POAC`15
Trondheim, Norway

Proceedings of the 23rd International Conference on
Port and Ocean Engineering under Arctic Conditions
June 14-18, 2015
Trondheim, Norway

A Framework for a Design and Optimization Platform for Ships in Arctic Conditions

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ABSTRACT

Climate changes and recent discoveries of hydrocarbon resources in the High North have strongly influenced research and development activities in arctic marine and offshore industries, resulting in new design approaches, methods and tools. These are, however, usually not readily available and rarely appear as a full ship design package, which lead to the objective of this study: The development of a design and optimization platform for ships in arctic conditions. This software framework will incorporate most of the significant aspects relevant to the design of arctic ships. These aspects are the topics of a series of research projects by the Sustainable Arctic Sea Transport (SAST) research group at NTNU's Marine Technology Department.

The design process within the framework commences with a module for the mission definition and the ship's operational profile. Based on these requirements the corresponding route-specific ice conditions are obtained from an integrated database. The mission specifications and expected ice condition scenarios provide the constraints for the optimization procedure. The analysis of the ice-ship interaction takes place in the framework modules being currently developed within the SAST group. These methods cover the area of ice-breaking pattern and local ice loads, ice resistance prediction, estimation of sliding resistance, machinery response and propulsion evaluation, structural response to service and accidental ice loads, followed by an assessment of the accidental consequences. The final step in the optimization routine is a compliance module that assesses whether the design goals are met or if further optimization iterations are required. The modules listed above, their interdependencies and the design and optimization process will be systematically described in the paper.

The main feature of the software framework will be the optimization of a ship under the specified constraints and operational conditions. In addition, the platform will offer numerous further applications, e.g. detailed performance assessment of new or existing designs, simulation-based design selection, selection of ice class, hull form, machinery elements, etc. Furthermore, the framework will

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allow the use of each module individually and is intended to provide a knowledge base of the SAST research results. In its full development stage, the platform will allow the visualization of the ship-ice interaction modules and, once completed, will be publicly available.

INTRODUCTION

The Arctic shipping, including upstream and downstream transportation to and from northern locations, as well as transit shipping between continents and global markets, is under development. Although, the Arctic shipping cargo flow can be still considered as relatively small compared to global cargo shipping volumes, the Arctic environment with its sensitive nature and valuable resources requires a 'sustainable' approach for arctic ship transport.

The term sustainable in this context defines the requirement to find the best compromise between ecological, economical and engineering considerations. Ecological, with respect to the prevention of accidents and recovery of oil spills and economical, with respect to the establishment of an efficient transport system. The remoteness of the arctic region and its harsh conditions create numerous engineering problems with respect to hull shape, structural safety and propulsion requirements.

The SAST research group at NTNU's Marine Technology Department addresses these challenges with a series of research projects which are presented in the next section.

The purpose of the development of a design and optimization platform for ships in arctic conditions is to create a software framework that allows to connect these research projects, provide an interface to access the different methods and establish a common data structure in order to exchange data between the projects.

Once the concept of the design and optimization platform is fully implemented, it will provide numerous possible applications: The individual use of the research methods through a common data interface, the coupling of several methods in order to utilize synergy effects and finally, the optimization of certain design parameter. Furthermore the platform can be used to test ships designs under ice loading and develop transport scenarios in arctic conditions.

PLATFORM CONCEPT

Figure 1 shows a simplified illustration of an ship in arctic conditions and the blue and green blocks indicate the different projects within the SAST research group. Each 'block' represents a software module in the computational framework. The modules are grouped into two categories: the blue modules are coupled to three research projects that model the ship in a more global scenario view by methods related to control theory. The green modules belong to the category of projects that model the ice-ship interaction in direct physical way.

The methods of the SYS module can be used to model a complete ship fleet system, the LOG module is concerned with the transport logistics of e.g. offshore supply vessels and the ENV module will use to ice-ship interaction methods to predict the environmental impact of accidents in arctic conditions.

The two modules MAP and ICE play a special role. The MAP module is an intermediate layer between the scenario control modules and the ice-ship interaction. It used the the transport task from the mission definition to determine a route and predict the ice condition along the route which can then be passed to the other ice-ship modules as boundary conditions. The ICE module is not directly connected to the other modules, but will provide the properties and material law for ice.

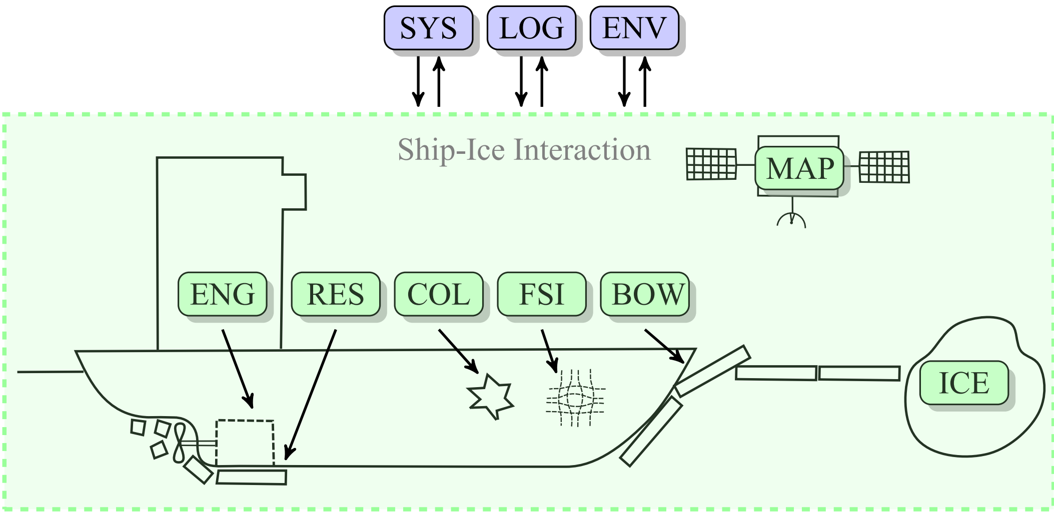

Figure 1: Design and optimization platform overview

The remaining five modules have arrows pointing to ice-ship interaction effects their research projects are related to. The BOW module can be used to predict the ice breaking and loads on the ship bow. The next module FSI allows to determine the ice load and structural response in service conditions, while the COL module is used to simulate the effects of collision events. The RES module provides methods to predict the sliding resistance of a ship in ice and the ENG module simulates ice-propeller interaction and its influence on the machinery.

