HOLISTIC Ship Design Optimisation

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ABSTRACT:

The present paper describes the HOLISHIP–Holistic Optimisation of Ship Design and Operation for Life Cycle project approach to ship design and operation and demonstrates a subset of its functionality on the basis of a case study. This refers to a RoPAX ferry optimisation for minimum powering requirements and maximum life-cycle economic performance in realistic operating conditions by use of concurrent engineering tools from different project partners operating in collaboration on a common design software platform. The impact of alternative operating/speed scenarios on case study ship's efficiency and safety is presented and discussed.

1 INTRODUCTION

Today’s shipping industry operates in a complex environment with numerous economic, environmental and even social restrictions. Energy efficiency, safety and environmental protection are key requirements for a sustainable shipping industry and the means of transportation need to be adapted accordingly. This calls for significant changes in the traditional ship design process, which is a complex, multi-disciplinary and multi-objective task of both technical and non-technical nature. Likewise multi-faceted is ship operation. A system approach to ship design and operation considers the ship as a complex system, integrating a variety of subsystems and their components, e.g. for energy / power generation and ship propulsion, for cargo storage and handling, accommodation of crew / passengers and ship navigation. Any state of the art design process inherently involves optimisation, namely the selection of the best solution (trade-off) out of many feasible ones for a given target function or transport task, depending on vessel type. Today, this trade-off or formalised optimisation increasingly involves life-cycle considerations and objective functions.

In practice often only parts of the ship design and even less of the ship's life-cycle are integrated in a common database and software platform. This typically results in less favourable selections of optimised sub-systems or components while the optimal ship would have been the result of a holistic optimisation of the entire ship system. It should be noted that the system ship is actually a component of the wider transport system, thus a holistic approach to ship design should actually also consider aspects of fleet composition and transport/mission scenario optimisation, which are not addressed in this paper. For a systems approach to ship design see, e.g. (Hagen et al., 2010) and (Guégan, A. et al., 2017) in the HOLISHIP project.

The approach chosen in the HOLISHIP project (www.holiship.eu) acknowledges the fact that, in practice, surrogate models need to be employed for several sub-systems and components to reduce computational/processing time and the complexity of the overall optimisation problem; also, the often conflicting constraints and requirements of the optimisation, which in turn result from contradicting interests of the various stake holders in the maritime transport chain, need to be optimally balanced. The volatility of market conditions and associated transport demand, the variability of the operational conditions over a ship's life-cycle, the cost of raw materials as well as energy cost during operation all need to be considered in compliance with continuously changing regulatory requirements regarding ship safety and the ecology of the marine environment.

The present paper addresses the topic of design and optimisation of ships and their operation by a holistic approach, as elaborated in (Papanikolaou 2010), constituting a multi-disciplinary and multi-objective problem. The implementation of this approach requires the coupling and integration of a series of software tools within a design software platform, sharing common data, as will be outlined in the next sections. For illustration purposes a representative application case covering important design aspects for a modern RoPAX ferry is shown. The

HOLISHIP project will further address 8 other application cases for merchant and research vessels which will be shown in the future.

1.1 *The EU-project HOLISHIP*

To meet present and future challenges as outlined above, a large team of 40 partners, led by HSVA (Hamburgische Schiffbau-Versuchsanstalt) and NTUA (National Technical University Athens), set out to develop the concept of an integrated, holistic ship design platform and implement it in the context of the Horizon 2020 Research Project HOLISHIP – Holistic Optimisation of Ship Design and Operation for Life Cycle (2016-2010, www.holiship.eu). The project considers all relevant design aspects, namely energy efficiency, safety, environmental compatibility, production and life-cycle cost, which are to be optimised in an integrated manner with the aim to deliver the right vessel(s) for future transport tasks. To do so, HOLISHIP addresses different design steps, covering basic design and contract design of vessels as well as virtual prototyping for design and operational assessment. These are implemented in two platforms of which the first one, covering concept and contract design, is addressed in the present paper.

This HOLISHIP design platform is built on CAESES®, a state-of-the-art process integration and design optimisation environment developed by FRIENDSHIP SYSTEMS. It integrates first-principles analysis software from various disciplines relevant to ship design and combines them with advanced multi-disciplinary and multi-objective optimisation methods. Due to the complexity of several evaluations surrogate models are employed to limit computational effort.

Compared with traditional approaches the interplay of all design components in form of a design synthesis model – hosted via the HOLISHIP platform(s) – allows exploring a much wider design space and, finally, helps achieving superior designs in less time (see, e.g., an application to tanker design by Sames et. al, 2011). Figure 1 illustrates the holistic approach to tool integration which enables a concurrent analysis and optimisation of systems and components, contrasting the sequential approach associated with the idealised view of the classical design spiral.

During its first project phase HOLISHIP integrates a full range of disparate software tools into the design platform. This paper presents a snapshot after 15 months of development (late 2016 to 2017). It highlights a first application of the HOLISHIP platform and the tools coupled so far to the design of a modern RoPAX ferry. This utilises parametric models for the hull form, general arrangements, structural design, engine layout and energy simulation and life-cycle assessment. Simulation codes are used for hydrodynamic analyses, provided by HSVA and NTUA, as well as for intact and damage stability, realized by NTUA and engine room and energy simulation from BV. This application case is continuously enhanced as more tools will be added to the platform. By the end of the project nine different application cases, as diverse as a double-ended ferry and an offshore platform for an arctic environment, will have been worked on through the HOLISHIP platforms.

