – Environmental limits and Tagline control
Shuzhou Jiang	M	(Joint thesis) Installation of an offshore wind turbine blade using a jack-up installation vessel in water depth of 60 m
Taewoo Kim	M	(Joint thesis) Installation of an offshore wind turbine blade using a jack-up installation vessel in water depth of 60 m



Accounts

- Project 1: OW: Low Cost Offshore Wind Installation and Maintenance – 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
 Project 7: Design for Workability – was completed in 2020

(All figures in 1000 NOK)

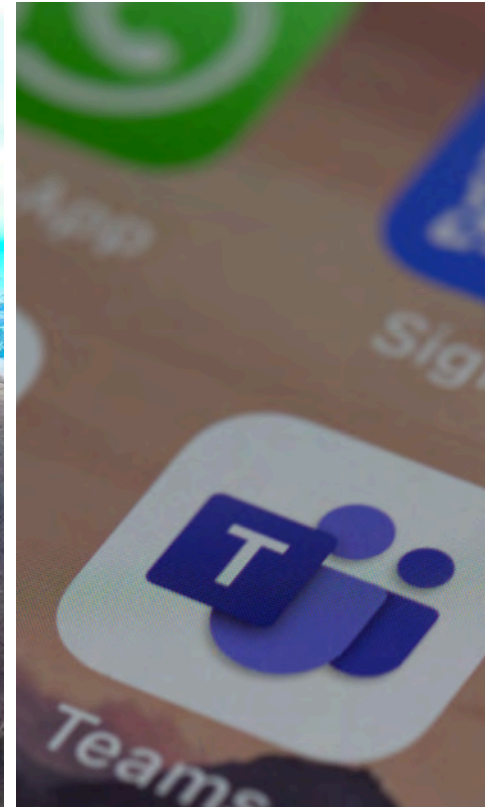
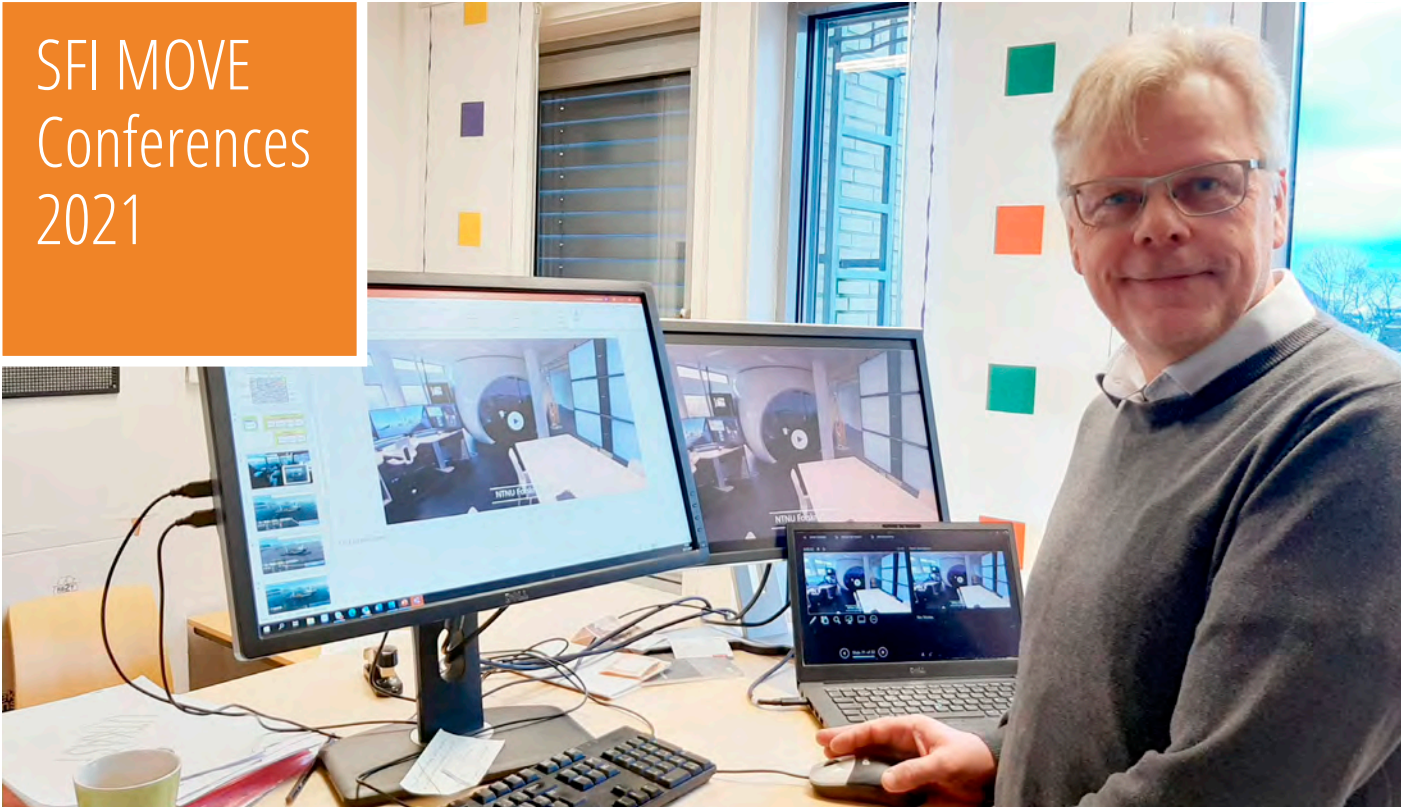
Funding		Project 5	Project 6	Project 8	Lab/Dissemination	Management	Total
The Research Council		5 487	4 523	317	156	1 171	11 654
The Host Institution, NTNU in Ålesund		272	-	1 068	-	-	1 340
Research partners:		256	2 836	-	-	-	3 092
	NTNU	235	1 760	-	-	-	1 995
	SINTEF	21	1 076	-	-	-	1 097
Enterprise partners:		1 189	2 645	1 002	400	100	5 336
Total		7 204	10 004	2 387	556	1 271	21 422