The objective of the design and optimization platform is to provide a common environment that provides an access to the collection of computational methods and simulation tools developed within the SAST group.

Once all components and coupling procedures for the software framework are implemented, the platform can be used in several ways. Each module will be accessible individually or by conducting a complete ice-ship interaction analysis. Once fully developed the platform can be used to optimize ship design parameter. Another possible application is to use the platform to test external ship designs for their performance in arctic conditions.

RESEARCH PROJECTS

Each module presented in Figure 1 is connected to one of the research projects briefly summarized in the following paragraphs.

Overview of the ship-level ice interaction model [BOW]

One of the main tasks in the research project is to develop a methodology for modeling the icebreaking pattern of ships in level ice and the development of a numerical simulation procedure for ship-level ice interaction. Figure 2 shows the general process of icebreaking. In continuous bow-first operation mode, a ship enters an unbroken level ice sheet. The initial contact between ice and a ship hull takes place at the very fore part of the bow. The penetration of the stem into the ice edge initiates the process of ice edge crushing, in some cases a longitudinal crack is formed. The level of forces generated by crushing strongly depends on the bow form. This mode of ice failure continues until the vertical component of the interaction force is sufficiently high to cause bending failure of an ice sheet at a certain distance from the contact zone. At the end of this repetitive process, roughly semi-circular pieces - so called ice cusps - break from the ice sheet off Thereafter, almost instantaneously, depending on numerous parameters (e.g. ship speed, bow shape, ice thickness), the contact zone reaches fore shoulders, accompanied by producing ice cusps that bulk up the area surrounding the bow. As a result, the advancing ship motion creates a channel of a certain pattern underneath and behind the vessel.

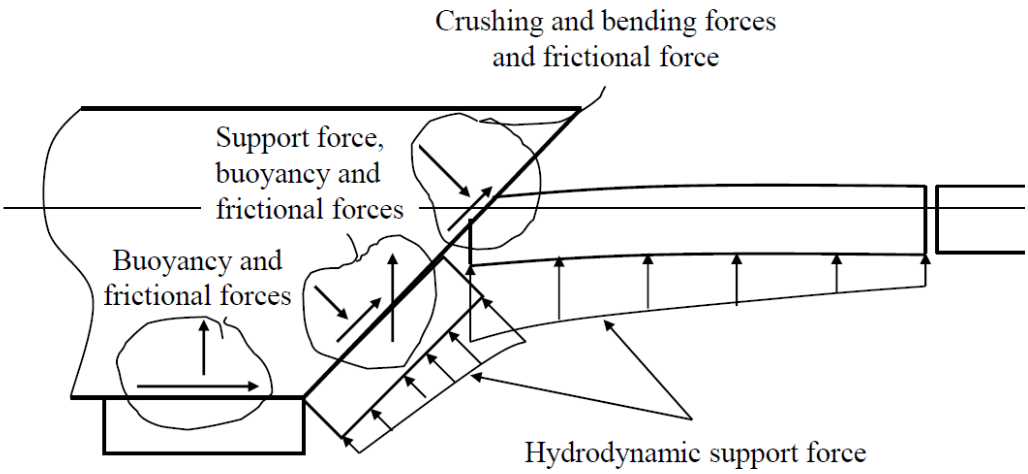

Figure 2: A schematic representation of the ship-level ice interaction [Riska, 2010]

Numerical models of ship-ice interaction and icebreaking phenomenon have grown in popularity as the computational capabilities increased (e.g. [Naegle, 1980], [Lindström, 1990], [Valanto, 2001], [Liu et al., 2006], [Martio, 2007], [Nguyen et al., 2009], [Sawamura et al., 2009], [Su et al., 2010], [Lubbad and Løset, 2011] and [Tan et al., 2013]). However, most of these methods have been developed based on predefined icebreaking patterns, derived from observations from model- and full-scale tests (e.g. [Naegle, 1980], [Kotras et al., 1983], [Wang, 2001]), which may not be apt for a variety of hull forms or an even wider diversity of ice conditions ([Erceg et al., 2014b]).
One of the most valuable outcomes of the research project will be a more realistic icebreaking pattern, that is sensitive to the bow shape, interaction velocity and ice properties. In addition, knowing the icebreaking pattern will facilitate the prediction of ice-induced forces acting onto the ship hull and their distribution, as well as the calculation of the icebreaking component of ship's level ice resistance.

Consequence assessment following design relevant service actions in ice [FSI]
Ships navigating in ice-covered waters experience ice loads and ice-induced damages, [Kujala, 1991]. Therefore, their structures have to be able to withstand these loads, making structural design paramount. During ice-structure interaction, protrusions and gaps on the ice face ensure that the real contact area is never distributed over the whole nominal area. As a result, areas of high local force – high-pressure zones will form, [Jordaan, 2001]. Additionally, the observed load has a line-like nature, where the loading height is just a fraction of ice thickness, [Riska, 1991].

To achieve compliance with classification societies' rules, analysis of ice loads is achieved through the introduction of a uniform pressure patch applied to the hull surface, [Riska and Kämäräinen, 2011]. That approach does not account for the high degree of spatial and temporal variations observed in ice load measurements, which are inherent to the ice failure process, see [Taylor and Richard, 2014] and [Erceg et al., 2014a]. Additionally, it applies general safety margins for different structural elements and does not account for exposure of a vessel to ice crushing, see e.g. [Taylor et al., 2010] and [Ralph and Jordaan, 2013].
The current work addresses highlighting the importance of considering the effect of spatial load distribution in hull design. The response of the structure using the rule-based method is compared to pressure distributions obtained in field measurements (see [Erceg et al., 2014a] and [Ehlers et al., 2014]) and design load obtained using the probabilistic method for design of arctic ships, [Erceg et al., 2015]. The presented results clearly indicate the need to consider the line-like contact including high-pressure zones. Consequently, utilization of a simplified non-uniform pressure patch (SNPP) is being developed as an alternative to the rule-based ice load application model, [Ehlers et al., 2014].

