High-level demonstration of holistic design and optimisation process of Offshore Support Vessel

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ABSTRACT: Design of highly complex vessels involves a multitude of disciplines designing different modules and units of the vessel using different tools and methods requiring specialist competence in specific areas. The vessel may have a complex operational profile and multiple key performance indices. Sub-optimisation of each module for different KPIs without taking into account the interaction between the modules does not necessarily lead to an optimised overall performance of the vessel. A holistic approach is needed to achieve this. At the early design stage of a vessel, important parameters are defined having a huge impact on the performance of the vessel according to the KPIs. Changing these parameters at a later stage in the design process is difficult and requires a considerable effort from the multidisciplinary design team. This paper introduces a practical approach for holistic design approach at an early stage of the design process of an Offshore Service Vessel.

1 INTRODUCTION

Vessels with complex operational profiles have multiple key performance indices (KPIs), determining the operational and economic performance of the resulting vessel. Diverse modules and units in the ship contribute in each of these KPIs to some level. All the designers and manufacturers of different units in the maritime sector, particularly in offshore industry, are trying to optimise different KPIs, such as energy consumption, environmental impacts, operational windows, etc. However, the complexity and interconnection of the different modules in the system defy the concept of having efficient ship with maximal performance through optimisation of each module independently. As a matter of fact, improving the efficiency of a subsystem without considering its interaction with other models does not necessarily contribute to total efficiency of the system. Hence, a holistic optimisation framework is required to analyse the overall design in an early design stage. The current article not only seeks to propose sound concepts and techniques for designing vessels with optimised performance but also to define valid and practical approaches to assess the effect of each sub systems using integrated numerical simulations.

For Offshore Service Vessels (OSV), defining the main dimensions requires significant effort and review by a wide range of expertise. The choice of main design parameters results in a narrow bandwidth of performance expected for all of the KPIs. Significant adjustment of these parameters at later stage of the design process is often difficult, as this would result in going through the full design process again.

The ability to assess a wider range of main design parameters against the major vessel KPIs at an early concept definition stage, provides benefits in engineering time, operational efficiency and vessel cost in both CAPEX and OPEX.

As part of the HOLISHIP project (HOLISHIP, 2016-2020), which aims to bring Model Based System Engineering approach in ship design to a new level, Rolls-Royce Marine has teamed up with Friendship Systems, Sintef Ocean and DNVGL to establish an integration platform for the various design tools required for the high level concept development based on CAESES (https://www.caeses.com/products/caeses). These tools include:

- Hull lines import and transformation
- Stability
- Vessel motions
- Station Keeping and Dynamic Positioning
- Resistance and propulsion
- Lightship and steel weight
- CAPEX Cost
- OPEX Cost

These tools are often used at more detailed stages of the design process. However, the integration platform also allows the use of these tools at an early stage. The integration platform enables the various tools to be run, provide inputs and collect the outputs. It also provides the capability to perform a multi-parameter optimisation of the main design parameters based on the output of the various tools.

2 BACKGROUND

2.1 *Software integration case study*

To demonstrate the integration platform, a demonstration case has been defined based on an existing Subsea Construction Vessel (Fig. 1). The mission of the vessel is to perform subsea installation of heavy modules in ultra deep water using a subsea crane. So the main purpose of the vessel is to transport the heavy module from shore to the installation site, and to be a stable platform for the lifting operations over the side of the vessel using the subsea crane. The objective of the case is to find the combination of vessel size and crane type capable of performing the mission at lowest cost considering both CAPEX and OPEX.

The dimensions of a subsea construction vessel results from a large number of operational factors as well as chosen mission equipment. The development of fibre rope cranes using lifting ropes with neutral buoyancy, resulted in higher lifting capacities at larger depths. This may have an important influence on the dimensioning of the vessel and consequently on the CAPEX, OPEX and emission levels. Other dimensioning factors like operability, cargo deck dimensions and accommodation size must also to be taken into consideration in the design process.
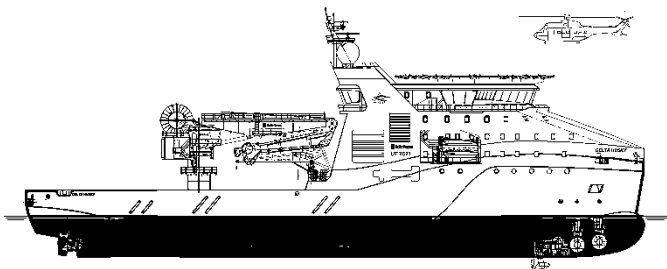

Figure 1. Subsea Construction Vessel.

2.2 *Case implementation*

Implementation of the holistic design tool for the case study is described in the following sections starting with the integration platform followed by a description of each step in the design process with the corresponding specialist tools and methods used. An overview of the holistic design process is shown in Figure 2.

The main steps are:
- Case setup / input
- Step 1: Definition of hull lines.
- Step 2: Steel weight estimates.
- Step 3: Hull verification/Stability.
- Step 4: Vessel motion calculations.
- Step 5: Station keeping calculations.
- Step 6: Resistance calculations.
- Step 7: Propulsion and machinery systems.
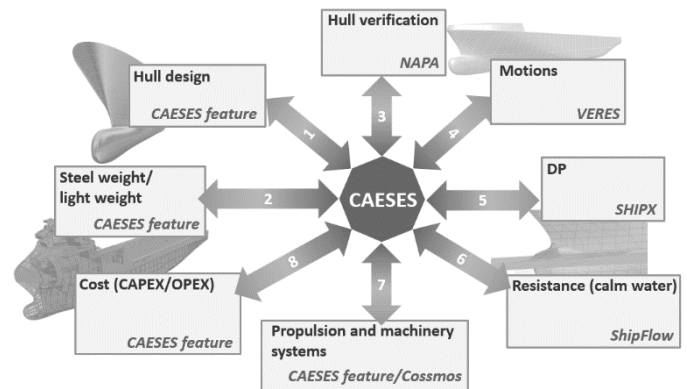- Step 8: CAPEX and OPEX estimates.