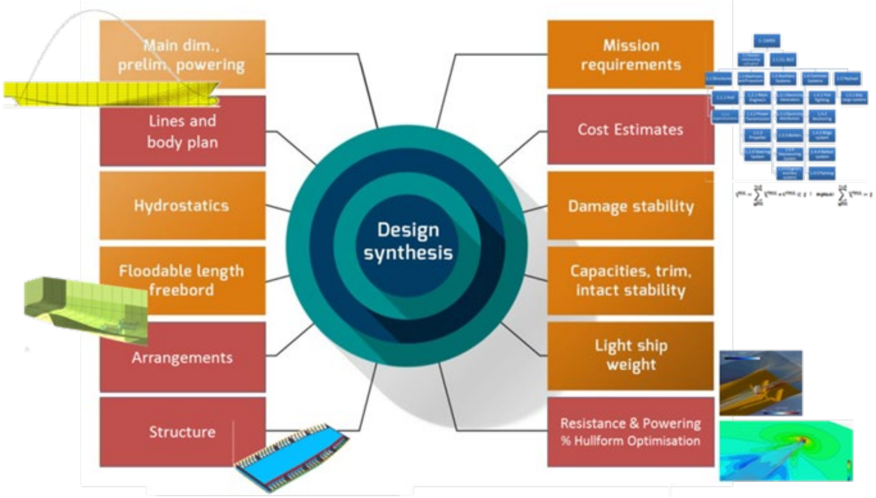

Figure 1: HOLISHIP design synthesis combining all relevant disciplines of ship design

2 INTEGRATION APPROACH

2.1 *The integration platform for concept and contract design*

The HOLISHIP design platform is based on CAESES®, a general process integration and design optimisation (PIDO) environment developed and licensed by FRIENDSHIP SYSTEMS. It allows to couple any software which can be run in batch-mode and to set up process chains for automated design and optimisation studies.

The available coupling mechanisms are very flexible and based on template files for input and output of external s/w components. The templates are used to specify parametric data relevant for the optimisation. An elaborated example is given in MacPherson et al (2016), for more background see Abt et al. (2009). Software tools to be coupled can be made available either locally (on the same computer) or remotely (e.g. within the same network), possibly combining different operating systems (Windows and Linux).

Within a CAESES project many different software connections can be used concurrently so that arbitrary process chains can be built. Moreover, CAESES supports the set-up of hierarchies so that every entity of a model knows on which data items it depends and which data items it serves.

2.2 *Coupling tools for HOLISHIP*

While the coupling mechanism within CAESES is very flexible the actual process needs both expert knowledge of the tool to be integrated and expertise in using CAESES itself. In order to enable a larger group of users to effectively exploit integrated software tools in standard applications a new functionality is introduced into CAESES that reduces complexity and makes it easier for the non-expert to run high-quality simulations. A novel wrap functionality for specific use cases offers technical APPs, short for applications, which provides customised expert knowledge for a given task.

2.3 *Usage of Surrogate Models*

Since several simulation tools require substantial computer resources (flow computations, structural analysis, parametric stability models) and special environments which may not all be available at the same time and to the same people, CAESES provides methods to pre-compute data for later usage and store them in response surfaces: the Surrogate Model. Here a design-of-experiment (DoE) is undertaken for a chosen set of free design variables, which form a task-specific sub-set of the total design space of interest to build a surrogate model in CAESES. To this end DAKOTA, an open-source optimisation kit by Sandia National Laboratories (dakota.sandia.gov), is embedded in CAESES. A simulation tool can then be run from CAESES separately and upfront to be subsequently replaced by a suitable response surface. A range of models are made available, for instance, Artificial Neural Networks (ANN), polynomial regression and kriging (Harries, 2010).

3 DESIGN DISCIPLINES IMPLEMENTED

3.1 *Hydrodynamics*

The hydrodynamic performance of a ship determines to a large extent the energy efficiency and – together with stability – a major part of its safety. The required propulsive power for a specified speed is a key contractual item for any new vessel as it determines fuel consumption and hence cost and emissions. Low resistance and high propulsive efficiency are fundamental prerequisites and optimising the hullform and the propeller / propulsor performance using different specific CFD tools is a must. A variety of further analysis tools for seakeeping performance, added resistance in seaways and due to wind, manoeuvring or the effects of hull appendages and energy saving devices up to the prediction of the effect of increased frictional resistance due to hull fouling form the basis for a complete hydrodynamic analysis.

The range of simulations applied to a specific design is adapted to its particular requirements. CFD predictions typically require substantial computational effort which is barely tolerable during an actual design optimisation process. Such analyses are successively implemented and generate response surfaces (surrogate models) which can be used during design and optimisation.

3.2 *Ship Stability*

The safety of ships against sinking/capsize in case of loss of their watertight integrity is of prime interest to the maritime regulatory bodies, the maritime industry and to the entire society. The new probabilistic damaged stability regulation for dry cargo and passenger ships (SOLAS 2009) represents a major step towards the rationalisation of the procedure for the assessment of a ship’s survivability in damaged condition. While the new regulation is more rational than the earlier deterministic approach (SOLAS 90), it requires the consideration of some hundreds of damage stability/flooding scenarios, which can only be studied by dedicated software tools (Papanikolaou, 2007). This effort is further increased when considering alternative arrangements and thus calls for specialised design software tools as an alternative to the traditional manual study of a few design/compartmentation alternatives. This is a crucial, yet very demanding task of contemporary passenger ship design. The EU funded project GOALDS (Papanikolaou et al., 2013) developed software tools for the parametric design and auto-mated multi-objective optimisation of RoPAX (and cruise ships), which are adapted to the new regulations and lead to vessels of enhanced survivability, while considering also building cost and efficiency in operation (Zaraphonitis et al, 2012). These software tools for the assessment of a ship's damage stability, along with corresponding ones for the intact stability, are now integrated in the HOLISHIP platform, allowing the concurrent optimisation of a ship’s stability/safety with all other major design disciplines.