Experimental and numerical investigation of the model ice failure process [ICE]
The definition of ice properties has been and still is a challenge. Ice is a complex non-homogeneous, non- isotropic and crystalline material (see e.g. [Assur, 1958]), but the representation of ice properties is often simplified in analyses due to its complex nature. [von Bock und Polach and Ehlers, 2014] demonstrated the variation of engineering stresses with the variation of specimen dimensions. The definition of actual material properties may be supported by numerical simulation such as finite elements, FE. Therefore, [von Bock und Polach et al., 2013] conducted systematic model-scale ice property tests and analyzed them with FE-simulations.
The results presented in [von Bock und Polach and Ehlers, 2013] delivered actual material parameters for the model-scale ice of Aalto University. Model-scale ice was favored over sea ice due to its availability, its good performance in full-scale predictions [Riska et al., 1994] and the larger specimen set number and the lower costs compared to experiments with sea ice.
The numerical model of the Aalto model scale ice revealed that the behavior is not linear elastic as generally assumed, but has a low yield strength after which a hardening modulus governs the deformation process (see [von Bock und Polach and Ehlers, 2013]). The accumulated damage represents the softening in the deformation process. Furthermore, the built model accounts for inclusions of air and water and is modeled on grain size level to represent the physical constitution as close as possible. As [von Bock und Polach and Ehlers, 2014] indicated - based on the work of [Gürtner, 2009] - the found behavior of Aalto model-scale ice may principally apply also on other model-scale ice types.
In order to actually include the material model into the presented framework (Fig. 1), the data of additional ice sheets has to be implemented and the systematic experiments presented in [von Bock und Polach et al., 2013] have to be repeated for sea ice.

Ice induced design loads for ships operating in the Arctic [MAP]
Current design rules for ships operating in the Arctic are not based on statistical load data of operational area in question and therefore actual risk level is unknown. In order to improve this, a probabilistic methods to estimate design loads could be used linking route specific ice conditions with design loads. [Ralph and Jordaan, 2013] present applicable probabilistic design load method for ice induced design

loads. The method combines suitable parent distribution (see e.g. [Jordaan et al., 1993], [Taylor et al., 2010], defined from full-scale measurements, with number of estimated annual interaction with ice along the defined route. The number of annual interactions is estimated using available data from satellite sources from past. [Tõns et al., 2015] will present probabilistic design load method applicable for Northern Sea Route.

Performance of ships in ice [RES]

The assessment of the ship performance in ice covered waters has become more and more important in view of the increased interest in Arctic field logistics and transportation. The performance of ice breaking ships is usually defined by their ability to proceed in uniform level ice, where good performance means low ice resistance, high propulsion efficiency and continuous ice breaking.

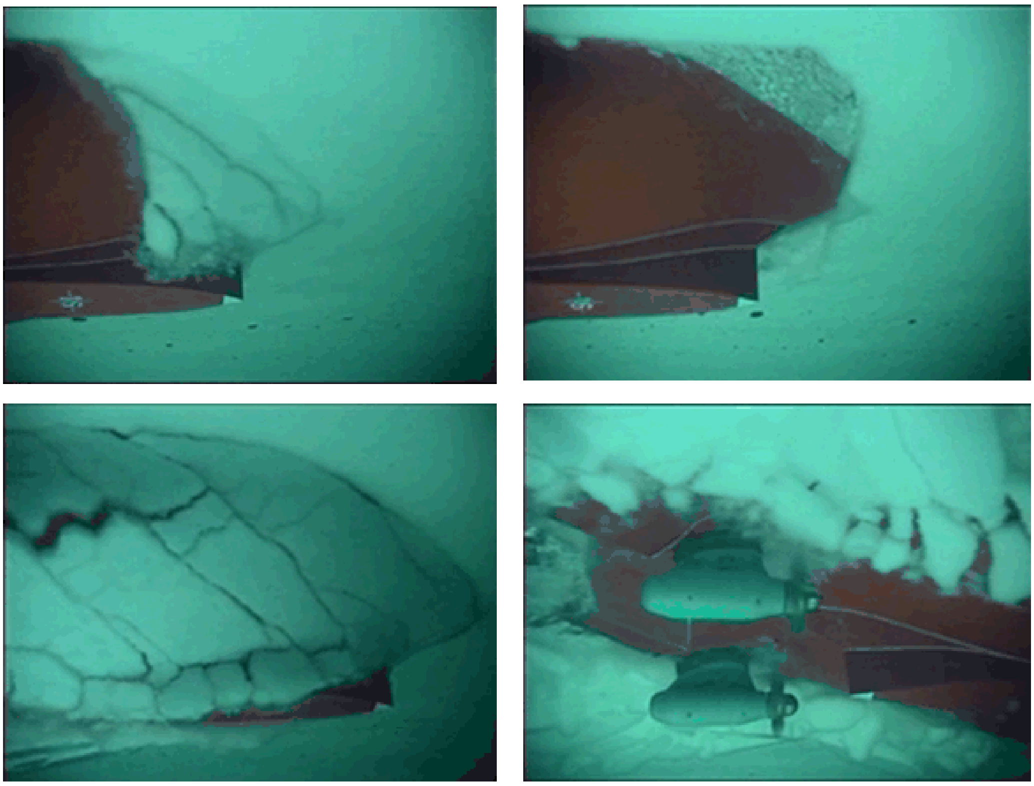

Figure 3: Ice breaking model test at HSVA [Myland and Ehlers, 2014]

Within the research project the effects which contribute to the total resistance of a ship operating in level ice are investigated. Especially the ice breaking in the bow region and the sliding process are of interest to analyze potential propeller-ice interaction. The results from past and future model tests, conducted at HSVA (Fig. 3, [Myland and Ehlers, 2014]), are used to identify the influence of hull shape parameters and ice conditions on the breaking process and thus the ice resistance. Finally an assessment method to evaluate hull shapes of common ice breaking ships, such as Anchor Handling Tugs and Ice breaking Supply Vessels is developed.