Figure 2. Overview of the holistic design process.

When setting up the case, information about the mission and the crane type must be provided in addition to definition of the design space that shall be explored using a parametric hull model (Step 1). For each hull size, steel weight is estimated (Step 2) before stability calculations are performed taking into account the heeling moment from the crane operation. This is resulting in a go/no-go decision (Step 3). Vessel motion performance is calculated defining a limiting weather criteria taking into account the active heave compensation performance of the crane (Step 4). Station keeping calculations are performed to define the required thrust forces fore and aft of the vessel in Dynamic Positioning (DP) operation (Step 5). Resistance of the hull is calculated to dimension the main propulsion requirements for the vessel in transit operations (Step 6). Based on the thrust and propulsion needs, the propulsion and thruster units are selected (Step 7). Fuel consumption is estimated based on a simplified operational profile and a power system setup adapted to the selected propulsion and thruster units. High level estimates of CAPEX and OPEX can then be calculated (Step 8).

This process is iterated to explore the entire design space followed by an optimisation process to identify the optimum hull. To compare the two vessel alternatives for the given mission based on fibre rope crane and steel wire crane respectively, the process is repeated twice with different set of input date. The final result is a relative comparison of the performance and the CAPEX and OPEX of the created designs.

3 INTEGRATION PLATFORM

3.1 *Holistic design tool architecture*

The architecture of the tool is quite basic in set-up with CAESES in a central position and the various specialist software tools arranged around it. CAESES uses a central database which is set up in a bottom up procedure, i.e. additional information can be added and detailing of methods can be performed at any time. The central database stores all direct input, like

operational conditions and parameters to control the shape of the vessel or other relevant data that influence the performance of the design. In addition to direct inputs, relationships between inputs to assessment tools and methods are managed – as well as the methods for evaluating results of the integrated assessment tools. The involvement of time costly simulation methods, e.g. for predicting the power requirements by means of CFD, calls for a software architecture that only triggers an update of the individual results if any supplying data to the result has been changed (D. A. Watt, W. Findlay). This behaviour is realized by utilizing *lazy evaluation.* In the strictly hierarchical dependency, every object has a logical link to its suppliers and clients, except for those objects in the top level that only have clients and those in the lowest level that only have suppliers. The chosen approach allows for an economic management of computational recourses and ensures at the same time the integrity of the entire model.

3.2 *CAESES Platform*

As the central hub to complex projects in a CAE context, CAESES comes with a variety of CAD interfaces, geometric modelling and pre-processing capabilities, probably the most prominent difference to other Process Integration and Design Optimisation (PIDO) tools (Ora Research LLC and intrinSIM LLC). The capability for defining new features and customised import and export routines inside CAESES allows the seamless integration of most tools that can be remotely controlled.

3.3 *Tools integration*

Running a tool and evaluating its results in an automated way requires three classes of information relating to input, execution and output:
– files that are made available to the tool,
– the location of the executable of the tool,
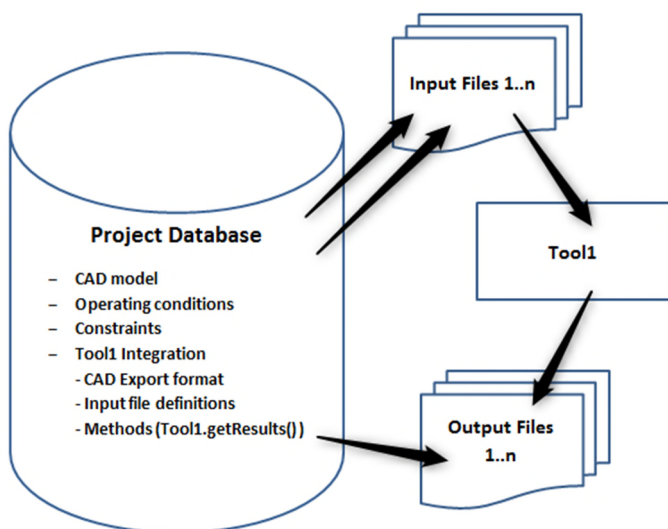– files that contain the results of the tool execution.

Figure 3. Tool integration.

This information is configured in the *Software Connector* in the platform which is also responsible for maintaining the consistency of data (Fig. 3).

Files that are made available to a tool usually contain data that depends on other objects, e.g. the shape of the vessel for resistance prediction, the vessel's speed and the type of crane or any other relevant information. These relationships are modelled in the software connector and managed by CAESES to ensure that the tool is executed anew, as soon as information from the output of the tool is requested, under the precondition that supplied data has also changed.

Figure 4 illustrates the dependency of two tools. Tool 2 requires an output from Tool 1, e.g. station keeping calculation using the environmental limits calculated by the seakeeping code. If an input to the seakeeping tool has changed, both tools will be executed in a sequence, if only an input to the station keeping code has changed, the latter will re-compute its results.
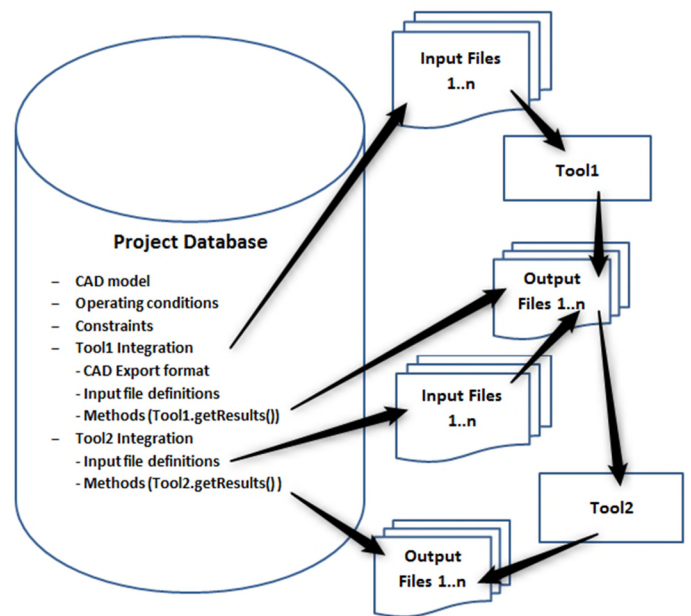

Figure 4. Dependency of Tools.