3.3 *Energy Systems Simulation*

Energy system simulation focuses on the way energy is produced and consumed on-board. In an approach to reduce overall energy consumption during ship operation, this complements traditional optimisation to improve propulsive power requirements which are largely based on hydrodynamics and (combustion) engine improvements. A ship is a highly complex system of sub-systems and components, e.g. propulsion, electricity, cooling, fresh water etc. with strong couplings between the different energy flows. This offers vast opportunities for simulation and optimisations which are typically performed using a Model Based System Engineering approach. The tool applied in the present context is SEECAT, an energy modelling and simulation software package developed by Bureau Veritas which takes into account the various operational and environmental conditions met during the life time of a vessel (Marty et al., 2012). This Model Based System Engineering approach has proven suitable to model complex energy flows while considering complex ship operational profiles. It has been successfully implemented for ship optimisation in previous research and industrial projects (e.g. Faou et. al. 2015)

The innovative and challenging aspects developed in HOLISHIP concern the way such an approach can be integrated in the new design synthesis developed in the project. This covers the definition of the energy systems optimisation workflow as well as parametric models of the ship energy systems and the exchange mechanisms between tool and the design platform. In a first step SEECAT was connected to the HOLISHIP platform using a Python script whose parameters are modified by CAESES. The script drives the simulations and modifies parameters in the SEECAT environment using a COM interface (Component Object Module) thus allowing to perform energy system optimisation in-line with hull calculations. The approach offers the opportunity for a parallel execution of hull design and energy system optimisation which will change the traditional – sequential – workflow.

3.4 *Cost Assessment*

Enhanced software tools for the evaluation of building and operational cost, annual revenues and eventually for the life-cycle assessment of alternative designs are currently developed in HOLISHIP. In the meanwhile, simpler tools, specifically developed for the application case presented here are used for the cost assessment aiming to close the design loop and to enable the demonstration of the potential of the adopted design procedure and of the developed optimisation platform. To account for some inherent uncertainty in the underlying cost data, differences in cost and Net Present Value (NPV) are used to compare with the baseline design rather than using absolute cost figures. The impact of design modifications on building and operating cost and annual revenues are calculated first and, based on them, the variation of the NPV for a specified life time is estimated.

3.5 *Further HOLISHIP Platform Elements*

The present study describes a snapshot of the HOLISHIP developments which will continue until 2020. During this period more tools will be added to the platform, as necessary for the conduct of the planned Application Cases. These mainly refer to structural design and life cycle assessment (LCA).

For ship's structural design and the generation of related data like structural weight / lightship / displacement, centroids and their effect on payload, stability etc. a variety of methods and tools are developed as appropriate for the various application studies. Structural design data for concept design are semi-empirical in principle or classification society rules-based, whereas contract design structural data are resulting from the application of advanced structural analysis methods like FEM. Such tools play an important role in the design of innovative vessels for which no empirical data are available, or when optimising vessels for minimum structural weight.

Life cycle aspects and their assessment (LCA) receive special attention in HOLISHIP. Future and better vessel designs need to adapt to changes of the operational profiles encountered during their life span. Assessment of the environmental, energy efficiency and economic performance of a vessel will be via suitable Key Performance Indicators (KPIs), e.g., Cumulative Energy Demand - CED, Global Warming Potential - GWP, Net Present Value - NPV. This assessment will include the evaluation of different operational profiles and maintenance strategies, allowing validation of the fit-for-purpose properties of the equipment and to extend warranty to the ship owner. A Decision Support System (DSS) will be developed allowing the identification of the most effective decisions / strategies to be assumed at any stage of the vessel's life cycle (as a function of the vessel's design features), while considering lifecycle uncertainties (e.g., fuel, chartering).

4 APPLICATION CASE

To illustrate HOLISHIP developments a realistic

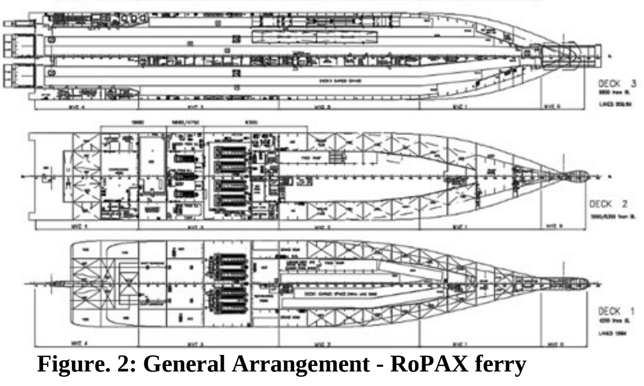

Figure. 2: General Arrangement - RoPAX ferry

design example in form of a RoPAX ferry sailing between Piraeus (mainland Greece) and Heraklion (Crete) was chosen. This representative example serves as both a testbed and a show case to illustrate the potential of the design platform developed. An operational profile comprising a daytime trip of 6.5 hours at 27 kts and a night trip of 8.3 hours at 21 kts was specified.