By now, an examination of the effects which contribute to the total resistance of a ship operating in level ice was carried out on the basis of model test results. In particular influences of hull shape parameters and ice conditions on the ice breaking process were determined. The application of a semi-empirical approach served for identification of the individual resistance contributions and a comparison to model test results outlined the limitations of the method. A systematic comparison of existing, representative ice resistance prediction methods has been performed. Finally, the incorporation of the ice resistance contributions in the different prediction methods was presented and differences were determined [Myland and Ehlers, 2014]. Based on the knowledge gained an assessment of the assumptions and simplifications of the numerical methods was carried out.
Presently, the ice breaking at the waterline is further investigated by help of existing model tests results. The detailed analysis is done by use of breaking patterns with respect to relevant hull shape parameters as identified for common ice breaking ships of today. The application of the results on an existing semi-empirical method leads to an adjustment of the approach in terms of the ice resistance component which is related to ice breaking for the named common ships.

Propulsion machinery response simulations under ice-related torque load [ENG]
The design of a propulsion system is depends on operational requirements (ship speed and usage), limiting conditions of the hull shape and the load conditions. Under normal conditions the load on the propulsion would be more or less steady (assuming calm water condition) and predictable fluid forces. In an Arctic environment these load conditions become more complex because stochastic events like ice-propeller interaction have to be considered. The aim this of this research project is to address this problem by the development of an simulation model of the propulsion system that is able to process these stochastic events.
The propulsion machinery is a coupled system, connecting the main diesel engine or electrical motor through a transmission line with the propeller, which is used to generate a directional thrust to move a ship across open and ice-covered water. Irregularly the submerged ice pieces, broken by the ship hull, hit the propeller blade and result with the ice-related load. This transient propeller load is transmitted – in form of propagating energy – through the transmission line to the diesel engine, thereby generating a dynamic response in all mechanical elements of the system. Figure 4 shows the two step approach that is used to compensate the dynamic response: First, by establishing a correlation between the ice-related torque load and propeller shaft torque response and secondly, by use this correlation to develop an inverse model of the system.
[Polić et al., 2014] presented this correlation as a function of the inertia and stiffness of propeller and propeller-shaft, using a simple bond graph model. The simple inverse model with a rigid or flexible propeller shaft was derived from the main model by reformulating the governing equations of the main model. The prediction quality of both models and the influence of the sampling frequency are evaluated by the 'residual' module in Figure 4 which compares the deviation between initial and inverse propeller load.

Consequence assessment of accidental ship and ice impact [COL]
This project is focused on the research of the global and local behavior of ice and structures under Arctic conditions [Ehlers and Østby, 2012]. Part of the research is the investigation of accidental events which will contribute to the risk assessment of shipping in the arctic region. The phenomena

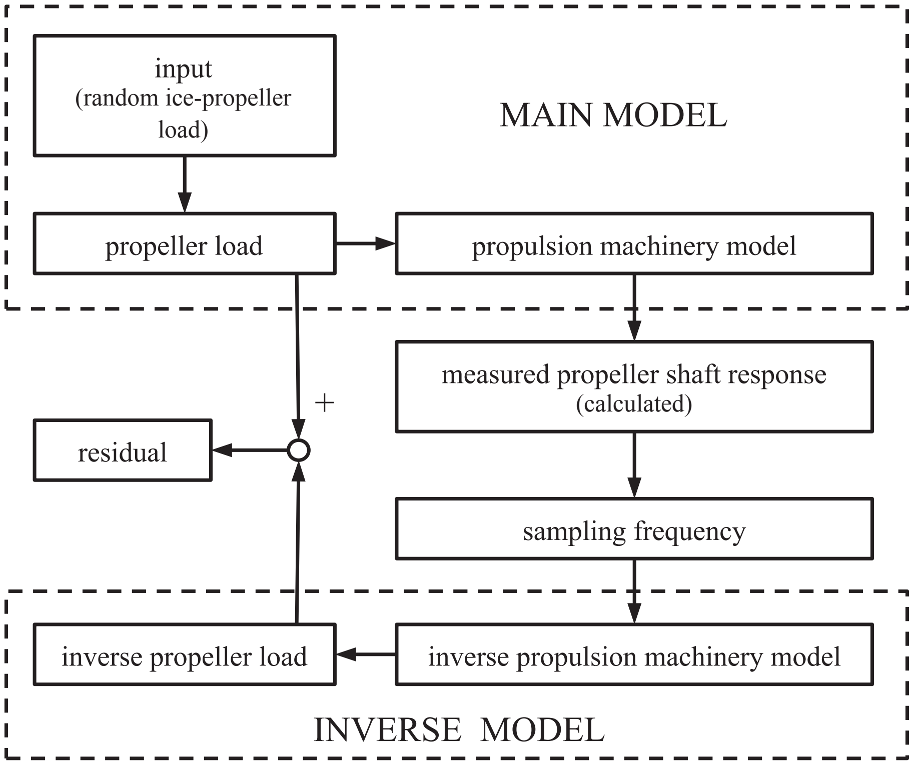

Figure 4: Overview of the transformation procedure to convert the propeller shaft torque to the propeller torque load

that have to be considered in ice-ship impact simulation range from physical effects of ice and steel on a microscopic length scale over fracture initiation and propagation up to the global ship response due to ice loads.

In order to investigate the bending and crushing failure of sea ice on a local scale the mesh free method of Smoothed Particle Hydrodynamics (SPH) is used. The capability of this numerical simulation method has been evaluated for bending and crushing separately. [Das et al., 2014] compared the force, displacement and failure time of the SPH method with the results from experimental in-situ four-point bending test and FEM computations. The performance of SPH to simulate crushing failure will be tested by comparison to the experiments conducted by [Häusler, 1977].

In the next step, the method will be further extended to provide the capability to simulate a ship progress through level ice. The methods developed within this project will contribute to the computational framework by providing tools that help to understand the physical principles of the key phenomena and to minimized overall uncertainties in the risk-based design of ships.

Risk-based design methods and risk mitigation measures for arctic ships [SYS]

An arctic ship can be considered as a component of an arctic sea transport system that often includes icebreakers. Therefore, when designing an arctic ship, a holistic approach is necessary. To this aim, this module provides a method for design of cost-efficient and robust arctic sea transport systems, which might consist of one or multiple arctic cargo ships, a fleet of icebreakers, and port-based facilities such as cargo storages.

