Tackling Complexities in Boat Powering Process with System Simulation

A White Paper for Project Managers and Boat Designers

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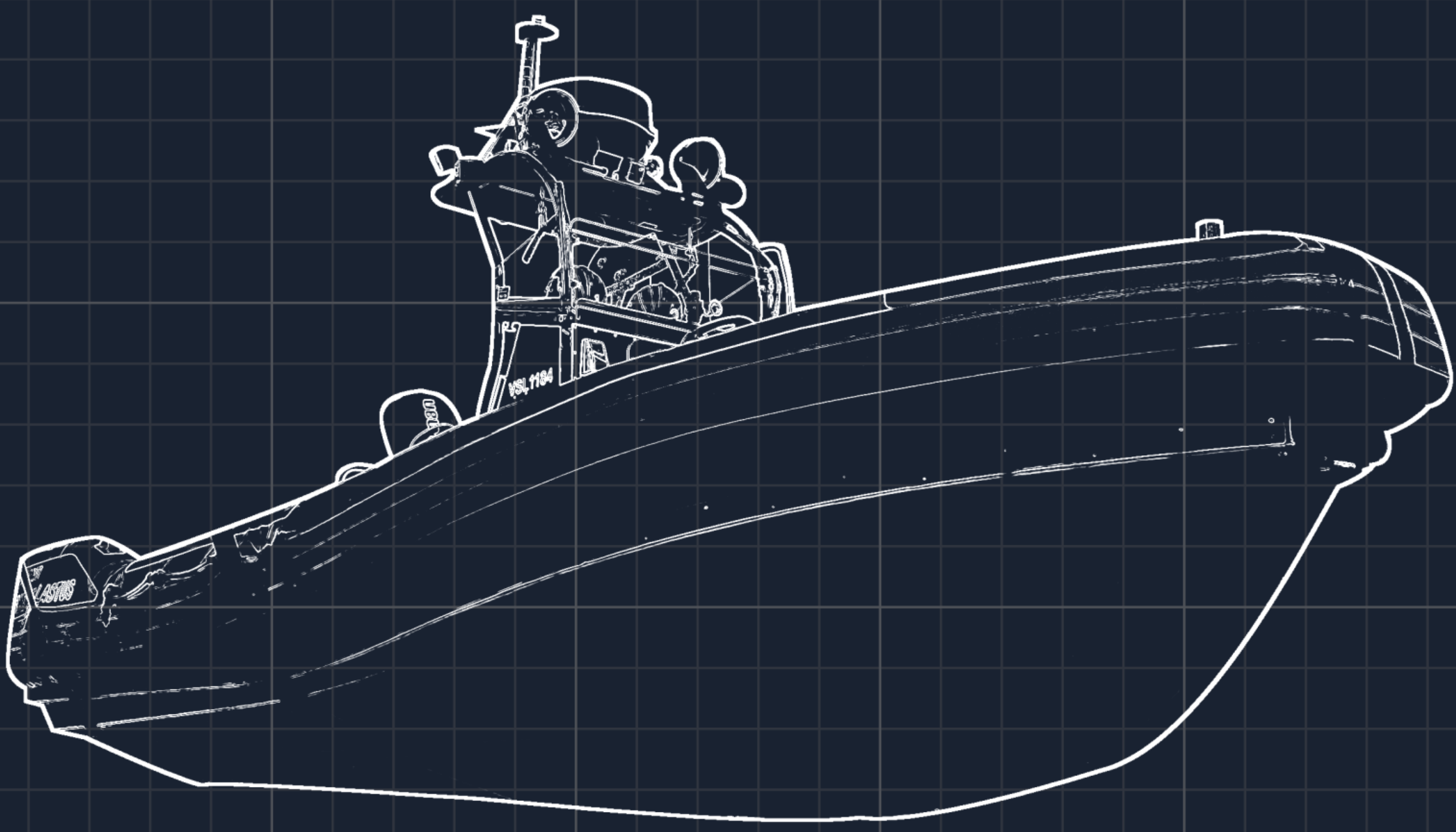

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Executive Summary

Innovative marine propulsion systems can be found everywhere from large sea-going vessels to small leisure craft. New innovations and optimization of propulsion and power distribution systems are vital to meeting the environmental goals and controlling of OPEX and CAPEX costs.