4.1 *Owner's requirements, operational profile and basic design.*

For the chosen application case a set of most important owner's requirements with regard to transport capacity have been selected on the basis of equivalent vessels. These are given in the following table:

Number of passengers	≥ 2,080
Number of passenger cabins	> 300
Lane length	≥ 1,950 m
Payload	≥ 3,500 t
Number of crew	120

TABLE I: OWNER'S REQUIREMENTS

The above owner's requirements correspond to a baseline design initially developed by FINCANTIERI in the context of the EU-funded research project GOALDS and are further elaborated by the HOLISHIP partners. This is a twin screw RoPAX with mechanical propulsion, fitted with a main and an upper trailer deck and a lower hold. A hoistable deck is also fitted on the upper trailer deck. For loading and unloading of vehicles, the ferry is fitted with two stern ramps and side hinged bow doors with a bow ramp. The main characteristics of this vessel are given in Table II:

Length between perpendiculars	162.85 m
Beam	27.6 m
Subdivision draught	7.10 m
Height of bulkhead deck	9.80 m
Gross tonnage (GT)	≈ 36,000
Deadweight (DWT)	5,000 t

TABLE II: MAIN CHARACTERISTICS OF BASELINE DESIGN

The ship will be operated year-round, considering a high season of seven weeks with seven roundtrips per week, a medium season of twenty four weeks with five roundtrips per week, and a low season of twenty two weeks with three roundtrips per week resulting in total in 235 roundtrips per year. Appropriate occupancy rates for passengers, cars and trucks for each of these three periods have been assumed for the calculation of annual revenues. Since there are always limits in the demand for transport work, a gradual reduction of the occupancy rates for ships with larger transport capacity is assumed, when, for the purpose of optimisation, parametrically varying ship's size. For example, for a 10% (resp. 20% or more) increase of transport capacity, compared to the baseline design, it was assumed that the annually transported passengers or vehicles increased by 7.5% (resp. 10%). This assumption ensures that larger vessels are only modestly exploiting the economy of scale.

4.2 *Parametric Design Models*

Various parametric models were built in order to undertake a first design and optimisation study:

- A flexible geometric model for the form of the bare hull within CAESES
- A comprehensive compartment model for spaces, including decks, bulkheads, tanks etc, within NAPA
- A weight model that estimates the weights and centres of gravity of key systems and components as functions of main dimensions
- A preliminary cost model (to be replaced in the future by more advanced life-cycle cost assessment).

The geometric model for the RoPAX hull uses main dimensions and relevant form parameters for hydrodynamics and stability, i.e., length, beam, draft, block coefficient, midship coefficient, centre of buoyancy, etc., along with local parameters for the bulbous bow. The model was set up in CAESES, allowing specific export of geometry to the coupled software tools in the formats required. For instance, NAPA receives the hull form as an IGES-file, the viscous flow solver *FreSCo*$^+$ would be fed by a watertight *stl-file* while the potential flow solvers, ν-Shallo and NEWDRIFT+, obtain dedicated panel meshes of different topology (Harries et. al., 2017).

A comprehensive parametric model for the watertight subdivision was developed within NAPA. It receives the hull form from CAESES as an IGES-file and subsequently creates all watertight compartments below the subdivision deck and on the main car deck. All openings and cross connections required for the damaged stability assessment are also created. Based on this model, the ship's light weight and the weight centre along with its transport capacity are calculated. A simplified procedure for the calculation of lightship is employed, which shall be later replaced by a more accurate external tool being currently developed within the HOLISHIP project. A series of loading conditions are defined for the evaluation of compliance with relevant intact and damage stability criteria. When changing the hull form all bulkheads and decks are "snapped" to the new shape, preserving the topology of the general arrangement. At this point all compartments are linearly scaled in longitudinal, transverse and vertical direction. This is a simplification and may become subject to a more elaborate treatment in the future.

4.2.1 *Hydrodynamics*

Hydrodynamic analysis requires precise knowledge of the actual hull geometry and a reasonably constructed parametric model of the hull. Using the parametric model described above, different hydrodynamic analysis tools have been employed to predict calm water resistance and power requirements as well as the effect of added resistance in a seaway.

For the C*alm Water* analysis a combination of HSVA's in-house tools ν-Shallo (panel code, wave resistance) and FreSCo$^+$ (RANS) was used. More information on the codes can be found in (Gatchell et. al., 2000) and (Hafermann, 2007), the integration in the design platform is described in more detail in (Harries et. al. 2017).

For the RoPAX design example two response surfaces for delivered power were established, one for the ferry's lower speed of 21 kts and the other for the top speed of 27 kts. Two design-of-experiments (Sobol) were run with ν-Shallo, each comprising 360 design variants. Combining both ν-Shallo and *FreSCo*$^+$ results to estimate power demand for all ferry variants during an optimisation, the response surface approach described in 2.3 was applied. Artificial Neural Networks were employed within CAESES and their accuracy was checked by comparing additional variants that were not contained in the training set with the corresponding results from direct simulations. A typical deviation of about 1 % was found. Note that these hydrodynamic response surfaces can be viewed as a numerical hull series.

For the prediction of *Added Resistance* in waves NTUA’s NEWDRIFT+ code (Liu et.al, 2017) was employed. This 3-d panel code uses Green Functions to evaluate motions, wave loads and mean second order forces on ships in the frequency domain. The code is a further development of the original NEWDRIFT code by adding software tools for the calculation of added resistance of ships in waves based on the far field method, with empirical corrections for the short waves regime (Liu & Papanikolaou, 2016). It is fully integrated into the CAESES platform using a hull panelisation created in the CAD section of the platform.

