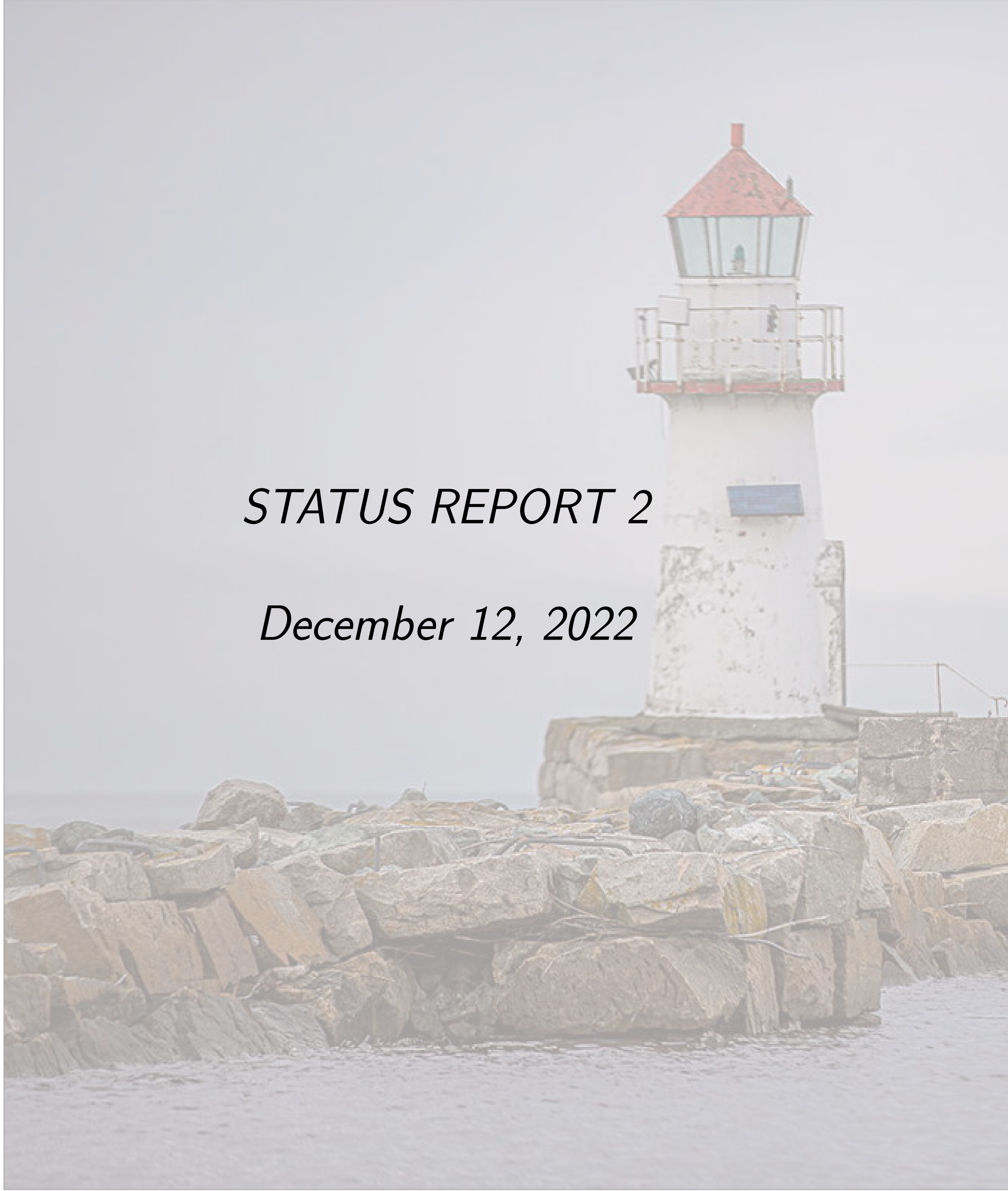

STATUS REPORT 2

December 12, 2022

Stian Skjong
Karl-Johan Reite
Håvard Nordahl
Lars T. Kyllingstad
Severin S. Sadjina
Siegfried Eisinger

PREFACE AND CONTENTS

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Hilde Wanvik, SINTEF Ocean

Preface

This report summarises the work, both planned and executed, the results and findings so far in the project SEACo – Safer, Easier and more Accurate Co-simulations. This report is the second official status report in the project and will report on the news since the last status report.