4 HULL LINES

This section refers to step 1 in Figure 2.

4.1 *Tool application*

In order to determine the optimum dimensions of the OSV considering the crane type and size, first a hull has to be created. From a baseline vessel hull, a variation of hull main dimensions is performed. Traditionally this was done by hand and this limited the amount of configurations that could be reviewed. This tool allows for automatic generation of hulls within a design space.

All tools integrated and described in the following paragraphs are preconfigured for an OSV vessel of a particular range, in the example illustrated this is in

the range of 80-120m in length. Technically this is implemented by linking an empty container object of the geometry to the tools that require the hull-form for analysis.

To initialise a project, the baseline geometry is imported into the platform and an analysis feature is executed to adjust the settings of main particulars to the baseline (Fig. 5).
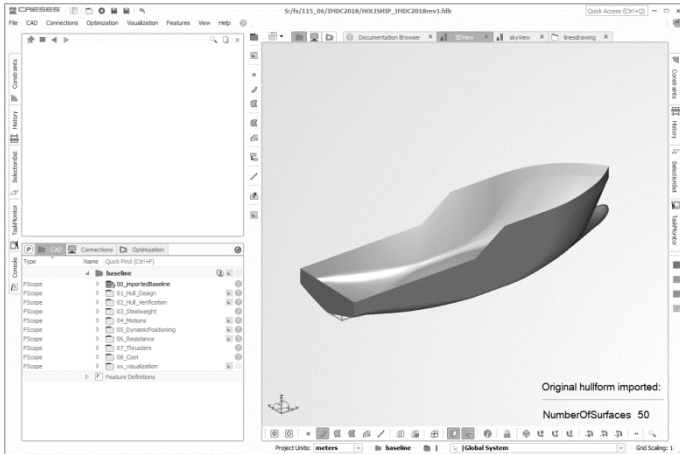

Figure 5. Imported baseline.

The setup of the project allows creating a parametric twin of the imported vessel (Fig. 6), i.e. if the preconfigured design variables are not changed, the imported, original geometry is analysed by all tools described. This analysis generates the datum design as a reference.
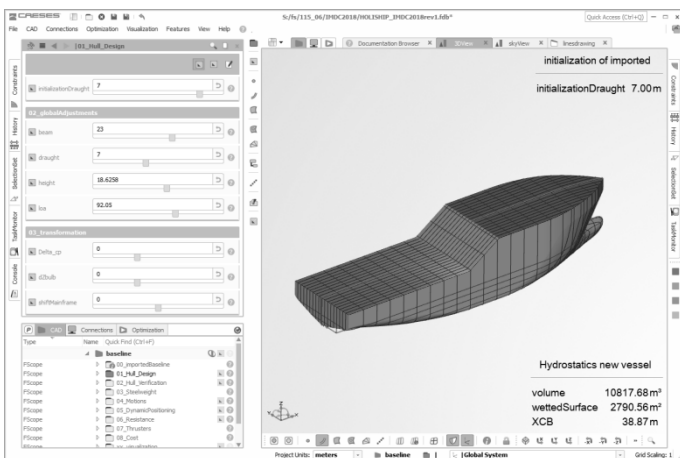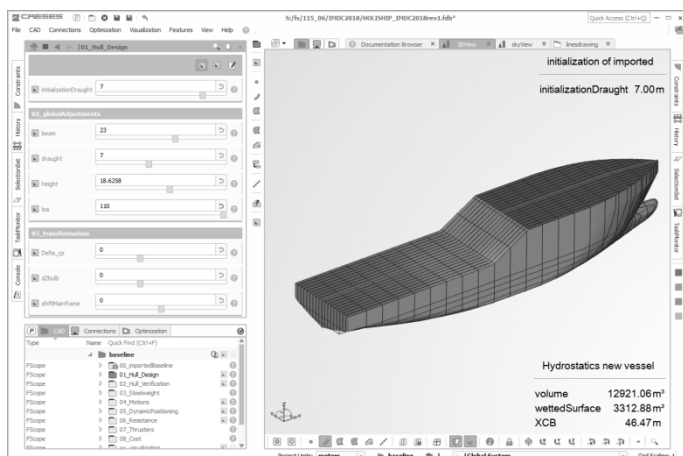
Instead of starting from the imported vessel, all design variables can be modified to define a new starting point and hence a new baseline design. For the envisioned design space exploration of its main particulars, the vessel's length, beam, height and draught are preconfigured as design variables in a given range, which can be adapted according to the specification of the study. Figure 7 shows a parametric variant of the vessel featuring a different length.