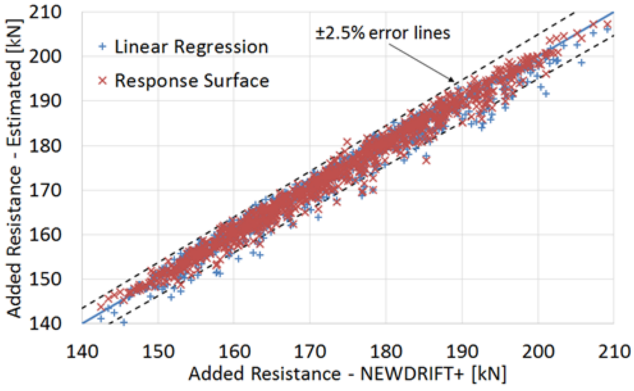

Figure 3: Comparison of added resistance in head seas at 27 kts calculated by NEWDRIFT$^+$ and estimated by response surfaces and error bounds

Calculating the added resistance for a wave spectrum (here a JONSWAP spectrum with h_S = 3m and T_P = 7s) may require up to 20 minutes on a standard computer. Therefore, again a surrogate model in form of a response surface has been created for use in the optimisation. A comparison of added resistance results calculated by NEWDRIFT+ and estimates from the response surfaces are presented in Figure 3. Both models capture the relationship quite well, namely generally with an error of +/- 2.5%, which is considered much smaller than the accuracy of the ensuing seakeeping code (and of similar SoA codes in general) .

4.2.2 *Stability*

According to SOLAS 2009, the ship's Attained Subdivision Index is calculated as the weighted average of partial indices at the deepest subdivision draught d_s, the partial subdivision draught d_p and the light service draught d_l (i.e. $A = 0.4A_s + 0.4A_p + 0.2A_l$). Each partial index is a summation of contributions from all damage cases: $A = \Sigma p_i s_i$, where i represents each group of compartments under consideration, p_i accounts for the probability that only this group of compartments may be flooded, and s_i accounts for the probability of survival after flooding. In addition, a Required Subdivision Index, is introduced, as a function of the number of persons on-board. The subdivision of a passenger ship is considered sufficient if the A-Index is not less than the R-Index and if, furthermore, none of the partial indices (A_S, A_p and A_l) is less than 0.9 of the R-Index.

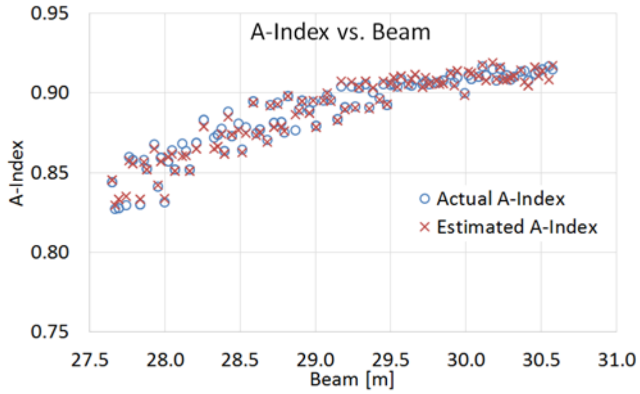

Figure 4: Actual and estimated A-Indices by response surfaces for parametrically varied ships vs. beam

In order to speed up calculations during an optimisation campaign, the integrated models developed in CAESES and NAPA were used to carry out a series of preparatory calculations, to provide adequate data for the development of surrogate models for fast yet reasonably accurate estimation of the A-Index and the corresponding partial A-Indices. A comparison of the actual A-Index calculated according to SOLAS 2009 as amended and the estimated

A-Index obtained using the response model is presented in Figure 4 and the error proves to be in general less than +/- 1%.

4.2.3 *Energy Simulation*

A rather complete energy model of the RoPAX ship has been built by Bureau Veritas in its SEECAT simulation tool as indicated in Fig. 5.

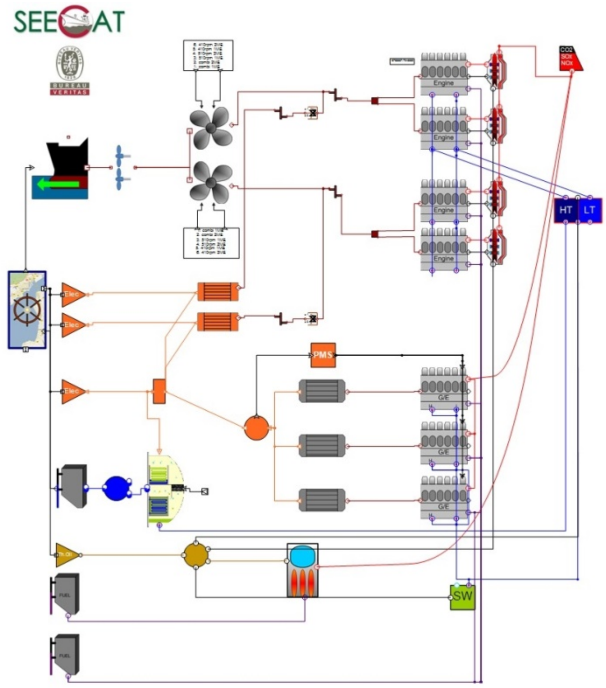

Figure 5. Energy System Model

The vessel's energy system comprises:

- a twin screw propulsion system, using one or two diesel engines per shaft line, depending on speed, and two controllable pitch propellers (CCP);
- An electric plant with three diesel generators and two PTO (Power Take-Off). The electrical power required at sea is 2.5 MW;
- Some auxiliary systems as shown in Fig. 5.