The intention with these status reports is to inform the steering committee, as well as the advisory board, about the developments in the project. These status reports are classified as open documents and are freely distributable. The plan is to publish at least two status reports annually.

Contents

OVERVIEW AND OUTLOOK

Project Metrics:

- KSP project
- September 2021 – June 2025
- 19.5 MNOK (5.6 MNOK to industry)
- **2022:** 5.3 MNOK
- 5 technical work packages
- International Advisory Board
- One Ph.D./Post.Doc position (NTNU, N/A)

Project Leader:

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Project description

During the last few years, the maritime industry has started using co-simulation successfully to boost digital collaboration and innovation based on existing investments and knowledge. Still, several technical challenges remain, and collaboration is inhibited by tools that are often too complicated to use and not unified.

In the SEACo project, we aim to tackle these inhibitors of rapid digital innovation head on. We seek to contribute to more reliable and easier-to-use co-simulations of maritime systems by drawing on the knowledge and the skills acquired over the past decade. To ensure high interactivity and value creation, several key partners from academia and the industry are committed and eager to contribute: SINTEF, DNV, Kongsberg Maritime, Equinor, Aukra Maritime and NTNU.

The project consists of five technical work packages (WPs). A short presentation of each WP will be given in this status report.

Status

This year has been characterised by a slow start. The KPN project *TwinShip*[1] finished in June this year and laid a good foundation for the SEACo project, especially WP4, where SEACo is to continue the work on variable time step size co-simulation master algorithms. Earlier this year we also had to change work package leader for WP1 - Identical Environmental Conditions since Martin Rindarøy, the former WP leader, left SINTEF Ocean. This caused delays in the schedule for WP1. Moreover, despite two job advertisements for the Ph.D. position in the project, the position has not yet been filled. Nevertheless, third time's a charm. We will put out a new advertisement and appreciate all the help we can get spreading the word about the academic position. Please forward any possible candidates to eilif.pedersen@ntnu.no.

Figure 1.1: First physical workshop in SEAco, held in Trondheim.

So far, the SEACo project has published one journal article named *"A distributed object-oriented simulator framework for marine power plants with weak power grids"* [1]. Two more publication are in the pipeline, the first one with the topic of variable time step size control in co-simulation master algorithms. The second one is inherited from *DTYard*[2] and de-

[1] *Digital twins for life cycle service* (2018–2022), funded by the Research Council of Norway (grant no. 280703) and industry partners.

[2] *Digital Twin Yard - An ecosystem for maritime models and digital twin simulation* (2019–2022),

OVERVIEW AND OUTLOOK

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scribes the development of OSP-IS.

22nd to 23rd September, the first physical workshop in the project, a lunch-to-lunch meetup in Trondheim, was held. This was 8 months later than planned due to COVID. Each of the work-packages were presented along with various discussion topics. Even though the workshop resulted in many fruitful discussions and extended insight in various problems, the most important outcome was to get to know each other in person.

On 15th of November, the annual OSP conference was held in Ålesund at the Norwegian Maritime Competence Center, hosted by SINTEF Ålesund with Severin Sadjina in charge. This was the first OSP-conference that took place physically. Most of the presentations from the conference are available at the OSP website. About 50 participants followed the conference in person while about 50 more joined online. During the OSP conference we also had many good discussions with participants, both domestic and international, and we start to see the possibilities for a joint EU project application. If this is something that interests you, please make contact.

Outlook

For the remainder of 2022, focus will also be given to drafting the work plan for 2023, which is to be approved by the project's steering committee. We also hope that we are able to fill the academic position in the project as soon as possible.

In 2023 we plan to involve the industry partners and the advisory board even more than what has been done so far. We believe that close collaboration between research institutes and industry, both domestic and international, is crucial for the project outcomes.

Also, in 2023 SINTEF plan to submit a new project application to Research Council of Norway, together with DNV and Kongsberg, to increase and support the a OSP activities.

The topics treated in this project will be optimisation and automatic system stress testing through co-simulations. All details regarding this project proposal have not yet been ironed out, but we believe optimisation and system stress testing would be two new important steps towards utilising the full potential of co-simulations in the industry.

Figure 1.2: OSP-conference 2022 hosted by SINTEF Ålesund at The Norwegian Maritime Competence Center.

funded by the Research Council of Norway (grant no. 295918) and industry partners.