The design of such a transport system requires the consideration of several arctic specific parameters, including environmental parameters (e.g., future sea ice conditions), vessel parameters (e.g. ice loads and resistance), operational parameters (e.g., availability of icebreaker support), and financial parameters (e.g., future icebreaker fees). This is challenging, due to the resulting complexity and the fact that there is typically a significant degree of uncertainty in several of those design parameters. To facilitate the management of the parameter uncertainty in the design process, the proposed method integrates risk management in to the design process, i.e., it utilizes the principles of Risk-Based Design (RBD). RBD is already being applied on ships to manage safety risks, i.e., risks to human life. In particular, it is being applied on large passenger ships to manage safety risks related to flooding and fire. In the present method, we extend its application beyond safety to the management of operational and financial risks related to arctic shipping.

Work that has been carried out to date is documented in two conference papers. [Bergström et al., 2014b] present a design approach that makes it possible to, for assumed environmental and operational parameters, design an arctic sea transport system for a specific transport task in terms of the required number of vessels and vessel parameters such as capacity, speed (both in open water and in ice), and ice class. [Bergström et al., 2014a], present an additional approach that, for a specific transport task, makes it possible to compare various ice mitigation strategies (e.g. use of ships with a high ice class that enable independent operation vs. use of ships with a lower ice class that require icebreaker support) in terms of costs for various future ice condition scenarios.

Arctic field logistics and Trans-Arctic shipping [LOG]

The potential usage of transarctic shipping routes can be assessed through comparison between traditionally used shipping lanes and transarctic shipping lanes. The evaluation is performed mainly by assessing the financial justification of an investment into an ice-class, necessary for sailing the Arctic routes. The relation between the investment into an ice class (together with some additional costs imposed by sailing in the Arctic) and the potential of fuel saving, due to shorter distances through the Arctic, is the main variable influencing the economical feasibility of the system.

The research project objectives are twofold: it is concentrated on the analysis of transarctic shipping lanes at one hand; and the development of Arctic-compliant logistic systems for offshore operations at the other.

Under the topic of Arctic-compliant logistic systems for offshore operations, the development is focused on the upstream part of the supply chain for an offshore oil and gas field in the Arctic. The influence of Arctic-specific conditions on the supply chain of the offshore installation is assessed and the required measures for keeping the effectiveness of the supply chain at the desired level are proposed [Milaković et al., 2014]. The optimal fleet composition and the usage of multi-purpose supply vessels, as well as the usage of forward-based supply bases are some of the concepts taken into consideration.

Both research topics are approached from an economical feasibility perspective, and thus economically sustainable business models for both research areas are being searched for. The overall goal of the project is to develop an integrated decision support tool that can be used for assisting in the decision-making by the involved stakeholder. This is to be achieved through the development of simulation-based decision support tools for both transport systems which finally will be unified into one tool. Simulation-based models are being developed by using mathematical representations of the systems with the aim to create a better understanding of the interlinkages between the system's components. Once implemented the models can be used to conduct various sensitivity analysis tests, thus evaluating the robustness of the proposed transport system.

Environmental risk assessments of shipping in ice covered waters [ENV]

Today, there are standardized methods for definition of the polluter's financial liability for environmental damage caused by an oil spill; however, there is an uncertainty in defining which method will be applied in the real case with an accidental spill of liquid hydrocarbons [Bambulyak et al., 2014].

Accidental probability assessment can be based on simulations and navigation data. Consequences analysis are made by using existing internationally approved rules for financial liability definition, national methods for calculating environmental damage compensation ([IOPC, 2014], [Bambulyak et al., 2014]) or environmental impact assessment based on probable ecosystem services loss [Boyd, 2010] with seasonal and spatial distribution.

Accident scenarios are simulated by using a FEM-model of a scaled vessel for the structural part and a LS-DYNA solver to predict the possible oil spill size. Grounding and collision with an oil tanker scenarios are prioritized as main sources of an oil spil ([IOPC, 2014], [ITOPF, 2014], [Khan et al., 2014], [Krata et al., 2012]). The NSR waters are chosen as a study area, where both international and Russian methods can be applied for calculating oil spill environmental damage compensation [Bambulyak et al., 2014]. The results of the simulation give an indication of environmental risk levels as financial liabilities for oil spill damage.

Further, the module is to be improved with accidental scenario simulation for ice-covered waters (available collision and grounding energy; oil spill size and distribution); use of available data on navigation, oil spill response efficiency, ecosystem services distribution; and generalized for planning purposes.

IMPLEMENTATION CONSIDERATIONS

The heterogeneity of the methods used in the above described projects poses a great challenge in the development of the design and optimization platform. The problems arise from several aspects: closed commercial software that only allows very restricted control and data exchange, different time scales and spatial dimensions (3D data vs scalar properties) and a mix of deterministic and stochastic variables.

These problems have to be approached by the right choice of programming language, data structure and strategy to handle the different time and spatial scales of the modules.

The implementation of the platform will be realized in 'Python'. This interpreted language was chosen for several reasons: It is free, open source and runs on all common operating systems. As an interpreted language Python allows fast code development provides access to a large number of tools, for visualization, programming interfaces to external code, numerical operations, web and database services and mapping tools. The drawback of a slow execution speed can be circumvented by using compiled python code (Cython) or C++ for time-sensitive computations.

Data structure

In addition to the above described modules, the development of the platform will center around a 'parametric ship', that is defined by a set of variables that represent ships the current design state. This ship-object is used define a ship with a minimum amount of parameter while storing all required information that will be required by the modules. The parameter are grouped into four categories:

- Hull shape: main particulars plus additional parameter for the shape of the bow and stern section
- Load state: displacement, center of gravity, moment of inertia
- Structure: plate thickness and spatial distribution of structural elements (girder, stringer, etc.)
- Machinery: parameter for the configuration of propeller, shaft, bearings and engine

In addition to storing the design state, the parametric ship object checks if the dependencies between parameter are met (eg. the draft depends on the load state and hull displacement) and provides methods to generate an initial ship design, change parameter and import/export the hull design. With the use the parametric ship representation it will be possible to use a common data-interface for all modules, which then will allow to couple the modules.

he coupling between the parametric ship and the environment will be modeled with a system of rigid bodies that allows simulate the ship motion and its interaction with drift ice. Two additional data objects will be used: One, to store information about the mission and environment conditions (e.g. the ice condition along a route) and another one for the parameter constraints needed by the optimization algorithm. T In order to manage the different design states and the results from the ice-ship modules, all data objects will be stored in a database.