While more boat yards are looking to adapt novel propulsion and energy technologies in their boats, the increasing complexity, stricter regulations, and involvement of more suppliers introduce significant challenges in project management. The integration of individual subsystems and components into system of systems to achieve maximum efficiency and reliability on system level further exacerbates the already difficult process.

This whitepaper focuses on the challenges of small craft powering process including an analysis of available design tools and methodologies. We explore how other industries are battling similar challenges and system simulation method is introduced as a solution to cut design iterations and to improve system optimization. Lastly, we look at the viewpoints of the classification societies and how their adaptation of innovation influences the boat powering process.

By rethinking the powering process, the project managers and designers can adopt innovative technologies, assess larger quantities of alternative designs, and optimize complex systems.

Today's Challenges

Environmental goals and restrictions as well as OPEX and CAPEX costs are the major drivers for innovation in marine propulsion and energy systems. This means that boat powering process is becoming increasingly complex bringing together alternative energy sources, hybrid systems and more suppliers. The traditional powering process of a marine craft is already a multi-dimensional problem with factors summarized in (Molland, et al., 2017) Table 1:

Table 1. Powering process

1.	Compactness and weight
2.	Initial cost
3.	Fuel consumption
4.	Grade of fuel
5.	Level of emissions
6.	Level of noise and vibration
7.	Maintenance requirements
8.	Propulsor efficiency

Recent technology advancement brought about new capabilities such as dynamic positioning, operating modes, and emission limits. These capabilities each have their own requirements adding to the already long list of operating points that require evaluation.

Increased number of suppliers, system complexity and project requirements impose new challenges to the project manager responsible for the powering process. Project managers now need to put more focus in management of changes, as the likelihood of design change elevates from increased project complexity. It is common knowledge that implementing changes in late stages of project lifecycle is both expensive and highly restrictive (Artto, et al., 2011). One should always remember, for complex systems, optimal system solution can only be achieved if engineering discipline boundaries are crossed to allow a global view of the system as shown in Figure 1 (Budinger, et al., 2019).

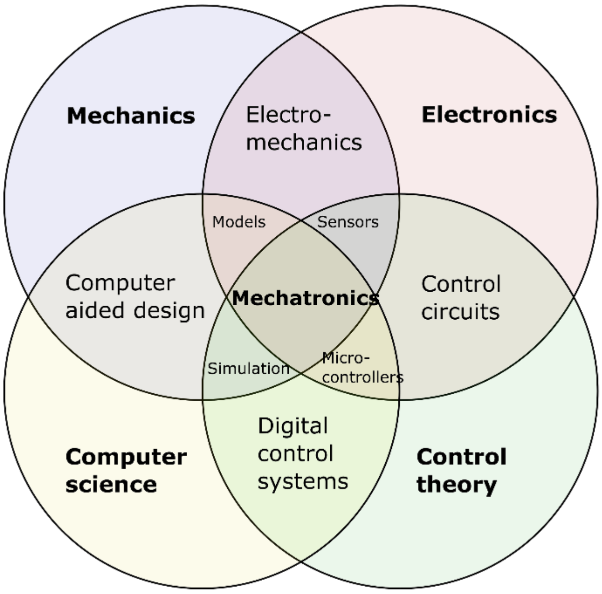

Figure 1. Engineering disciplines (Budinger, et al., 2019)

Limitation of Traditional Design Methods

The design spiral method has played an essential role in boat design by ensuring that the multi-dimensional project -, statutory - and class requirements are met. It is a sequential process consisting of several iteration rounds, each developing more detailed knowledge of the product in development. The early iteration rounds rely heavily on guesstimated values, non-dimensional ratios and performance evaluation based on data from existing similar designs (Larssen, et al., 2014).

Due to its sequential process, the designer is not able to explore the effect of design changes and options early and in a timely manner using design spiral. This makes adaptation of innovative solutions and technologies difficult (Koch & del Castillo, 2017). Also optimizing each discipline individually rarely leads to optimization at the system level. Instead, a successful application is based on an overview of different individual components, different domains, and their interaction as a part of the multi-domain system (Budinger, et al., 2019).

Virtual prototyping tools, such as CFD and CAD have brought great relief in the later stages of the design spiral. However, word processing, spreadsheet and presentation tools are still the only software used widely throughout the design spiral (Koch & del Castillo, 2017). Spreadsheets' role is to work as a repository and to summarize, plot and compare data from other sources such as from the suppliers, design software and databases.