IDENTICAL ENVIRONMENTAL CONDITIONS

Work Package Metrics:

- WP number 1
- 15.2% of total budget
- 771 000 NOK in 2022

WP Leader:

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Description

In this work package we will seek to standardise the description of environmental models for current, wind, and waves as used in most maritime co-simulation systems and develop a standardised co-simulation interface for each. Added focus is put on waves because of their higher complexity and fidelity. Transitions between sea states poses an additional challenge, as simply changing parameters causes abrupt changes in the sea state realisation.

For multiple models to share the same environment one typically can either share values (e.g. sharing the surface acceleration for given positions) or formulations (e.g. parameterised predefined models). These have different pros and cons, such as the ability to include vessel-generated waves or estimating values between time steps. It is therefore possible that multiple sharing strategies should be available, to suit different use cases.

Another important issue is to what extent extensions to the standards can be proposed to facilitate more efficient environment sharing strategies.

Status

The initial objective of WP1 has been to establish the short and long term requirements of potential users, as well as exploring various methods and concepts for meeting these requirements. A central task has been to establish and consider various concepts for sharing a common environment. This resulted in a decision tree as shown in Figure 2.1. This formed the basis for a questionnaire which was answered by the project partners and discussions in the project group. Based on these input, plans for the work package was laid. In short, this includes:

- Sharing environment information between FMUs using the FMU port system, specifically using string ports and serialisation.
- Creating a development environment facilitating visualisation and co-simulation testing.
- Creating a public available library which implements predefined methods which a FMU can use for realisation of environment processes also between macro time steps.

Implementation of the public library, preliminary named *MarEnv*, as well as the development environment has begun and will continue next year.

IDENTICAL ENVIRONMENTAL CONDITIONS

Work Package Metrics:

- WP number 1
- 15.2% of total budget
- 771 000 NOK in 2022

WP Leader:

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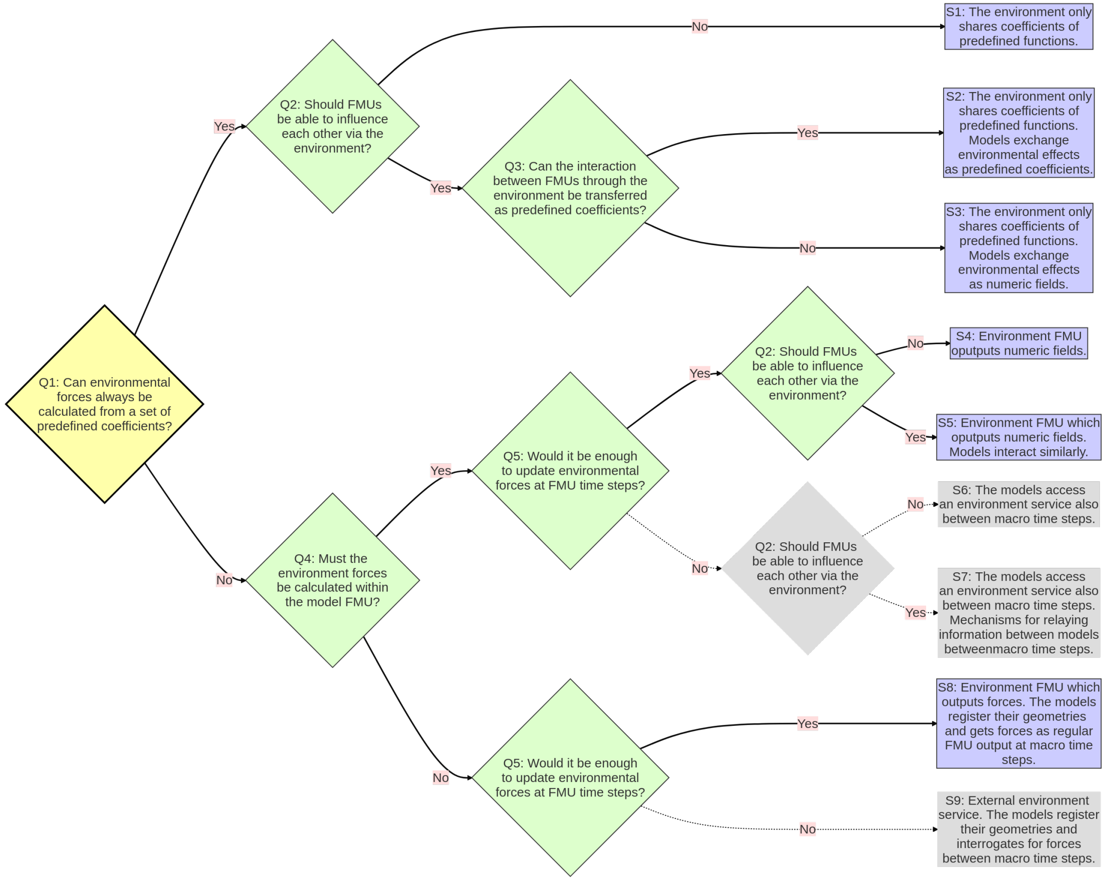