Time and spatial scale problems

A problem of mismatching spatial dimensions – for example when the results of a field method (e.g. FEM or SPH) has to be transferred to a single scalar parameter – can be solved by using simple interpolation methods.

A 'time scale' problem between two modules can be attribute to two different effects: Differences in the simulated time or in the computation time. The first problem can be handled in a the same way as the spatial scale problems, by using interpolation methods. If the execution of a method takes too much time, the computational speed may be by increased by reducing the complexity (degrees of freedom) of the system, if the resulting decrease of accuracy is acceptable. Another approach to reduce the runtime is to distribute the computation onto multiple CPUs or by using an intermediate database at the interface between the platform and a module. This database could be used to stored precomputed results from the 'slow' modules and provide only interpolated results at runtime.

Instead of interpolating the data, an alternative application of such a intermediate database could be to apply a regression analysis methods in order to derive a fast prediction model of the underlying 'slow' simulation module.

DEVELOPMENT APPROACH

In order to reduce the complexity of the development of the platform, the process is divided into three steps. In the first 'base' step the modules are implemented and tested individually. At this level the data structure and the computation time plays only a secondary roll. In the second 'coupling' stage a common data structure will be implemented, that allows to connect the modules. In order to complete the last 'optimizing' stage the procedures for the optimization have to be implemented. In this stage the computation time of a module will become essential in order for the optimization routine to run within a reasonable time-frame.

Base level

The first step in the development is the implementation of the individual modules the will provide the access to the research projects. Figure 5 shows the class definition of a module and its relation to a research project. These modules are not intended to implement the research methods within in the software framework, they will only provide the a computational interface. The principle procedure for each module follows three steps: define the boundary conditions (`set()`), call the external method (`compute()`) and retrieve the results (`get()`). With this encapsulation of the research method, it is possible to use a standardized data structure and computation procedures on the platform side and allow a wide variety of method-types on the project side. These methods may consist of equations, matlab script, C++ code, function libraries and executable programs. As long as these methods can be controlled directly by Python, they can be coupled to the software framework.

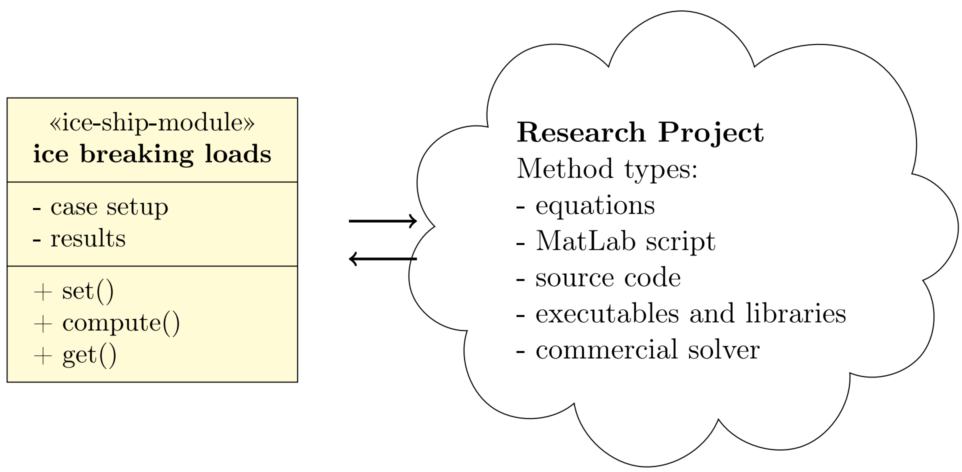

Figure 5: The software object provides an interface to the computation methods of the research projects

Coupling level

The flow chart in Figure 6 shows the typical structure of the optimization process ([von Bock und Polach et al., 2014]) which will be used in the implementation of the platform. While in the first development phase the exchange format between the modules was secondary, the modules now have to share the same data structure. This will allow to couple the modules and create more complex analysis procedures without manually processing the in- and output data. For this purpose the above described 'parametric ship' will be implemented.

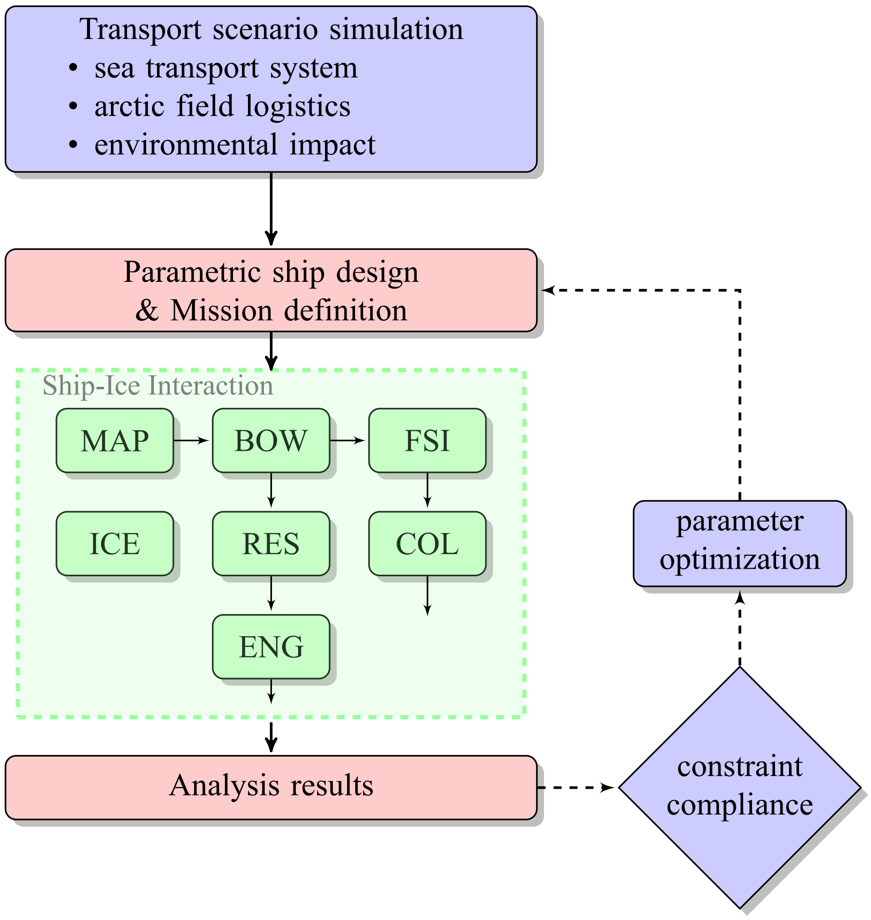

Figure 6: Module coupling and optimization loop

The use of the platform can be explained at the example of one of the possible applications: The transport scenario module is used to create an initial ship design for a given transport mission, this design and the route data will be stored in the parametric ship state. The route data is then used to determine the expected ice load along the route which is then passed to the BOW module and together with the parametric ship, used to predict the ice load on the bow. These results are used by the RES module to compute the resistance of the hull in ice and finally all the results are passed to the ENG module to predict the propeller ice interaction and to estimate the requirements of the propulsion system.