The objective functions CAPEX and OPEX call for minimum thruster sizes within the given constraints to achieve the required transit speed and to keep station during crane operation. During a design space exploration focusing on principal dimensions, additional shape characteristics can be utilized for minimizing required power in transit mode within a nested optimisation based on potential flow analysis. A set of design variables is provided in the set-up that allows changing properties of the vessel that are commonly used in standard hull form optimisation processes: Bulbous bow shape, shoulder location as well as longitudinal centre of buoyancy. The number of design variables is kept relatively low to reduce the overall computational effort, since for each design of new principal dimensions, a set of variants is assessed aiming for minimum resistance. Figures 8 and 9 show the bulb shape based on the baseline design and a modified variant respectively.
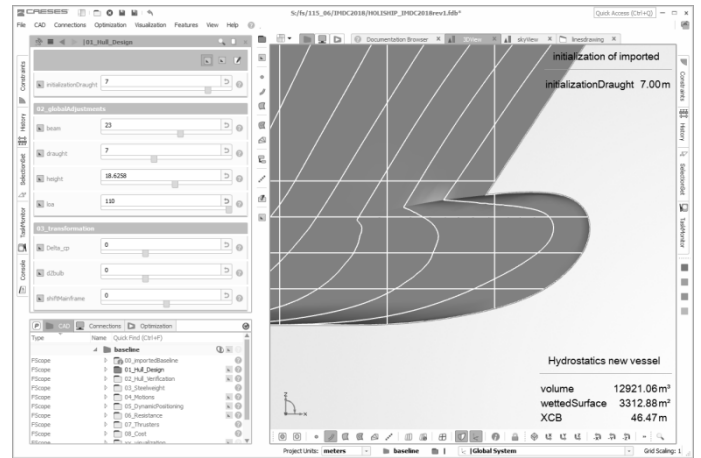

Figure 6: Parametric twin.

Figure 8. Bulb base line design.

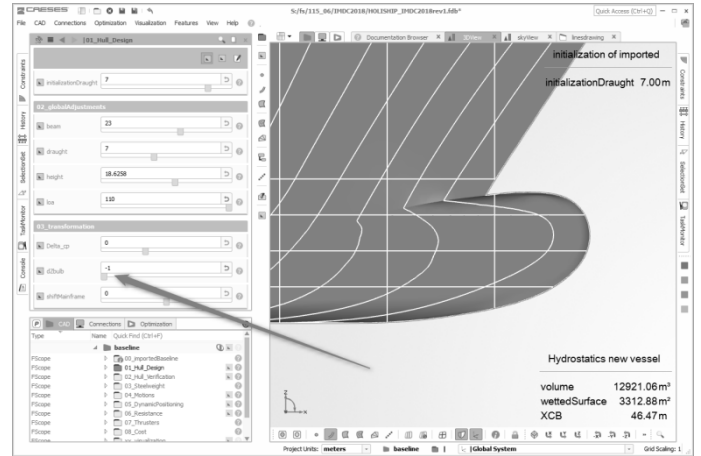

Figure 7: Parametric variant.

Figure 9. Bulb modified variant.

The new vessel geometry based on the shape modifications as described in this chapter are linked to export methods and specialized features that provide the required file format for the calculation and assessment methods integrated in the case study and don't need any a further manual processing.

5 WEIGHT ESTIMATIONS

This section refers to step 2 in Figure 2.

5.1 *Tool application*

For the stability and cost calculations, the weight of the vessel is of importance. Relative changes in weight compared to the baseline vessel are calculated. As indication of the change in lightship weight, estimations for steel weight and main equipment weight are calculated.

5.2 *Tool description*

The steel weight is calculated based on main dimensions and steel coefficients for the hull and deckhouse. These coefficients are based on the reference vessel and can be adjusted in case other features like ice class or larger accommodation space are to be considered.

With regard to the lightship weight of the vessel, changes in main components are taken into consideration. The most important items are the crane and the lifting wire.

The centre of gravity of the lightship in vertical direction is also considered based on the changes in steel weight and equipment weight. The longitudinal position, as a simplification is considered to be at the longitudinal position of the centre of buoyancy. This because the actual loading conditions are not considered, due to the high level nature of the tool. It is assumed that adjustments can be made by ballasting the vessel. This is also the case for the vertical centre of gravity, where ballast is used to obtain suitable metacentric height values. However a check of the vertical centre of gravity position against the baseline vessel and the hydrostatics of the hull configuration, provides an additional quality check.

6 STABILITY CALCULATIONS

This section refers to step 3 in Figure 2.

6.1 *Tool application*

The stability tool is used to evaluate the feasibility regarding the vessel stability for each of the hull configurations generated with each crane type. Not all hull dimension combinations are viable regarding vessel stability.

6.2 *Tool Description*

Stability calculations are performed in NAPA for Design (https://www.napa.fi/Design-Solutions). NAPA is a leading software for design stage development of hull shape and stability calculations. NAPA handles a variety of different hull definition methods, including import and export of graphic formats like IGES.

In this application, the hull shape is obtained from CAESES.

6.3 *Hydrostatics*

The hydrostatic model is set up by typical OSV parameters like height of working deck and length of buoyant accommodation above working deck. Refinement of the model, like introducing a moonpool or additional buoyancy can be easily controlled by CAESES parameters.

6.4 *Stability*

Based on the hydrostatic model, together with the input from the weight estimation tool, the stability characteristics are verified against typical IMO requirements. These criteria investigate the extent of positive stability, the energy reserves against capsizing and the sensitivity to wind heeling moments.
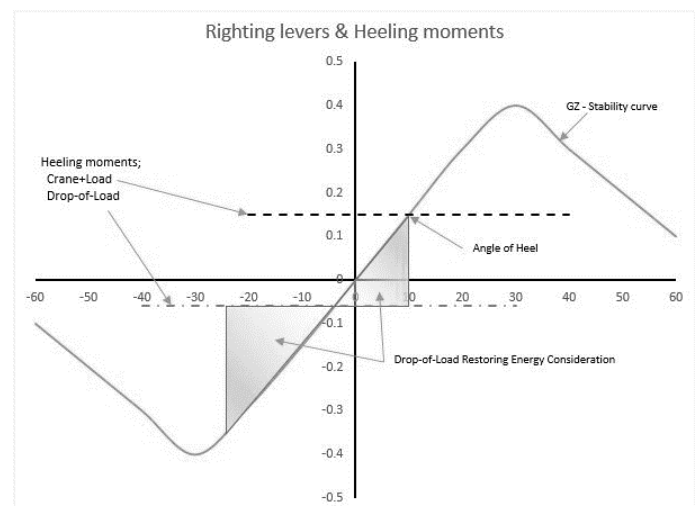

Figure 10. Crane operation stability – angle of heel & restoring energy.