Figure 2.1: Possible concepts for sharing a common environment in a cosimulation.

Safer, Easier and more Accurate Co-Simulations

IDENTICAL ENVIRONMENTAL CONDITIONS

Work Package Metrics:

- WP number 1
- 15.2% of total budget
- 771 000 NOK in 2022

WP Leader:

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Progress of current activities

Planned
Actual

Identify models: Identify relevant environmental models through literature study and project group discussions. Document the identified environmental models, with pros and cons for use in co-simulation.

Investigate sharing strategies: Identify possible sharing principles and their pros and cons when applied to different scenarios and models, implement proofs of concepts, and document the most promising strategies.

Implement sharing: Implement the relevant environmental sharing strategies, for the purpose of testing their applicability for co-simulation and widespread use.

Plans for next period

We will focus on establishing proofs of concepts. This will enable us to test and iterate on the principles for sharing environment information between FMUs in a co-simulation. It will also be beneficial for implementing the resources we aim to provide for model developers to facilitate their adherence to the developed standards. To facilitate easier debugging, and as a possible result in its own right, we will implement an environment visualisation tool. This will enable us to visualise both environment aspects (waves, winds, currents) and how multiple FMUs simultaneously reacts in this environment. We will implement the developed methods for sea state realisation into this, and develop methods for sharing information about ocean currents and bathymetry. We will also start the work on methods for realistic and synchronously transitioning between sea states. A possible concept for FMUs to interact through the environment is shown in Figure 2.2.

IDENTICAL ENVIRONMENTAL CONDITIONS

Work Package Metrics:

- WP number 1
- 15.2% of total budget
- 771 000 NOK in 2022

WP Leader:

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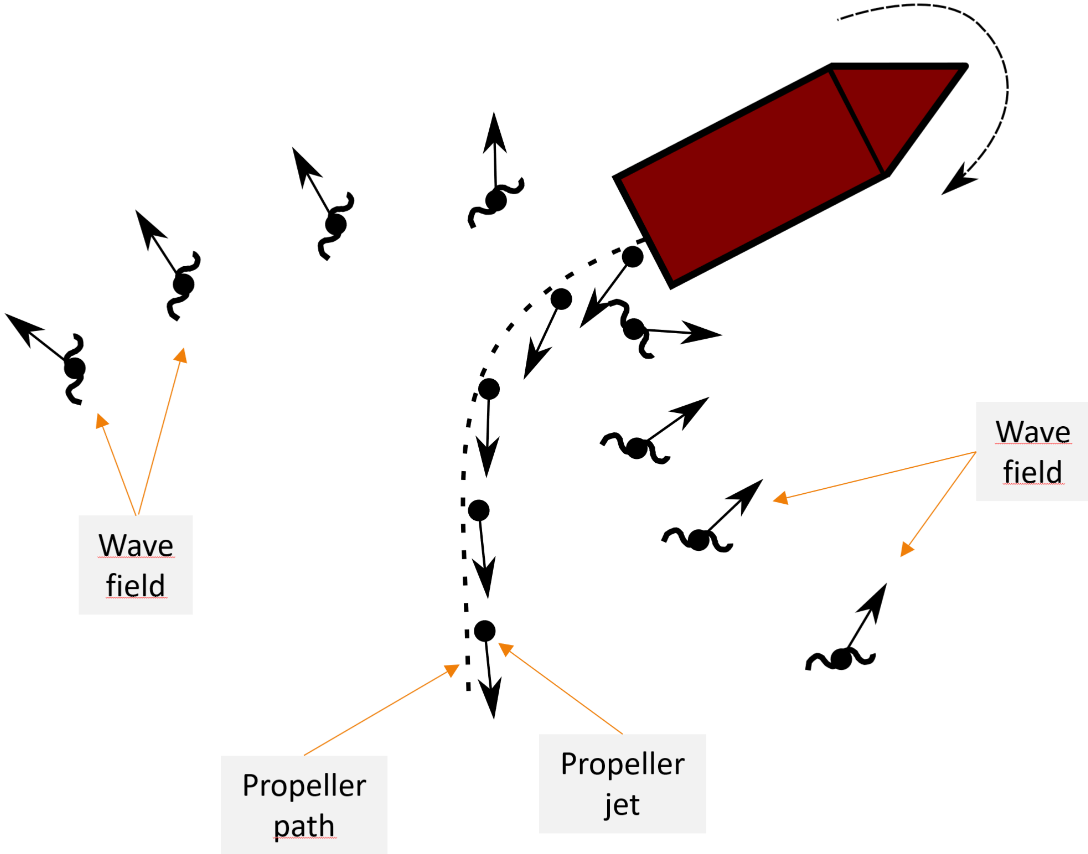