Optimization level

The final step in the development of the platform is to incorporate an optimization routine into the software framework. The right side of Figure 6 shows two additional modules that are required for an iterative optimization procedure. In general the optimization process will start with the definition of mission requirements and an initial ship design. The ship-ice interaction modules will be used to analyse the performance of a ship design under the set conditions. If the results do not comply to the constraints set in the mission definition the ship parameter have to be optimized and the analysis process is repeated until some convergence or optimum criteria is reached. At this stage in the platform development the runtime of each module becomes important in order to conduct an optimization within reasonable time. To accelerate 'slow' modules, one of the approaches proposed in the paragraph 'time and spatial problems' can be applied.

CONCLUSION

In this study the concept for a design and optimization platform for ships in arctic conditions was presented. The motivation for this development project originates from the research projects of the SAST group at the NTNU. The purpose of the platform is to provide access to the projects within the group and to allow an easy exchange of the developed methods, test data and research results.
The next steps in the development of the platform will be the implementation of the basic structure: a virtual ice-ship module class, a parametric ship object with methods for hull shape manipulation and geometry in- and export. Furthermore the incorporation of an internal database, access to an online ice-map database and the link to external solver and libraries will be tested and implemented.

References

[Assur, 1958] Assur, A. (1958). Composition of sea ice and its tensile strength in arctic sea ice. *U.S. National Academy Sciences - National Research Council*, 598:106--138.

[Bambulyak et al., 2014] Bambulyak, A., von Bock und Polach, R., Ehlers, S., and Sydnes, A. (2014). Challenges with oil spill risk assessment in arctic regions: Shipping along the northern sea route. *Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering , OMAE2014, San Francisco, California, USA*, (OMAE2014-24419).

[Bergström et al., 2014a] Bergström, M., Ehlers, S., and Erikstad, S. (2014a). An approach towards the design of robust arctic maritime transport systems. *International Maritime and Port Technology and Development Conference, Trondheim, Norway*, (ISBN 978-1-138-02726-8):185–192.

[Bergström et al., 2014b] Bergström, M., Ehlers, S., Erikstad, S., Erceg, S., and Bambulyak, A. (2014b). Development of an approach towards mission- based design of arctic maritime transport systems. *Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering , OMAE2014, San Francisco, California, USA*, (ISBN 978-0-7918-4556-1).

[Boyd, 2010] Boyd (2010). Lost ecosystem goods and services as a measure of marine oil pollution damage. *Resources of the Future report RFF DP 10-31, Washington DC.*, page 22.

[Das et al., 2014] Das, J., Polić, D., Ehlers, S., and Amdahl, J. (2014). Numerical simulation of an ice beam in four-point bending using sph. *Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering , OMAE2014*, 10(OMAE2014-23228).

[Ehlers et al., 2014] Ehlers, S., Erceg, B., Jordaan, I., and Taylor, R. (2014). Structural analysis under ice loads for ships operating in arctic waters. *proceedings of Martech 2014, 2nd international conference on Maritime technology and Engineering, Lisbon, Portugal.*

[Ehlers and Østby, 2012] Ehlers, S. and Østby, E. (2012). Increased crashworthiness due to arctic conditions – the influence of sub-zero temperature. *Marine Structures*, 28:86--100.

[Erceg et al., 2015] Erceg, B., Ralph, F., Ehlers, S., and Jordaan, I. (2015). Structural response of ice-going ships using a probabilistic design load method. *Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering, St John's, Newfoundland, Canada, (accepted)*.

[Erceg et al., 2014a] Erceg, B., Taylor, R., Ehlers, S., and Leira, B. (2014a). A response comparison of a stiffened panel subjected to rule-based and measured ice loads. *Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering , OMAE2014, San Francisco, California, USA*.

[Erceg et al., 2014b] Erceg, S., Ehlers, S., von Bock und Polach, R., and Leira, B. (2014b). A numerical model to initiate the icebreaking pattern in level ice. *Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering , OMAE2014, San Francisco, California, USA*.

[Gürtner, 2009] Gürtner, A. (2009). *Experimental and Numerical Investigations of Ice-Structure Interaction*. PhD thesis, doctoral thesis at NTNU. ISBN 978-82-471-1421-6.

[Häusler, 1977] Häusler, F. U. (1977). Druckfestigkeitsversuche mit salzwasser-eis. *Schriftreihe Schiffbau; Bericht Institut für Schiffbau*, (358).

[IOPC, 2014] IOPC (2014). International oil pollution compensation funds (iopc), london, annual report 2013. page http://www.iopcfunds.org/publications/.

[ITOPF, 2014] ITOPF (2014). Oil tanker spill statistics 2013. the international tanker owners pollution federation limited. *http://www.itopf.com/knowledge-resources/data-statistics/statistics/*.

[Jordaan, 2001] Jordaan, I. (2001). Mechanics of ice-structure interaction. *Engineering Fracture Mechanics*, (68):1923--1960.

[Jordaan et al., 1993] Jordaan, I., Maes, M, A., Brown, P., and Hermans, I. (1993). Probabilistic analysis of local ice pressures. *Journal of Offshore Mechanics and Arctic Engineering*, (15 / 83).

[Khan et al., 2014] Khan, F., Yang, M., Veitch, B., Ehlers, S., and Chai, S. (2014). Transportation risk analysis framework for arctic waters. *ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, San Francisco, California, USA*, (OMAE2014-23421).

[Kotras et al., 1983] Kotras, T., Baird, A., and Naegle, J. (1983). Predicting ship performance in level ice. *Transactions of Society of Naval Architects and Marine Engineers (SNAME)*, 91:329--349.