The necessary inputs for the energy simulation are the hydrodynamic resistance curve, as well as the thrust deduction factor *t* and the wake coefficient *w*. The platform integration assures the availability and consistency of the data and predictions parallel to hull computations without increase in effort.

The machinery optimisation focuses on the best configuration to operate the ship.

The machinery optimisation is done for a given operational profile as indicated before. A full round trip operational profile is defined as a time series of:

- Speed profile: 21 kts for 8.3 hrs and 27 kts for 6.5 hrs (daily rountrip requirement),
- Navigation mode (at berth, manoeuvring, at sea),
- Fresh water consumption: 5m^3/s and electrical power required: 2.5MW,
- Fuel type (MDO at berth or HFO when manoeuvring or at sea).

In this case, the fresh water consumption is considered constant. The optimisation is carried out considering 9 different configurations:

Config.	1	2	3	4	5	6	7	8	9
PTO	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
ME / shaft line	2	1	1	2	2	1	1	2	2
Rpm / ME	free	410	410	410	410	510	510	510	510

Rules and boundary conditions for the simulations include:

- The PTOs can't be used on the same electrical network as the electric plant, so at sea both cannot be used at the same time,
- Similar configurations for port and starboard side.

An example of the instantaneous fuel consumption at 21 kts and 27 kts for the configurations is shown in Figure 6. MCR has been set to 13 MW which means that only configurations with 2 engines per shaft line (#1,4,5,8,9) can reach 27 kts.

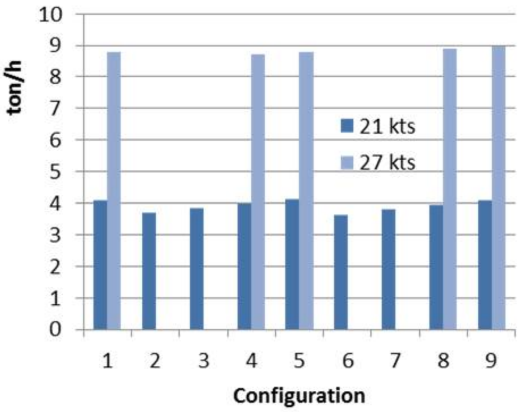

Figure 6: Instantaneous consumption at 21 and 27 kts, MCR = 13 MW / engine

It appears that for 21 kts the best configuration is no 6 (PTO: on, 1 engine/shaft line, 510 rpm) and for 27 kts configuration 4 (PTO: on, 2 engines/per shaft line, 410 rpm). The interest of using PTOs is demonstrated as the simulated fuel consumption is reduced by 4% in average. The assessment of fuel consumption yields 86.8 tons of HFO per day/roundtrip for the optimal scenario. Different engines shall be compared in the next steps of the project.

4.3 *Design Optimisation Set-up*

With the vessel presented in Section 4.1 as a baseline, an optimisation study was undertaken to identify optimal RoPAX vessels fulfilling the owner's requirements. It should be noted that the FINCANTIERI baseline was originally designed according to the older SOLAS 2009 regulations. Any new design, however, should comply to the considerably more stringent damage stability requirements introduced by the IMO Resolution MSC.421(98), adopted in June 2017. It was therefore anticipated that, although sharing the same topology with the baseline, the outcome of the optimisation should be a significantly different design. In other words, the baseline, although being a valid RoPAX ferry when developed several years ago, would now have to be considered an *infeasible* design and, consequently, the design space was extended towards vessels of wider beam as can be seen in the following table:

Free Variable	Lower bound	Baseline	Upper bound
Length BP	155.0 m	162.0 m	170.0 m
Beam	27.6 m	27.6 m	30.6 m
Design draught	6.5 m	7.1 m	7.1 m

TABLE III: FREE VARIABLES AND RANGE

In order to allow for many investigations and variants to be studied, the computational effort generally needs to be as low as possible. As discussed in previous sections, resource intensive simulations were first performed upfront (and at different sites) and afterwards replaced by dedicated response surfaces. Using these fast yet sufficiently accurate response surfaces, approximately 200 designs could be studied per hour on a standard desktop computer. For comparison, about one hour per design variant would have been needed if the simulations had to be undertaken directly with the various CFD tools for hydrodynamics and NAPA for damaged stability.

Suitable optimisation constrains were introduced so as to distinguish feasible and infeasible designs. The most important constraint required compliance with the intact stability requirements specified by the IMO Resolution A.749(18) as well as with SOLAS 2009 Part B, Reg. 6 and 7, as amended by the IMO Resolution MSC.421(98). As a temporary safeguard against possible inaccuracies in the GM estimation, suitable safety margins were introduced: The intact stability requirements should be met with a GM margin of 0.20 m, meaning that the actual GM in all loading conditions tested ought to be greater by at least 0.20 m than the one required by the intact stability criteria. For the A-Index and the three partial indices a safety margin of 0.02 was introduced, i.e., all feasible designs need to meet the inequality constraints $A - R \geq 0.02$ and $A_i - R \geq 0.02$, respectively. Additional constraints were employed to ensure adequate transport capacity in terms of lane length and DWT for each feasible design variant.