Figure 2.2: Possible concept for FMUs to interact through a shared environment.

COORDINATE SYSTEM TRANSFORMATIONS

Work Package Metrics:

- WP number 2
- 16.9% of total budget
- 672 000 NOK in 2022

WP Leader:

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Description

In this work package, we seek to establish a method for communicating and solving coordinate system representations between independent models reliably. The aim is to detect whether a given transformation can be safely performed outside the models (when time lags cause no issues). And, if not, to find the best method for performing the transformation without introducing significant inaccuracy.

Status

Initially, the work in WP2 focused on mapping the most common coordinate system representations of signals, as well as the most common system boundaries (interface signals). This mapping was envisioned to be conducted via structured interviews with relevant actors. Interview questions were developed and tested internally in SINTEF Ocean. The results provided insight into the challenges related to coordinate system transformations, and it was found that simply mapping the relevant coordinate systems will not be sufficient to address these challenges. As such, the interview methodology was put on hold at this stage. The results of the preliminary interviews lead rather to a more in-depth study of the requirements and challenges associated with coordinate system transformations. The work has, therefore, focused on identifying the challenges and possible solutions related to static and dynamic coordinate system transformations. Initial models were developed for sensitivity analyses related to simplifications related to coordinate system transformations in co-simulation. Furthermore, it was found that a closer collaboration with WP3 should be conducted due to the connection between challenges related to dynamic coordinate system transformations and tightly coupled systems. The progress has been less than planned, but will be ramped up significantly in the next year.

Progress of current activities

Planned
Actual

Interviews and surveys: Map candidates for interview/survey and conduct interviews and collect data. Analyse data gathered from surveys and interviews and create the coordinate system overview/map.

Mathematical formulations: For each relevant transformation, formulate it mathematically.

Plans for next period

The initial focus for the next period will be on static transformations. We will investigate different approaches to describe the FMU signal coordinate systems, and to perform transfor-

COORDINATE SYSTEM TRANSFORMATIONS

Work Package Metrics:

- WP number 2
- 16.9% of total budget
- 672 000 NOK in 2022

WP Leader:

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mations. One option is to choose to define all relevant reference frames, such as vectorial notations (Euler angles) or quaternions, specific reference frames such as North-East-Down (NED), Earth Centred Inertial (ECI), etc. And to define one FMU's coordinate system as the master that the second coordinate system must be transformed into. This approach would require that which system to take the master role would have to be determined, and one solution to that would be to define some sort of hierarchy of coordinate systems.

The other option is to identify a global coordinate system and require that all subsystems transform their signals to this coordinate system. For each type of data exchanged there would be a generic transformation between two coordinate systems.

We will then investigate how these static transformations can be done automatically in a co-simulation setting and formulate the necessary transformations mathematically. The expected outcome is a mapping of the metadata that must be associated with FMUs and their input or output signals to facilitate the automatic detection of coordinate system representation, and the determination of the need for inserting a transformation and how that transformation must be. At the end of the next period, we will start to investigate dynamic transformations in co-simulations by studying the sensitivity of co-simulation models to various simplifications and identifying where and when errors arise and how significant they are. For instance, a monolithic simulation of a double pendulum can be compared to using modularised co-simulation with a stiff spring and strong damper between pendulum models with varying degrees of damping, and a co-simulation without a spring and damper between pendulum models. Furthermore, increased coordination with WP3 will be done to identify challenges and possible solutions related to dynamic coordinate systems transformations.