A system engineering approach, which is commonly used in automotive and aerospace industries, has been proposed to replace the design spiral due to challenges caused by increasingly complex projects (Smogeli, 2017).

Class Rules and Innovation

Class rules often guide the boat powering process. However traditional prescriptive class rules allow little room for innovation. During recent years goal-based rules have been appearing within the IMO. Application of goal-based rules is to ensure that the class societies are meeting certain goals while allowing room for innovation. Goal based standard allows the manufacturer to use any solution to meet a set goal, instead of being restricted by a predetermined solution (Jenkins, 2012). For example:

- **Prescriptive rule**: A filter of 120 microns must be installed in an exhaust line. The prescriptive rules account only for known hazards, not consequences or unknown hazards
- **Goal based rule**: Particles emitted by the system cannot exceed 1ppm. To meet the goal-based requirement, the manufacturer could for example meet the particle limit criteria at the engine side, instead of the exhaust.

System Simulation to Support the Powering Process

For a today's project manager involved in the powering process it is more important than ever to have as much information as early as possible. To achieve this, many alternative designs need to be generated and evaluated at the early stages (Koch & del Castillo, 2017). The value of early knowledge in terms of freedom and costs is shown in Figure 2.

While spreadsheets have their use, they are certainly incapable of assessing large sets of complex engineering systems quickly. They also lack support for many of the basic needs of design innovation and optimization such as solving multi-dimensional problems, assessment of system dynamics and control system design. In real-world, systems behave dynamically requiring the use of dynamic modeling tools, instead of static spreadsheet calculations.

Spreadsheets can also result in expensive errors in the powering process. A study by Raymond Panko reveals that 94% of spreadsheets contain errors, but when the developers were asked about their confidence in the correctness of their spreadsheet, the median score was "very confident" (Panko, 2005).

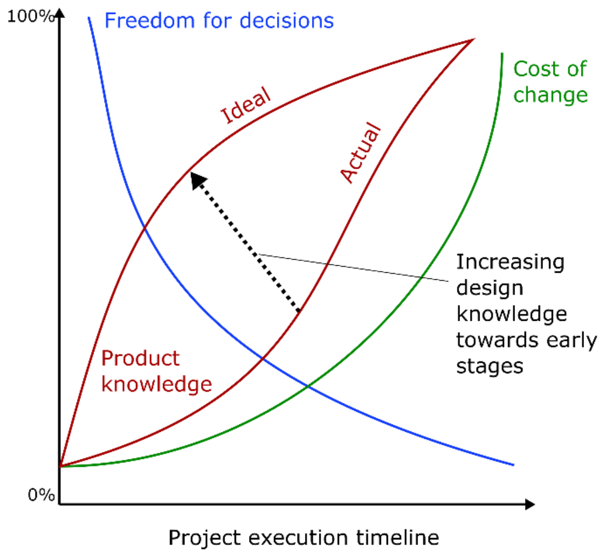

Figure 2. Value of early knowledge (Koch & del Castillo, 2017)

System simulation is introduced to solve these problems. System simulation tools allow for construction of a virtual prototype of the system containing information of its dynamic behavior. The system information can consist of blocks of mathematical formulas or look-up tables representing the system or its subsystems. Today's high computing power allows the simulations to run within a matter of seconds or minutes. As the system is described using equations, simulations can be done before 3D models are available. This makes it well suited for early evaluation of large quantities of alternative designs, maximizing the amount of information available at early design stages.

Other industries, such as automotive and aerospace, use system simulation widely in powering process. For example, automotive engineers use mathematical models and simulations to develop complex systems such as hybrid powertrains. Simulations are needed to manage complexity and enormous number of variants while keeping the development time low (Winke, 2017).

Due to the increasing complexity in boat design, classification societies such as DNV and ABS have highlighted the importance of system simulation as an essential part of the design process. DNV predicts that virtual ships, comprising of simulation models and data, will become the standard method of ship design within a few years (Smogeli, 2017). ABS suggests that traditional tools used in electric power distribution design, such as short circuit analysis and load analysis, are becoming impractical and that system simulation is needed to understand issues such as power quality, stability, and energy storage. (American Bureau of Shipping, 2022).