4.4 *Selected Results of first Optimisations*

Utilising the established synthesis model, the optimisation was conducted in two stages:

First, a design space exploration was undertaken in which 500 variants were generated within CAESES by means of a design-of-experiment (*SOBOL*). The hull forms were transferred to NAPA in order to create their watertight subdivisions and, following this, were evaluated using the tools and procedures described above. From these 500 designs only 3 proved feasible, emphasizing the challenge of finding acceptable let alone optimal designs.

Subsequently, a multi-disciplinary and multi-objective optimisation was carried out in which the Net Present Value of the designs was to be maximised while the fuel consumption per roundtrip was to be minimised. It is acknowledged that the minimisation of fuel consumption is inherently included in the first objective (i.e. the maximisation of NPV). However, it was decided to include this second objective in the optimisation to boost our search for designs of enhanced economic competitiveness and at the same time of minimal environmental footprint. The genetic algorithm NSGA II (Non-dominated Sorting GA II), available within CAESES, was used, resulting in 1130 feasible and 799 infeasible designs.

The aggregate of the results are presented in a series of scatter diagrams, see Figures 7 to 14 (for more clarity only feasible designs are shown). Figures 7 and 8 present scatter diagrams of the Net Present Value difference of each alternative design in comparison with the baseline (herein denoted as DeltaNPV) versus the ship's Length BP and Beam respectively. Note again that the baseline design is infeasible, since it fails to comply with the newly revised R-Index. These diagrams indicate that DeltaNPV generally increases with Length BP and de-

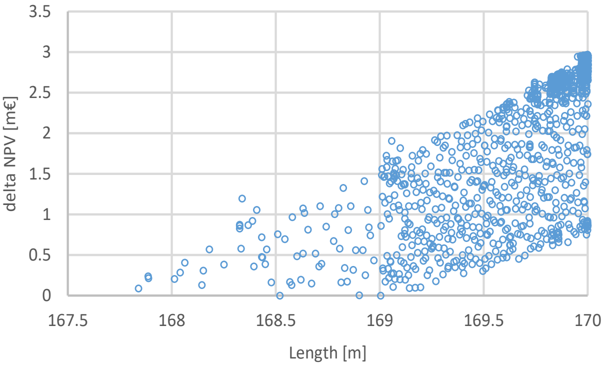

Figure 7: Increase of Delta Net Present Value vs. Length BP

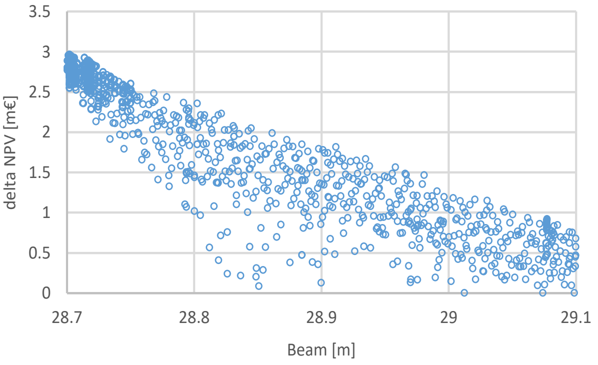

Figure 8: Decrease of Delta Net Present Value vs. Beam

creases with Beam. This is due to the impact of length and beam variations on the propulsion power, and eventually on the fuel consumption.

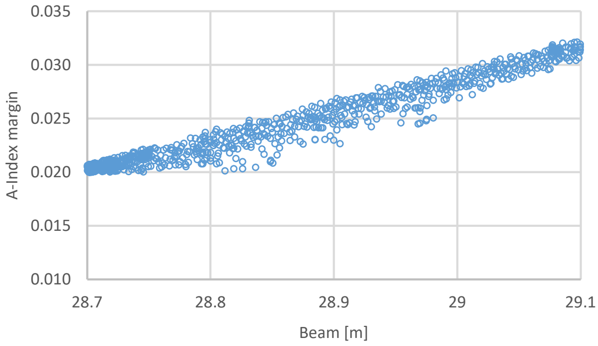

Figure 9: A-Index margin vs. Beam

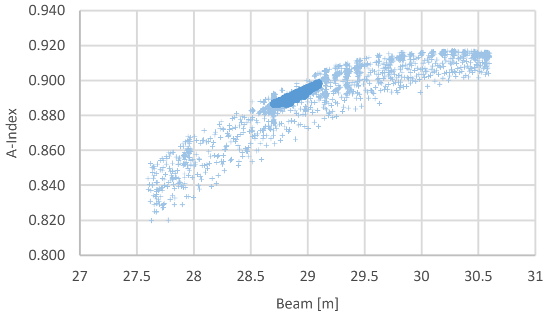

Figure 10: A-Index vs. Beam

A constraint was introduced in this study, according to which all feasible designs should have positive DeltaNPV. Because of this constraint, as shown in Figure 7 all feasible designs have a Length BP above 167.8 m. The A-Index margin (i.e. the difference between the Attained and Required Subdivision Indices) is plotted in Figure 9 as a function of Beam. All feasible designs have a significantly increased Beam (at least 1.1 m larger than that of the baseline). Not surprisingly, this is due to the new damaged stability requirement (which the baseline had not had to comply to). A diagram of the A-Index vs. Beam is presented in Figure 10. In order to provide more insight on the impact of Beam on damaged survivability, both feasible and infeasible designs are included in this figure. The feasible designs are marked by full blue circles and can be clearly seen surrounded by a 'cloud' of infeasible designs.