Costs		Project 5	Project 6	Project 8	Lab/Dissemination	Management	Total
The Host Institution, NTNU in Ålesund		5 959	389	1 785	556	1 267	9 956
Research partners:		656	8 970	-	-	4	9 630
	NTNU	573	4 664	-	-	4	5 241
	SINTEF	83	4 306	-	-	-	4 389
Enterprise partners:		589	645	602	-	-	1 836
Public partners		-	-	-	-	-	-
Equipment		-	-	-	-	-	-
Total		7 204	10 004	2 387	556	1 271	21 422

Name of ongoing projects in 2021:

- Project 5: OW: Installation and Service of Floating Wind Power Systems
 Project 6: On-board Decision Tool
 Project 8: Remote Operations / Dispersed Teams
 RA 5: Lab/Dissemination
 RA 6: Management

SFI MOVE
Conferences
2021



Due to the corona pandemic, both conferences in 2021, as in 2020, were carried out digitally on Teams and Zoom. 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 the last two year's digitally conferences.

Here is the program for the conferences in 2021:

Spring Conference, May 31

09.00 Welcome, Hans Petter Hildre

- Introduction, Henning Borgen
- Vessel motion prediction, Gowtham Radhakrishnan, NTNU
- Response based operations and rules, Tormod Bøe, DNV
- Open Simulation Platform, Levi Kristian Jamt, DNV

10.30 Innovative Installation of Wind Power Systems

- Introduction, Karl Henning Halse
- Marine operations and floating wind, Christophe Bekhouche, Aker Offshore Wind
- Numerical Model Update and Dynamic Analysis of a Floating Offshore Wind Turbine Installation, Sunghun Hong, NTNU
- Hydrodynamic response of a SWATH vessel for installation of assembled offshore wind turbines, Ting Liu, NTNU

11.45 Remote operations/Dispersed teams

- Introduction, Marie Haugli Larsen
- Preparing for remote operations, Øystein Engelhardtson og Arnstein Eknes, DNV
- Working across organizations in a dispersed team: Possibilities and pitfalls, Bjarne Pareliussen, NTNU
- Business model development by implementing remote operations, Viktoriia Koilo, NTNU

12.50 Some final remarks, Hans Petter Hildre

Workshop, June 1

- 09.00 **On-Board Decision Tool**
- 10.30 **Innovative Installation of Wind Power Systems**
- 12.00 **Remote operations/ Dispersed teams**