Migrating to System Simulation

Many vendors offer system simulation tools which are divided into causal and acausal tools. Causal tools include for example Xcos and Simulink which rely on predetermined causalities between mathematical models. Acausal tools such as Simulation-X and Dymola manage equations symbolically which ensures the highest reusability of models and hence saves time and error (Budinger, et al., 2019). Table 2 compares different modeling approaches and their strength and weaknesses.

Table 2. Modeling approaches

	Spreadsheet models	Causal models	Acausal models
General focus	Number crunching	Control system design	Engineering design of complex systems
Strengths	Easy to use	Modeling of control systems	Modeling of physical systems, model reusability, fast computing time,
Weaknesses	Restricted to steady state analysis, poor model reusability	Limited information on system dynamics, poor model reusability	Requires deep understanding of engineering systems and programming

The modern acausal modeling languages such as Modelica allow assignment of SI units to variables which enhances error checking. Modelica is also capable of sorting equations for computation which allows the inversion of models (Budinger, et al., 2019). This means, one acausal model of Ohm's law allows solving for either current or voltage without modification. This in contrast to using causal modeling, where separate models would be required to solve for current and voltage. The high reusability of acausal models and improved error diagnostics translates into considerable time saving and reduction of errors, which makes it an effective method for modeling physical systems.

System Simulation in Marine Engineering

While many of the software solutions include extensive libraries of mathematical models of engineering components, they also allow the creation of custom models. This is necessary in the field of marine engineering where empirical and semi-empirical formulas are common. Custom model creation often requires in-depth knowledge of a modeling language such as Modelica or Fortran. In case the design engineer is not familiar with these languages, migrating from e.g., spreadsheet tools can prove to be a challenge due to a steep learning curve. Figure 3 shows a dynamic model of a boat to calculate its acceleration. It includes models of hull resistance, propellers, and trim tabs. For more examples, see: https://performansea.com/portfolio/

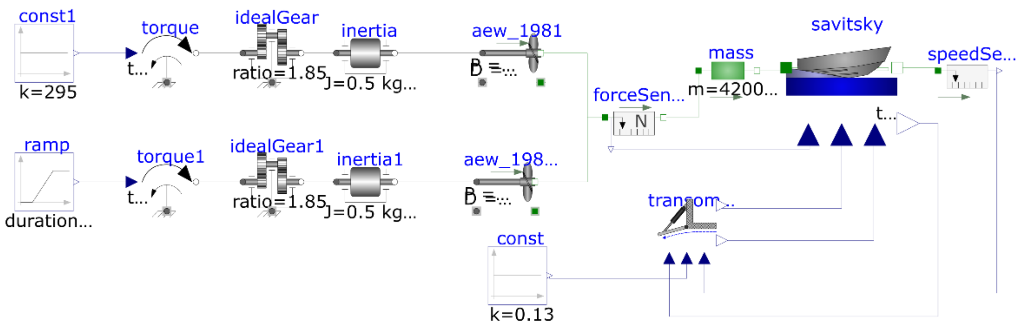

Figure 3. System simulation model of a boat and its driveline

Conclusions

Increasingly complex systems and changing regulations call for modern design methods and tools to be used in the boat powering process. The project team will require access to more product knowledge in the early design stages to avoid expensive errors and changes in the later design stages. Such errors translate into delays and exceeding budget.

System simulation helps project managers and designers to evaluate large quantity of design alternatives in the early design stages, even before 3D models are available, hence increasing early-stage product knowledge. System simulation model also serves as a digital prototype of the system helping to understand the dynamic behavior of the system and to evaluate compliance with classification rules. It is also the suggested solution by classification societies to manage design of complex systems.

To find out more about how system simulation can help your design team adapt to innovative technologies in marine propulsion, visit www.performansea.com or contact me directly at ben.landgren@performansea.com.

Author Biography

Ben Landgren is an independent marine engineering consultant specializing in system simulation using Modelica, Scilab, Matlab and Python languages. Ben has been working in the field of marine propulsion for over 10 years and he has a master's degree (MSc) in Marine Engineering from Newcastle University.

PerformanSea is a company by Ben that helps small and medium-size boat builders and propulsion system designers adapt to new technological innovations by using system simulation. By incorporating system simulation as part of the design process, project managers can cut project costs by reducing design time and error. Designers can create better systems as the system simulation facilitates the comparison of design alternatives at the early design stages.

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