[Krata et al., 2012] Krata, P., Jachowski, J., and Montewka, J. (2012). Modelling of accidental bunker oil spills as a result of ship's bunker tanks rupture – a case study. *International Journal on Marine Navigation and Safety of Sea Transportation*, 6(4):495--500.

[Kujala, 1991] Kujala, P. (1991). Damage statistics of ice-strengthened ships in the baltic sea 1984 – 1987. *Research Report for Winter Navigation Research Board. Helsinki University of Technology, Espoo, Finland*.

[Lindström, 1990] Lindström, C. (1990). Numerical estimation of ice forces acting on inclined structures and ships in level ice. *Offshore Technology Conference*.

[Liu et al., 2006] Liu, J., Lau, M., and Williams, F. (2006). Mathematical modeling of ice–hull interaction for ship maneuvering in ice simulations. *Proceedings of 7th International Conference and Exhibition on Performance of Ships and Structures in Ice (ICETECH), Banff, Alberta, Canada*.

[Lubbad and Løset, 2011] Lubbad, R. and Løset, S. (2011). A numerical model for real-time simulation of ship-ice interaction. *Cold Regions Science and Technology*, 65:111--127.

[Martio, 2007] Martio, J. (2007). Numerical simulation of vessel's maneuvering performance in uniform ice. *Report No. M-301, Ship Laboratory, Helsinki University of Technology, Finland*.

[Milaković et al., 2014] Milaković, A., Schütz, P., Westvik, M.-H., and Ehlers, S. (2014). Offshore upstream logistics for operations in arctic environment. *(MTEC) International Maritime and Port Technology and Development Conference, October 2014, Trondheim, Norway*.

[Myland and Ehlers, 2014] Myland, D. and Ehlers, S. (2014). Theoretical investigation on ice resistance prediction methods for ships in level ice. *Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering , OMAE2014*, (OMAE2014-23304).

[Naegle, 1980] Naegle, J. N. (1980). Ice-resistance prediction and motion simulation for ships operating in the continuous mode of icebreaking. *Ph.D. Thesis – University of Michigan*.

[Nguyen et al., 2009] Nguyen, D., Sørbø, A., and Sørensen, A. (2009). Modeling and control for dynamic positioned vessels in level ice. *Proceedings of 8th Conference on Manoeuvring and Control of Marine Craft,Guaruja, Brazil*.

[Polić et al., 2014] Polić, D., Ehlers, S., Æsøy, V., and Pedersen, E. (2014). Shaft response as a propulsion machinery design load. *Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering , OMAE2014, San Francisco, California, USA*.

[Ralph and Jordaan, 2013] Ralph, F. and Jordaan, I. (2013). Probabilistic methodology for design of arctic ships. *Proceedings of the ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering , OMAE2013, Nantes, France*.

[Riska, 1991] Riska, K. (1991). Observations of the line-like nature of ship-ice contact. *Proceedings of the 11th International Conference on Port and Ocean Engineering under Arctic Conditions, St. John's, Canada*, 2:785 – 811.

[Riska, 2010] Riska, K. (2010). Ship-ice interaction in ship design: theory and practice. *Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, EOLSS Publishers, Oxford, UK*.

[Riska et al., 1994] Riska, K., Jalonen, R., Veitch, B., Nortala-Hoikkanen, A., and Wilkman, G. (1994). Assessment of ice model testing techniques.

[Riska and Kämäräinen, 2011] Riska, K. and Kämäräinen, J. (2011). A review of ice loading and the evolution of the finnish-swedish ice class rules. *Proceedings of the SNAME Annual Meeting and Expo, Houston (TX), USA*.

[Sawamura et al., 2009] Sawamura, J., Riska, K., and Moan, T. (2009). Numerical simulation of breaking patterns in level ice at ship's bow. *Proceedings of the International Offshore and Polar Engineering Conference*, pages 600--607.

[Su et al., 2010] Su, B., Riska, K., and Moan, T. (2010). A numerical method for the prediction of ship performance in level ice. *Cold Regions Science and Technology*, 60:177--188.

[Tan et al., 2013] Tan, X., Su, B., Riska, K., and Moan, T. (2013). A six-degrees-of-freedom numerical model for level ice-ship interaction. *Cold Regions Science and Technology*, 92:1--16.

[Taylor and Richard, 2014] Taylor and Richard (2014). Development of a probabilistic ice load model based on empirical descriptions of high pressure zone attributes. *Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering , OMAE2014, San Francisco, California, USA*.

[Taylor et al., 2010] Taylor, R., Jordaan, I., Chuanke, L., and Sudom, D. (2010). Local design pressures for structures in ice: Analysis of full-scale data. *Journal of Offshore Mechanics and Arctic Engineering*, (132).

[Tõns et al., 2015] Tõns, T., Raplh, F., Jordaan, I., and Ehlers, S. (2015). Probabilistic design load method for the northern sea route. *Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering, St. Johns, Canada, (accepted)*, (OMAE2015-41841).

[Valanto, 2001] Valanto, P. (2001). The resistance of ships in level ice. *Transactions of Society of Naval Architects and Marine Engineers (SNAME)*, 109:53--83.

[von Bock und Polach and Ehlers, 2013] von Bock und Polach, R. and Ehlers, S. (2013). Model scale ice - part b: Numerical model. *Cold Regions Science and Technology*, 94.

[von Bock und Polach and Ehlers, 2014] von Bock und Polach, R. and Ehlers, S. (2014). On the scalability of model-scale ice experiments. Number OMAE2014-23183. ASME.

[von Bock und Polach et al., 2014] von Bock und Polach, R., Ehlers, S., and Erikstad, S. O. (2014). A decision-based design approach for ships operating in open water and ice. *Journal of Ship Production and Design*, 30(3):1 -- 11.

[von Bock und Polach et al., 2013] von Bock und Polach, R., Ehlers, S., and Kujala, P. (2013). Model scale ice - part a: Experiments. *Cold Regions Science and Technology*, 94:53--60.

[Wang, 2001] Wang, S. (2001). A dynamic model for breaking pattern of level ice by conical structures. *Department of Mechanical Engineering, Helsinki University of Technology, Finland.*, (Ph.D. Thesis).