Autumn Conference, November 29

09.00 Introduction, Hans Petter Hildre

09.15 Remote operations

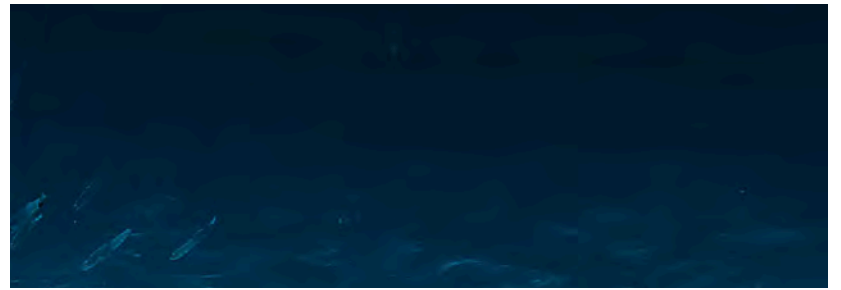
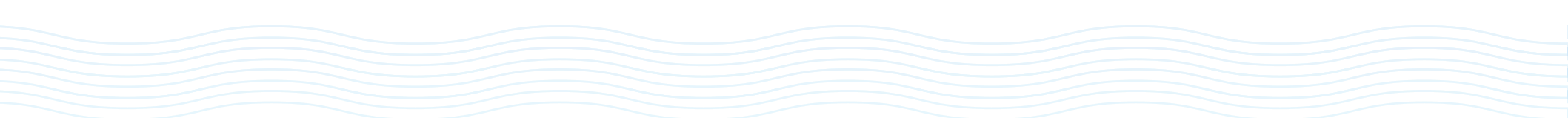
- Introduction, Marie Haugli Larsen
- Case: Remote Operations, Anton Westerlund, Kongsberg Maritime
- Use of digital twin technology in remote operations, Marie Haugli Larsen
- Designing business models for the future of marine remote operations, Viktoriia Koilo, NTNU
- Digital transitions in maritime organizations, Bjarne Pareliussen, NTNU

10.45 On-board decision tool

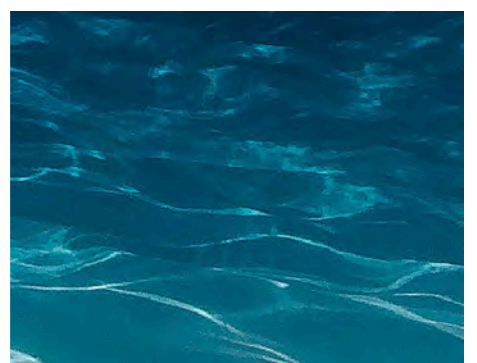
- Summary of activities and main findings, Henning Borgen
- Case: On-board decision tool for stability evaluation, Øystein Johannessen, Equinor
- Shielding effects – Why and how, Øyvind Ygre Rogne, Sintef Ocean
- Tuning of vessel models in an on-board perspective, Lars Kyllingstad, Sintef Ocean
- PhD + PD

13.30 Innovative installation of offshore wind system

- Intro and summary of activities, Karl Henning Halse
- Case: Installation of offshore wind, Christophe Bekhouche, Aker Offshore Wind
- Hydrodynamic response – effect of mechanical coupling between vessel and SPAR, Sunghun Hong, NTNU
- Hydrodynamic response – effect of alternative installation vessels, Ting Liu, NTNU
- Relative motion OWT-SPAR – behavior of lifting mechanism, Behfar Ataei, NTNU
- Framework for co-simulation using FMI/FMU, Shuai Yuan, NTNU
- Hydrodynamic response of floating dock in waves, Mael Moreau, NTNU



Research
organisation

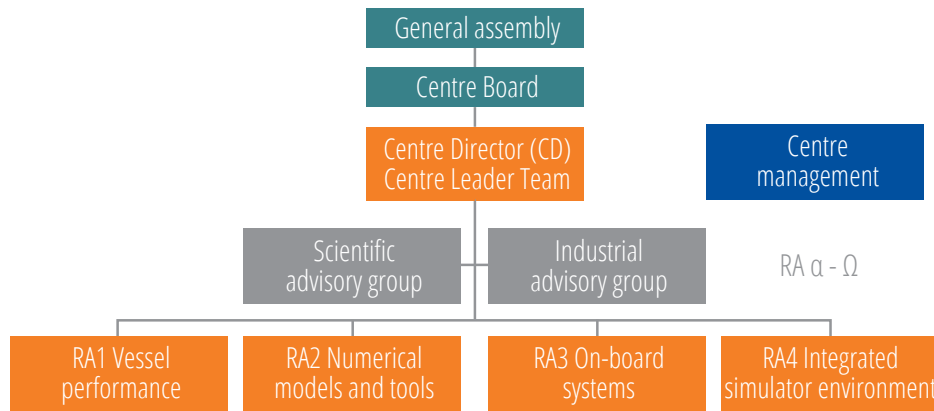


The following research partners were involved in 2021:

- 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 Aquaculture 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
Remote Operations/Dispersed Teams	Marie Haugli Larsen, NTNU

The Board of the Centre had the following Members in 2021:

- Rafael Rossi, Chairman (TechnipFMC)
- Erling Myhre, (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 and ÅKP/GCE Blue Maritime 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 2021 were:

- Olympic Shipping
- Havila Shipping
- Kongsberg (former Rolls-Royce Marine)
- Ulstein International
- OSC
- Vard
- NTNU Ocean Training
- Equinor
- Havfram (former Ocean Installer)
- DNV (former DNV-GL)
- Subsea 7
- TechnipFMC