MODULAR TIGHTLY COUPLED SYSTEMS

Work Package Metrics:

- WP number 3
- 23.2% of total budget
- 1 022 000 NOK in 2022

WP Leader:

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Description

There are several examples of interesting maritime systems that are *tightly coupled*, such as the connection between a ship's hull and its crane. Such systems are by nature poorly suited for co-simulation, and attempts to do so will usually be riddled with stability and performance issues. Still, the advantages of co-simulation are so many that it is worth investigating how to tackle these issues.

In this work package, we will perform a systematic and exhaustive study of tightly coupled maritime systems. We will examine the effects of different types of simulation techniques and algorithms and consider their suitability in a practical industrial setting. Based on the results, we will develop model interfaces to support modular modelling and co-simulation of tightly coupled systems.

Status

The first task in WP3 was to map out the problem domain, that is, to get an overview of the most relevant *examples* of tightly coupled maritime systems, the various *types* of tight coupling, and possible *methods* for solving such systems in a co-simulation setting. To do this, we held a group "mind mapping" exercise during the SEACo workshop in September, as a systematic method for eliciting knowledge about these matters from the participants.

After this, we selected the system that was considered most relevant as a starting point

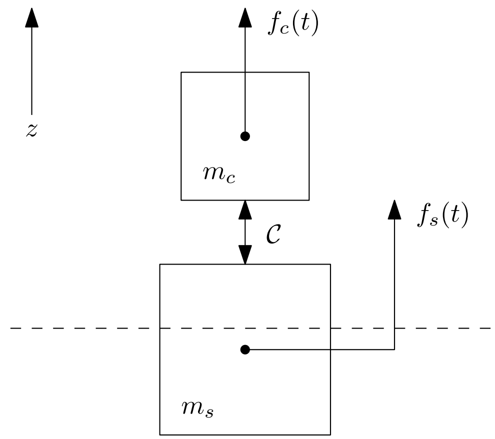

Figure 4.1: Toy model for the ship–crane system. The dashed line represents the "sea level".

for our methodological study. To no-one's surprise, this was the ship–crane coupling, which has the problem that the ship and crane both have the same causality. That is, in the "default implementation" both models expect a force as input and return the resulting motions as output, and are therefore incompatible.

To study this system, we have formulated a model of it which is highly abstracted and idealised—just two point masses moving in one dimension—but which captures the essential internal dynamics and external drivers to a (hopefully) sufficient degree. Figure 4.1 shows a schematic of the model.

We also selected a number of methods for resolving this coupling: 1) inserting a damped spring between them, 2) using a low-pass filter with derivative effects to fix causality is-

MODULAR TIGHTLY COUPLED SYSTEMS

Work Package Metrics:

- WP number 3
- 23.2% of total budget
- 1 022 000 NOK in 2022

WP Leader:

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sues, and 3) Baumgarte stabilisation. These three methods will be compared to each other and to a baseline monolithic implementation. Note that the first two methods are similar. The third method defines a convergence law for the constraints and solves the constraints explicitly by feeding the two connected models with constraint-action signals. An example of this for lumped cable models can be found here.

Progress of current activities

Planned
Actual

Model selected systems: Survey and systematise relevant tightly coupled systems. Make a set of simplified model systems.

Perform simulations and analyse results: Review state of the art. Test and compare methods for splitting/solving the systems.

Plans for next period

We will study the selected system and methods both analytically—i.e., by solving the equations "on paper"—and numerically—i.e., by simulation. The goal of both approaches will be to understand the advantages, drawbacks, and trade-offs associated with each method in terms of accuracy, simulation speed, stability, and so on. Specifically, we will investigate the relationship between *method parameters* (e.g. stiffness and damping), *system characteristics* (e.g. the relative mass and position of ship and crane), and *user requirements* (e.g. accuracy and speed).

MORE ACCURATE AND RELIABLE CO-SIMULATIONS

Work Package Metrics:

- WP number 4
- 22.1% of total budget
- 1 026 000 NOK in 2022

WP Leader:

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Description

The *energy-conservation-based co-simulation method* (ECCO) monitors the flow of energies between models, estimates co-simulation errors reliably, and chooses optimal co-simulation step sizes to control efficiency and accuracy. It poses no additional requirements on the models (such as re-stepping or interface derivatives) and can be used for any power bond connection between models. As such, it presents a promising choice for an easy-to-use and robust co-simulation algorithm. Here, we aim to extend the theory of energy-based co-simulation algorithms to make them more useful and more powerful.