For a vessel with a large crane for offshore lifting, additional requirements are introduced, like (Fig. 10):
– heeling angles, when subject to heeling moments from crane and crane load,
– heeling angles, as a result of a drop-of-load situation,
– consideration of restoring energy margins, following a drop-of-load situation,
– influence of counter ballasting.

7 VESSEL MOTIONS

This section refers to step 4 in Figure 2.

7.1 *Tool application*

The hull dimensions have an effect on the vessel motions in a given seaway. To determine the effect of the operability of the lifting operation, motion calculations are performed. From these calculations limiting wave heights and period are established based on the crane operational criteria on motions and accelerations. These limiting wave heights and periods are input into the station keeping evaluation. This to ensure that the station keeping performance is inline with the crane operability of each configurations.

7.2 *Tool description*

VERES is the vessel response plugin of SINTEF Ocean's ShipX workbench, which is applicable from the early design stage to the operational phase of a vessel (Fathi D.E. User Manual ShipX Vessel Responses (VERES) Plug-In). VERES is built upon strip theory and offers the ability to calculate ship motion and global loads in waves. The program calculates:

– motion (displacements, velocities and accelerations) transfer functions at arbitrary locations in six degrees of freedom for both, Fn=0 and Fn>0,
– motion transfer functions at specified points,
– unsteady global loads.

Mean drift forces and added resistance in waves can be calculated by either a pressure integration method or according to the radiated energy approach by Gerritsma and Beukelman (Gerritsma and Beukelman (1972)). Furthermore, global wave induced loads can be assessed. Beside the effect of the hull alone, VERES is capable of including the effects from the effect of bilge keels, moonpools, active and passive roll stabilizing tanks, rudder control, and other active and passive control surfaces (such as roll stabilizing fins, T-foils, and interceptors).

Moreover, the post-processor of the code can calculate short-term and long-term statistics, operability limiting boundaries and operability percentage for various relevant limiting motion criteria.

It is worth to mention that in VERES, the hull is defined by a set of body lines at freely selected longitudinal positions. Each of the cross-sections of the hull are specified by a number of offset points, which are further interpolated upon in VERES. In order to create the hull description in ASCII format for VERES from the parametric hull geometry in CAESES, a special module in CAESES has been developed. This module partitions the hull into strips by distributing the points on one half of the hull section which subsequently will be mirrored about the centre line plane by VERES to give a complete description of the hull section.

Figure11 shows results of numerical simulations in which CAESES executes VERES for different wave headings, from head sea (0˚) to beam sea (90˚). For each heading VERES finds the maximum wave height (HsLim) for which a certain criteria on operability of crane operation is met. Furthermore, for each heading, CAESES generates an operability index for each heading that can be used as an operability index in the final optimization routine.
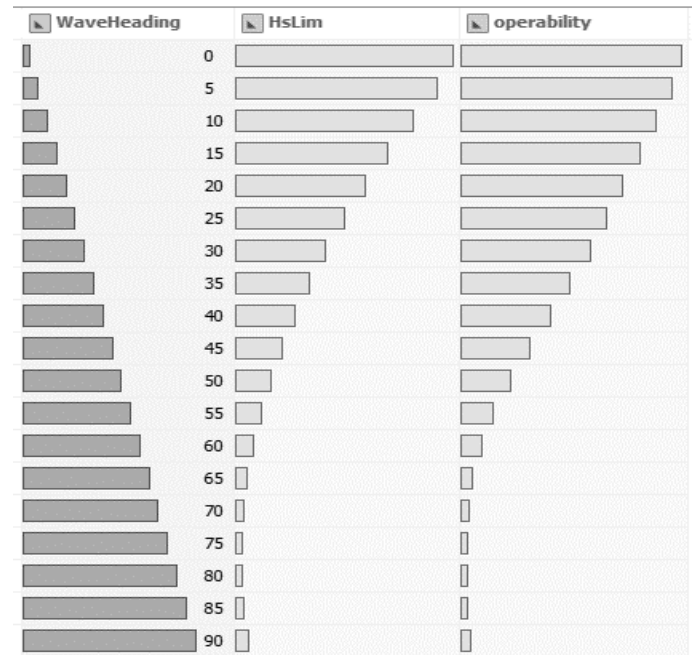

Figure 11. Maximum wave height (HsLim) and operability index for different Wave headings.

8 STATION KEEPING

This section refers to step 5 in Figure 2.

8.1 *Tool application*

Another critical aspect of an OSV vessel performance is the station keeping ability and the required thrust in relation to the environmental conditions. The required thruster sizes are driving both CAPEX and OPEX, and is therefore part of the optimisation process.

The maximum wave height and wave length from the motions evaluation is used as input for the environmental conditions for the station keeping calculations. An additional scaling factor allows for operational margins and the wind speed is added based on the Beaufort scale. The current is based on IMCA North Sea industry standard values. (IMCA, Specification for DP capability plots, 2000)

8.2 *Tool description*

Station Keeping is another plug-in of SINTEF Ocean's ShipX workbench that enables analysis of the

station keeping capabilities of a vessel in the early design process (R E. User Manual ShipX Station Keeping Plug-In). The results from station keeping analysis are of significant importance with respect to dimensioning, positioning and usage of the force generators on the vessel. It also allows study of the performance of the vessel in presence of faulty force generators. The station Keeping plug-in only addresses the static scenarios (steady state conditions); furthermore, static station keeping capability calculations are performed in the horizontal plane with a minimum amount of input data. While users can define their own force generator unit, the vehicle could be equipped seamlessly with any force generator model from the ShipX propulsion library developed by SINTEF Ocean. Similarly, users can develop their own thrust allocation algorithm or simply use any of allocation method developed by SINTEF Ocean and gathered in an allocation library. After configuring the vessel and defining different environmental conditions, the software can produce variety of performance indicators, including but not limited to the DP capability plot defined by IMCA (IMCA, Specification for DP capability plots, 2000), environmental regularity numbers (ERN) defined by DNVGL (DNV, Rules for Classification of Ships, PART 6 CHAPTER 7), and station keeping performance (SKP) defined by ABS (ABS, Guide for Dynamic Positioning Systems, 2014).