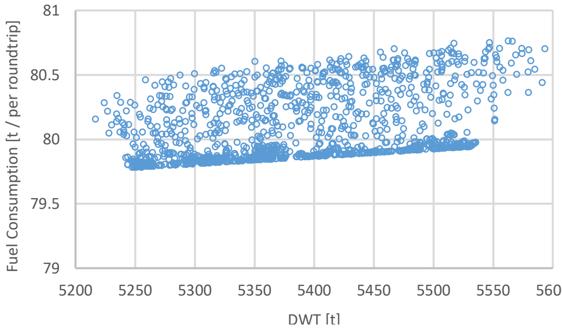

Figure 11: Fuel consumption (propulsion only) per roundtrip vs. DWT

The diagram in Figure 11 presents the relationship between the fuel consumption for the vessel's propulsion per roundtrip and DWT. Scatter diagrams illustrating the relationship between DeltaNPV and fuel consumption per roundtrip, DWT and CAPEX (i.e. the corresponding increase of building cost in comparison with the baseline) are presented in Figures 12, 13 and 14 respectively.

The most promising design, selected for further study was the one with the maximum DeltaNPV. This design has a length BP of 170 m, i.e., the maximum length considered, a beam of 28.7 m, i.e. the minimum beam for which the damaged stability requirement was fulfilled, and a design draught of 6.8 m. Its propulsion power at 21 kts and at 27 kts is equal to 14.7 MW and 40.3 MW respectively and its Net present Value and Building Cost are increased by 2.964 m€ and 8.814 m€ respectively, in comparison with the baseline.

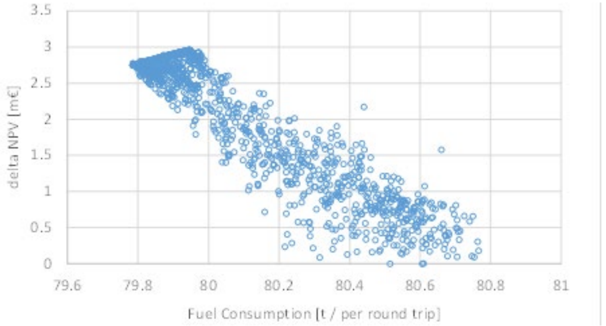

Figure 12: DeltaNPV vs. fuel consumption per roundtrip

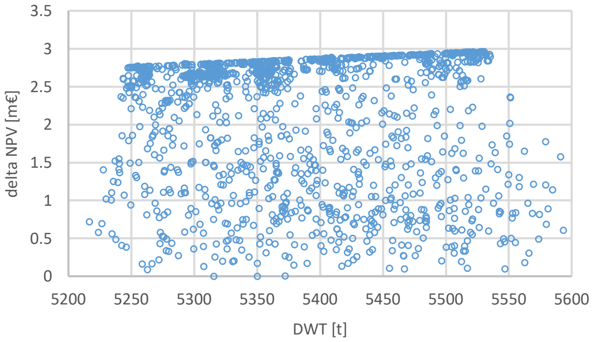

Figure 13: DeltaNPV vs. DWT

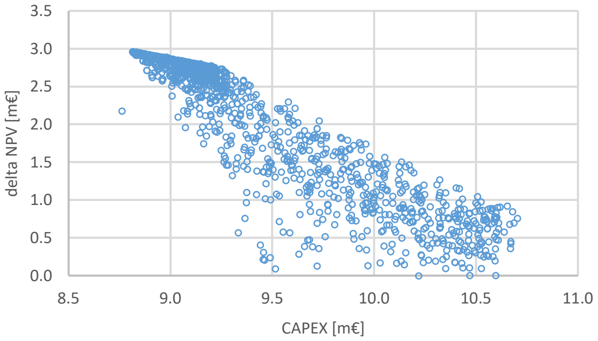

Figure 14: DeltaNPV vs. CAPEX

5 CONCLUSIONS

HOLISHIP develops novel concepts for ship design and operation, which are implemented in versatile, integrated design platforms, offering a vast variety of options for the efficient development of alternative ship designs by use of tools for their analysis and optimisation with respect to all relevant (ship) design disciplines. An open architecture allows for continuous adaptation to current and emerging design and simulation needs, flexibly setting up dedicated synthesis models for different application cases.

The material presented describes a "snapshot" of on-going developments in HOLISHIP 15 months into the project. These cover elements of intact and damage ship stability, hydrodynamic performance in calm water and in a seaway, energy simulations and initial cost assessments. Together they largely determine two fundamental criteria of ship design, namely high safety and excellent efficiency. The material presented highlights the integration concept which will be further refined and extended to other design disciplines during the following project phase. The present status already allows demonstrating the effect of the holistic design and optimisation concept for the application case of a RoPAX ferry.

The chosen application case represents a realistic transportation scenario for a combined passenger and car ferry operating in European coastal waters. Starting from the definition of the transport demand for a specific route (and a baseline design that will be made available by the interested shipowner or be taken from a database) the most suitable main particulars of the ship are determined using advanced design-analysis methods, which already indicate that the traditional borders between concept and (preliminary) contract design will be blurred in the future.

The procedure applied in the present study led to feasible and good designs within very short lead time. The impact of a varying service speed on ship design, which is often an uncertain parameter, was clearly demonstrated and even if the results obtained may not be a surprise for an experienced designer, the speed, quality and extent of information generated by an automated, computer-aided procedure, examining hundreds of realistic variants before concluding on the best designs, is convincing. Extrapolating these first results onto further developments, namely also including other design disciplines like structural design, more striking design improvements may be expected, especially when considering higher complexity and flexibility of operation during the life-cycle of a vessel.

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