Status

The main focus for WP4 throughout 2022 was on extending ECCO to multi-rate (per coupling) step size control. Previous work (notes, ideas, experiments and implementations with results) was surveyed and collected, we had technical discussions, and some experiments were run. We also started on writing a technical memo summarising the work so far. The memo is a good, comprehensive start for the multi-rate ECCO paper planned for 2023. During discussions, the idea of using machine learning methods on the data streams between subsimulators gained momentum and some promising experiments were conducted. We plan to build on these ideas throughout 2023. Last, but not least, DNV and SINTEF worked together in several workshops to start implementing the (single-rate) ECCO framwork in libcosim. This, too, will be an ongoing activity.

Relative to the original work plan for 2022, the literature survey on co-simulation methods remains to be finished, and the systematic handling of experiments and results for the WP4 test case for co-simulation techniques still has to be reviews and, possibly, improved.

Progress of current activities

Planned
Actual

Literature study: Review previous work on extending ECCO, survey methodologies and validation.

Test case: Define and implement test case, setup and manage experiments.

Multi-rate: Theoretical study of multi-rate (per coupling) approaches and validations.

Libcosim implementation: Getting the ECCO algortihm implemented in libcosim.

MORE ACCURATE AND RELIABLE CO-SIMULATIONS

Work Package Metrics:

- WP number 4
- 22.1% of total budget
- 1 026 000 NOK in 2022

WP Leader:

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Plans for next period

We will focus on two main topics for the next period:

1. Extending ECCO to multi-rate optimisation, that is, researching how the exchange of information between subsimulators can be optimised by letting them step almost freely in pairs. A good amount of work has already been done on this, and the next step is to gather key people for a technical workshop to review, exchange ideas, and to plan ahead.

2. Investigation of machine-learning and statistics-based approaches to step size optimization. We will basically treat the problem as a machine learning or probabilistic problem and investigate how useful both perspectives can be in that regard.

The research on multi-rate control will also be continuously documented in a manuscript that will be made ready for publication during 2023.

Lastly, there will be ongoing collaboration with DNV to continue implementing ECCO with libcosim.

TESTING AND VERIFICATION

Work Package Metrics:

- WP number 5
- 13.2% of total budget
- 715 000 NOK in 2022

WP Leader:

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Siegfried.Eisinger@DNV.com

Description

The assurance of complex systems and operations based on simulation models requires established trust in chosen simulation technologies. Here, we will develop and implement a case study for testing and demonstration of the methodology developed in WP1–WP4. We will also develop efficient methods for independent verification of the fitness of given component models and simulation configurations.

All the aforementioned work packages will provide input to a joint case study specified in this work package, e.g. A marine operation where a load is transferred between two floating platforms, one of which is a ship that carries the lifting crane. This case involves all the project's research areas, as it requires a shared sea environment for the floaters, multiple frames of reference (global, ship bodies, payload), and centres on a quintessential tightly coupled system (ship and crane), all of which pose a significant challenge to co-simulation accuracy.

Status

The following have been the main activities in this WP in 2022

DNV-RP-0513 (March 2022) Since this RP represents our starting point for this work package it is important that all project participants have a basic understanding of the RP. Therefore the RP has been presented to all interested participants. The (virtual) presentation was well attended.

Conceptual Model workshop (Sept 2022) The Conceptual Model represents the starting point for any modelling work and shall set the stage both with respect to model content and model quality. During summer the high level requirements to the SEACo use cases where developed and the main component models identified. During the SEACo workshop in September a dedicated conceptual component model workshop has been performed with all project participants

Conceptual Component Models (Oct 2022) Based on the workshop results first versions of conceptual models have been prepared for all component models of the anticipated SEACo use cases. These first versions are discussed and detailed and will suit as a planning and verification tool for the various component models (FMUs) when they are constructed.

Detailed crane conceptual model (Nov 2022) Aukra Maritime will deliver the crane model for the SEACo use cases. They are rather inexperienced with respect to Assurance and FMU work. During the workshop details of the conceptual model were discussed and a more detailed crane design was chosen.