Figure 12 presents a typical IMCA DP capability plot in which station keeping capability of the vessel is illustrated in a polar plot. The objective of a DP capability analysis, using DP capability plots, is to determine the limiting environmental conditions (wind speed, wave height, and current) within which the vessel can maintain position and heading while using its DP capability. This is done by balancing the maximum obtainable thruster force against environmental forces due to wind, wave drift, current, and possible other loads.
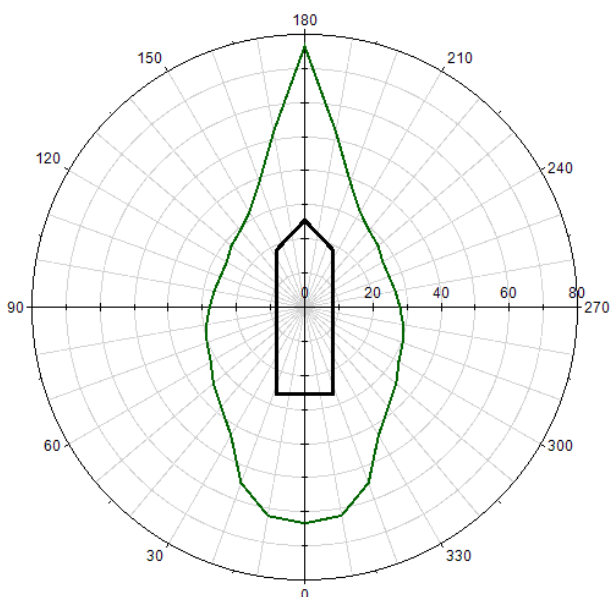

Figure 12. DP Capability Plot.

9 RESISTANCE

This section refers to step 6 in Figure 2.

9.1 *Tool application*

In order to determine the thrust and power requirement for transit operations, a resistance and propulsion evaluation is performed. The evaluation is performed for one speed, which is set as an input value. Since the resistance is influenced by the shape of the bulb and hull details, an optimisation is performed, to find the lowest values for each hull configuration. Setup of calculations:

- baseline total resistance calculations by RANS,
- divide total resistance into viscous resistance and wave resistance,
- assume mechanical efficiency based on chosen propulsion solution, and total propulsion efficiency from available model test data.

9.2 *Calculation approach*

The potential flow solver SHIPFLOW XPAN by FLOWTECH International AB is utilized for iterative vessel design investigation (SHIPFLOW: www.flowtech.se/products/shipflow-basic). The best calculation results from XPAN are normally obtained for ship speeds in the range between Fn=0.2 and Fn=0.35.

In this high-level approach, the XPAN calculation results are used for relative ranking of the different design iterations, not for determining absolute resistance values.

9.3 *Simplified approach*

Initial hull is calculated in RANS code STAR-CCM+ (www.mdx.plm.automation.siemens.com/marine). The pressure resistance component of the calculated total resistance for the initial hull is related to the CWTWC coefficient, which is a wave resistance value, obtained from a transverse wave cut method in the SHIPFLOW calculation. When ship speed or hull parameters (e.g. draught, length over all, and breadth) are modified, SHIPFLOW recalculates the wave pattern and a new CWTWC value is obtained. By comparing the CWTWC values of the baseline hull with the CWTWC value of the modified hull, it is possible to obtain a relative ranking of the resistance component contributed by the generated waves. This approach will show the effect of fore- and aft shoulder positions, bulb design and hull main dimensions on the wave-making resistance. Viscous resistance is calculated by a feature function following the ITTC 57 correlation line approach (ittc.info/media/2021/75-02-02-02.pdf Page 2 of 17).

9.4 Propulsion

Ranking of hull performance for transit operations is based on the resistance values. In a more detailed optimisation process, this would not necessarily be correct as propulsive efficiency can alter this. However, in this high-level approach this is reasonable. Propulsive efficiency assessment requires a detailed in-depth design analysis with experiments or advanced RANS runs.

The required propulsion power is directly related to calculated resistance through the total efficiency where the propulsive efficiency η_D is fixed and the mechanical efficiency η_M varies dependent upon main propulsion variant (ITTC symbol and Terminology List Version 2017).
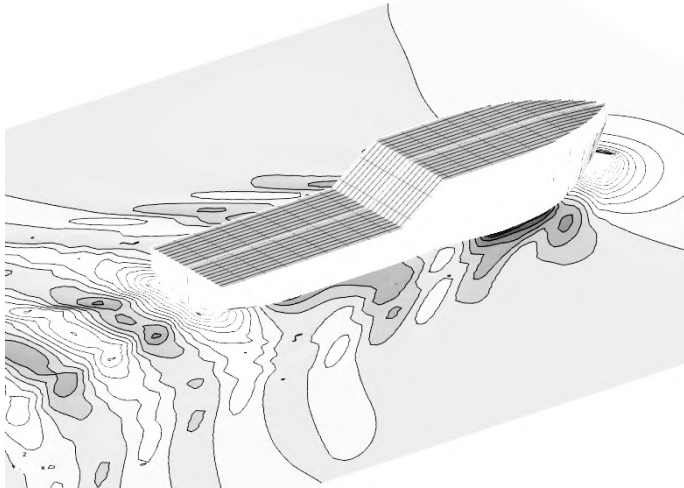

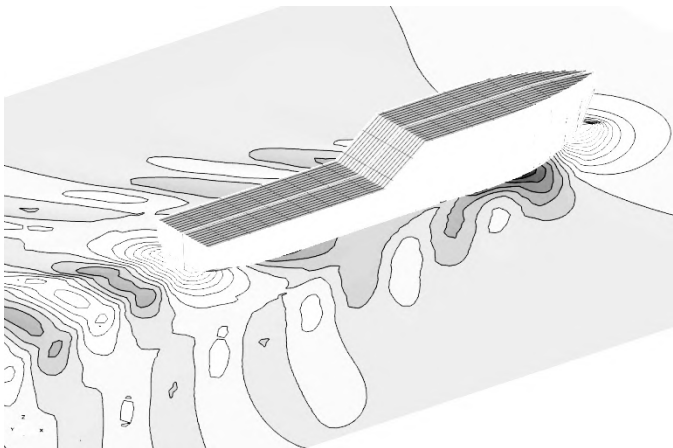Figure 13. Calculated wave pattern for hull Loa=92.05m, B=23.0m at draught T=6.0m and ship speed Vs=12kts.