It turns out that the crane represents an essential component model for the purpose of testing SEACo issues (see WP2

TESTING AND VERIFICATION

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WP Leader:

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- WP5). It was therefore decided that DNV provides a basic crane design in line with the conceptual model. This model is then shared with OSP and with Aukra Maritime for further usage in the future. In this way the SEACo team has full access to the component model down to code level. In addition DNV can test features of our own DNV-RP-0513, providing a component model in line with the recommended practice.

OSP conference (Nov 2022) DNV contributed to the OSP conference with three presentations relevant for SEACo:

- R.Stenbro. Usage of libcosim APIs
- C.Rostock. farn - an n-dimensional case generator
- S.Eisinger. Assurance of Simulation Models – just another time thief, or pathway to sufficient quality?

Progress of current activities

Planned
Actual

DNV-RP-0513: Provide an introduction to DNV-RP-0513 Assurance of Simulation Models.

Assurance of selected FMUs: Draft Conceptual Models for all SEACo FMUs have been prepared and published. This work will be extended for some of the FMUs (see below)

Assurance wrt. SEACo issues: General analysis of SEACo issues with respect to assurance, ensure assurance dimensions when specifying and planning case studies, risk assessment of case study model with focus on SEACo issues, identify verification and validation needs and suitable methods.

Assistance in OSP implementations: See also below. This work has started, but will continue also in 2023

Plans for next period

The following activities are planned for 2023

Finalisation of conceptual models Even if not all component models will be fully assured with respect to DNV-RP-0513 it is deemed essential that conceptual models are provided for all component models. Also basic qualification of the conceptual models should be performed. As far as possible, design contracts should be provided for all component models.

Crane model DNV has decided to design a basic crane model for usage within SEACo

TESTING AND VERIFICATION

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test, OSP in general and for further usage by Aukra Maritime. Since the model is essential for SEACo tests, this work will commence early in the period. DNV will also use the opportunity as a trial implementation of the RP-0513 Assurance of Simulation Models.

Assistance for selected FMUs For selected FMUs DNV will provide assistance in the design process. The assistance will be related to assurance, but will thus also aid in implementing a suitable design process and will aid in qualification, verification and validation activities.

Identification of efficient verification methods In order to verify that SEACo issues are properly addressed, suitable verification (testing and possibly other) methods are needed. This should be identified and implemented within OSP.

Identification of RP improvements The issues addressed in SEACo (see WP1-WP4) are important for co-simulation in general and especially of marine systems. DNV wishes to keep our RP-0513 updated with respect to important simulation issues. The updates should be twofold:

1. A checklist on how to identify SEACo issues in simulation models
2. A list of test methods to verify that the issues are properly addressed.

Assistance in OSP implementations Assist in the implementation of dedicated algorithms for use in the SEACo project within OSP. This work has already begun and will be continued in 2023

ACTIVITIES, COMMUNICATION, AND DISSEMINATION

This section lists all activities, communication and dissemination throughout the entire project period. Also, additional project information for the status report period, if any, is listed.

Additional resources:
SEACo project card
OSP website
OSP conference 2022: Presentations
DNV-RP-0513
ViProMa website
Other publications
FhSim

Activities

2021

1. Sept.	Project start

2022

20. Jan.	Kick-off (online meeting)
7. Feb.	Advisory board meeting
3. Mars	Presentation of DNV-RP-0513
11. Mars	Steering committee meeting
22.-23. Sept.	Physical workshop in Trondheim, lunch-to-lunch-meeting
31. Oct.	Steering committee meeting
15. Nov.	Annual OSP conference, held in Ålesund, hosted by SINTEF Ålesund

Publications

2022

[1] Stian Skjong and Eilif Pedersen. "A distributed object-oriented simulator framework for marine power plants with weak power grids". In: *Journal of Marine Engineering & Technology* 0.0 (2022), pp. 1–13. DOI: 10.1080/20464177.2022.2120171. URL: https://doi.org/10.1080/20464177.2022.2120171.

Additional information

- Ulrik Jørgensen, a researcher in SINTEF Ocean, will take over the lead of WP2 next year, replacing Håvard Nordahl.
- Lars T. Kyllingstad, the leader of WP3, will take over as the new QA for the SEACo project, replacing Håvard Nordahl.

SEA

Safer, Easier and more Accurate Co-Simulations

SINTEF

KONGSBERG

NTNU

Norwegian University of Science and Technology

AUKRA™

DNV

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