Figure 14. Calculated wave pattern for hull Loa=92.05m, B=16.6m at draught T=6.0m and ship speed Vs=12kts.

10 MACHINERY SYSTEMS

This section refers to step 7 in Figure 2.

10.1 Tool application

With the performance of the hull configuration established, the cost impact has to be determined. With the machinery systems evaluation tool, required thrust for the main propulsion and manoeuvring thrusters is converted to installed power generation. Base on this a machinery set-up is generated and both fuel consumption and cost calculations are performed, feeding into the CAPEX and OPEX evaluation.

10.2 Tool description

The thrust requirements for both transit and DP operations are compared and the minimum required thrust levels for bow and aft thrusters are determined, based on a basic thruster configuration, which is an input for the tool.

A database with equipment information, consisting of equipment sizing, is used to determine which main equipment is to be installed to fulfil the operational requirements.

With the main thrusters selected, the total power requirement is calculated taking into consideration the electric losses, hotel load and heavy consumers. With this total power requirement the power generation machinery is selected. The machinery configuration is kept the same as the baseline vessel, but the elements are sized according the power supply requirement.

The machinery system of the vessel and the propulsion powertrain is modelled using the DNVGL COSSMOS framework (Dimopoulos et al. 2014). COSSMOS is DNVGL's in-house process modelling framework and consists of a library of reconfigurable generic models of ship machinery components. The models capture the steady-state and dynamic thermo-fluid / mechanical / transport phenomena / electro-chemical behaviour of each component. The component model library is coupled with a graphical flow sheeting environment, in which the user can hierarchically synthesize system models of varying complexity. This process results in large systems of non-linear Partial Differential and Algebraic Equations (PDAEs), subject to initial and boundary conditions. The required numerical and optimisation solvers are incorporated to our framework in order to perform a wide range of model-based studies such as steady-state and dynamic simulations, parameter estimation, and non-linear, mixed-integer and dynamic optimisation. COSSMOS has been successfully applied to machinery studies in all ship segments, and with particular relation to this application in OSV vessels and LNG carriers with electric propulsion (Stefanatos et al. 2015, Dimopoulos et al. 2016).

In the current study, COSSMOS is used to model a diesel-electric propulsion powertrain at steady-state conditions. The developed system model is depicted in Figure 15. The propulsion powertrain consists of four diesel generating sets covering the total electricity demand from the propulsors and thrusters as well as and hotel and auxiliary electricity demand.

The base line vessel propulsion powertrain consists of:
- four RR B32:40L6 generating sets each with power at 2880kW, at 720rpm,
- two main stern azimuthing thrusters each with power at 3000kW,
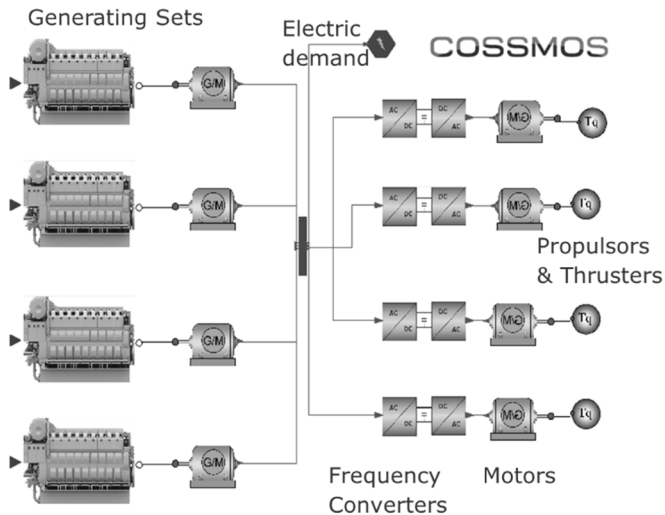- two forward tunnel thrusters each with power at 1200kW.

Figure 15. Propulsion powertrain model in COSSMOS.

The system model is utilized as the fuel consumption, efficiency and related costs estimator, within the CAESES optimisation framework. The steady-state simulation model receives information from the other CAESES modules on propulsion and electricity demand and returns the fuel consumption and related costs. The COSSMOS propulsion powertrain system module is packaged as a stand-alone executable and it is interfaced with CAESES in a batch file mode.

The subsequent steps, with respect to machinery systems modelling, simulation and optimisation, consist of the development of a more generic system model suitable for design and operation optimisation.

11 CAPEX AND OPEX ESTIMATION

This section refers to step 8 in Figure 2.

11.1 Tool application

In addition to the fuel consumption, which is part of the operational expenditure (OPEX), the capital expenditure (CAPEX) is represented by the cost of the power and propulsion system elements, crane and steel costs. Values of CAPEX and OPEX relative to the baseline, shows the differences between the various possible configurations reviewed by the tool. The early design stage application of this tool allows this simplification.

11.2 Tool description

The costs for power and propulsion system are based on the thrust requirement for station keeping and sailing, as described in sections 8, 9 and 10. The costs of these elements are summed up to obtain a reference value representing the power and propulsion cost of the CAPEX.

The steel cost is based on the steel weight, as described in section 5 and is based on a price per ton of worked steel. Since the deckhouse size is kept as a constant in this case, no corrections for accommodation outfitting is taken into consideration.

Further parameters determining the CAPEX and OPEX levels can be added if deemed important for the comparison, by adding additional features in CAESES or linking additional life-cycle cost tools e.g. Reliability, Maintainability and Availability (RAM) tools for assessment of maintenance and repair cost.

12 DESIGN SPACE EXPLORATION

This section refers to CAESES as the hub in Figure 2.

The process of finding promising designs and hence optimising a product for one or several objective functions is typically initiated by running a design space exploration (DSE). The design space is defined by the given range of input parameters that influence the system's behaviour and its objective functions. The number of input parameters –the design variables– defines the complexity of the system and also gives an indication how many designs need to be investigated for developing an understanding of the design space. A good estimate for investigating an n-dimensional problem in the context of hydrodynamic performance is n^2 samples. Algorithms for populating the design space are e.g. the Latin Hypercube method or a Sobol Sequence (M. Cavazzuti, 2013). Both methods aim for distributing design candidates in the design space such that all areas of the design space are covered with as little evaluations as possible.

In practical design tasks the design space is often strongly reduced by constraints. It can be easily understood that for an independent variation of length and beam as design variables, a constraint for the required displacement is violated frequently and feasible designs will not be distributed evenly in the design space. The aim of a DSE therefore is not only getting an understanding of the design space but also identifying its limitations by constraints. Figure 16 shows a design space that is dominated by constraints. Out of 100 variants only 3 feasible designs have been identified.
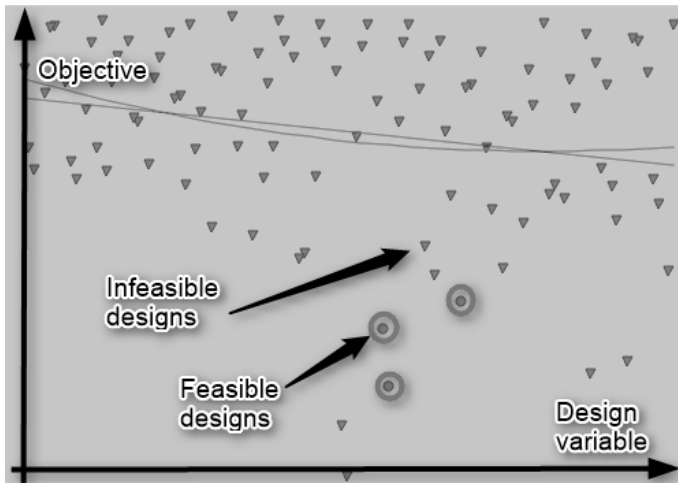
Figure 16: Constraint dominated design space.

A design space exploration helps the design team to understand the system's behaviour, adapting the design space or to reconsider limits of constraints. As long as the constraints are not subject to costly simulations a-priori investigations of the variants is very helpful without launching any CFD simulation.

After having identified the most promising feasible designs, pre-defined optimisation algorithms are executed to squeeze out their potential, starting from one or several of these candidates.

13 RESULTS AND FURTHER WORK

The implementation of the early stage holistic design tool for the case study of a Subsea Construction Vessel is ongoing and the following has been achieved to date:
− definition of a case study applying holistic design synthesis at an early stage of a design process,
− establishment of a multi discipline design team involving domain specialists from four different organizations located in four different EU countries,
− establishment of a integration framework based on the CAESES platform from Friendship Systems,
− implementation of a parametric hull model enabling automatic design space exploration,
− integration of NAPA for stability calculations,
− integration of ShipX/VERES from Sintef Ocean for vessel motion calculations,
− integration of ShipX/Station Keeping from Sintef Ocean for DP capability assessment,
− integration of SHIPFLOW from Flowtech for resistance calculations,
− integration of COSSMOS from DNVGL for fuel consumption estimations,
− Implementation of dedicated features in CAESES for weight estimations,
− Implementation of feature in CAESES for thruster and propulsion selection from Rolls-Royce Marine product portfolio,
− Implementation of feature in CAESES for CAPEX and OPEX calculations.

Next steps in this development are:
− implementation of automatic exploration of the design space in CAESES,
− implementation of multi parameter optimisation in CAESES,
− implementation of user interface.

The end results of this holistic design tool is an early definition of the main dimensions of a hull considering the mission of the vessel and exploring different key options like selection of mission critical products, propulsion system configuration and power system type and architecture.

14 SUMMARY AND CONCLUSION

Decisions taken at the early design stage can have a significant impact on the final performance and life cycle cost of a vessel. For specialized vessels with a complex operational profile, defining the best trade-off between main design parameters satisfying the mission requirements of the customer, respecting constraints in rules and regulations and providing the optimum solution with regard to multiple KIPs as life cycle cost, emission is a challenging task. Multiple disciplines working at different modules or units of the vessel must interact to find the best solution. At an early design stage major decisions are taken, e.g.:
− main dimensions of the hull,
− selection of propulsion configuration,
− definition of power system type and architecture
− selection of mission critical components like cranes and other deck machinery systems

This paper describes a methodology based on a Model Based System Engineering approach. The design integration platform CAESES is used to connect several specialists tools in a design synthesis assuring a consistent state of the overall design during the design process. The tool can explore a user defined design space automatically and perform multi parameter optimisation of the results to find the optimum solution based on KPIs. This is a tool for a naval architect, enabling him to perform early design synthesis involving advanced specialist tools. A simplified user Interface for the naval architect is important to make this a practical usable tool. A web interface where the design case can be configured and tools can be executed is planned to make this a practical usable tool.

Domain specialists are still as important as before in this design methodology, but the interaction with the naval architect is structured in a new way with the aim of reducing design time and increasing the quality of the decisions taken at an early design stage.

This paper has described a case study on this methodology based on early conceptual design of a Subsea Construction Vessel. The implementation of this case is still ongoing in the HOLISIP project (HOLISHIP, 2016-2020).

15 ACKNOWLEDGEMENT

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