Development of Design Configurator Tool for Rapid Initial Design of Fast Zero-Emission Battery-Electric Vessels

Myo Zin Aung(✉), Evangelos Boulougouris, and Amin Nazemian

Maritime Safety Research Centre (MSRC), Department of Naval Architecture, Ocean and Marine Engineering, University of Strathclyde, Glasgow, UK
{myo.aung,evangelos.boulougouris,amin.nazemian}@strath.ac.uk

Abstract. Small vessels, such as river buses, ferries, and workboats, have significant decarbonization potential by implementing battery-electric propulsion systems. Designing battery-electric vessels presents unique challenges due to the lower energy density of the battery. The battery constitutes a significant portion of the vessel's weight and space, and it size heavily influenced by operating profiles and availability of charging stations and charging speed. This creates feasibility concerns for pure battery-electric vessels in terms of weight, space, and charging requirements. To address this, a design configurator tool has been developed, which can swiftly generate initial designs of battery-electric vessels and evaluate feasibility based on the specific design and operational requirements. The tool takes design requirements as inputs and outputs include potential design candidates together with various ship design calculations including feasibility and optimality assessments. The design of the tool is based on a hull design database containing various combinations of main dimensions, with the corresponding hydrostatic and hydrodynamic data. The capability of the tool was demonstrated in designing two replicator vessels in the EU Horizon TrAM project. This design automation tool aims to expedite the transition to zero-emission battery-electric vessels by aiding decision-making processes for ship operators and designers, considering their unique operational requirements.

Keywords: battery-electric vessels · design configurator tool · ship design automation · parametric hull model · decarbonization · TrAM project

1 Introduction

Climate change has prompted urgent calls for reducing greenhouse gas emissions across all sectors. Ambitious decarbonization targets have been set both by the International Maritime Organization (IMO) and various governments for the maritime industry [1]. Different decarbonization options are being explored for the different ship types, sizes and operation profiles. Among various vessel types, smaller vessels such as river buses, ferries, and workboats stand out as excellent candidates for decarbonization through battery-electric propulsion systems. These waterborne electric vehicles not only produce

C. McNally et al. (Eds.): TRAconference 2024, LNMOB, pp. 432–437, 2025.
https://doi.org/10.1007/978-3-031-89444-2_63

zero emissions but also offer quieter rides with reduced vibrations. Furthermore, the efficiency of an electric propulsion can be as much as 90% [2]. Although the capital investment costs (CAPEX) are relatively higher, the operational costs (OPEX) can be lower due to the lower energy costs and reduced maintenance. Several pioneering battery-electric vessel projects have emerged worldwide. Notable examples include the MS Medstraum (2022) [3], Bastø Electric (2021) [4], Yara Birkeland (2021) [5], MV Ampere (2015) [6], MS Legacy of the Fjords (2020) [7] in Norway; the Ellen E-ferry (2021) [8] in Denmark.

In comparison to conventional hydrocarbon-fuelled vessels, designing battery-electric vessels presents unique challenges due to the significantly low energy density of the batteries. Since conventional fossil fuels have high gravimetric and volumetric energy, the fuel weight and tank space are not very critical as there is usually enough hull displacement and space for the fuel for most operational requirements. However, in the case of pure battery-electric vessels, the battery units constitute a significant portion of the vessel's weight and valuable space. The total weight and size of the onboard batteries are also heavily influenced by the operating profiles, availability of the charging stations on the route as well as charging duration and speed. This creates feasibility concerns for pure battery-electric vessels especially high-speed vessels, in terms of weight, space, and charging requirements. Minimizing the number of battery units became one of the primary objectives in the design optimization of battery-electric vessels.

Since the vessel dimensions, propulsion system and battery specifications are dependent on the operating profile and onshore charging infrastructure, all those variables need to be simultaneously taken into account during the initial ship design stage. In some cases, building additional charging stations and/or modifications to the operating profile might be required to obtain a feasible solution. To navigate these challenges, this paper introduces a design automation tool, which can swiftly generate design candidates for a battery-electric vessel and evaluate feasibility based on the specific design and operational requirements. By using this tool, ship operators and designers can quickly determine the feasibility of a battery-electric vessel for their specific use case and make decisions for new vessels and required charging infrastructure.

2 Design Configurator Tool

The tool's architecture is based on a design database of hull forms and associated hydrostatic and hydrodynamic (resistance) data for various combinations of main dimensions (Fig. 1). The use of a design database allows to quickly assess the various designs without requiring to generate new geometry and compute hydrostatics and resistance data whenever there are changes in the requirements.

The main inputs to the tool include:

- Vessel's main dimensions either specified by fixed values or ranges
- Operating profile that includes a table of distances or ranges and corresponding speeds
- Operating environment such as fresh or seawater, deep or shallow water
- Propulsion system type: propeller or water and optional efficiency value
- Specification of single battery string unit such as capacity, weight, dimension, as well as depth of discharge (DoD), End of Life (EoL) margin, etc.

- Auxiliary loads

The outputs include the list of design candidates with the following data:

- Hydrostatic data such as displacement, hull coefficients (Cb, Cp, Cm, Cwp), LCB, KB, etc.
- Resistance curves
- Propulsion motor and battery package specifications
- Weight estimation breakdowns
- Feasibility and optimality assessments
- 3D model of vessel

Fig. 1. Design configurator tool architecture

The following outlines how the tool works. When the user changes or specifies the ranges of main particulars, the tool will search for the design candidates from the database within the given ranges. Resistance data, operating profile, and propulsion efficiency are used to calculate the maximum brake power of the propulsion motor and the total energy required for propulsion between the charging stations. Additional loads, such as manoeuvring (docking, undocking), acceleration, and hotel loads, are added to determine the total net energy capacity of the battery. The gross battery is calculated based on requirements on Depth of Discharge (DoD) % and a margin for End of Life (EoL) capacity. Finally, the maximum weight is estimated by combining the weights of the hull, superstructure, propulsion system, battery, and others. If the displacement of the vessel is larger than the maximum weight, the design is deemed feasible in terms of weight. While the displacement value is relatively accurate since it is calculated from the actual hull geometry, weight estimation may have some uncertainty depending on the assumptions and methods used. Depending on the type of superstructure, equipment, and payload, the maximum weight of the vessel can vary significantly. Users can also adjust the total weight of the vessel to add corrections to the results of the built-in weight estimation method.

Initially developed as a MATLAB standalone application, the tool was later transformed into a web application to enhance user experience and accessibility across platforms. The MATLAB App interface of the tool is shown in Fig. 2, and the Web version of the tool is available at https://tram.myozinaung.com/.

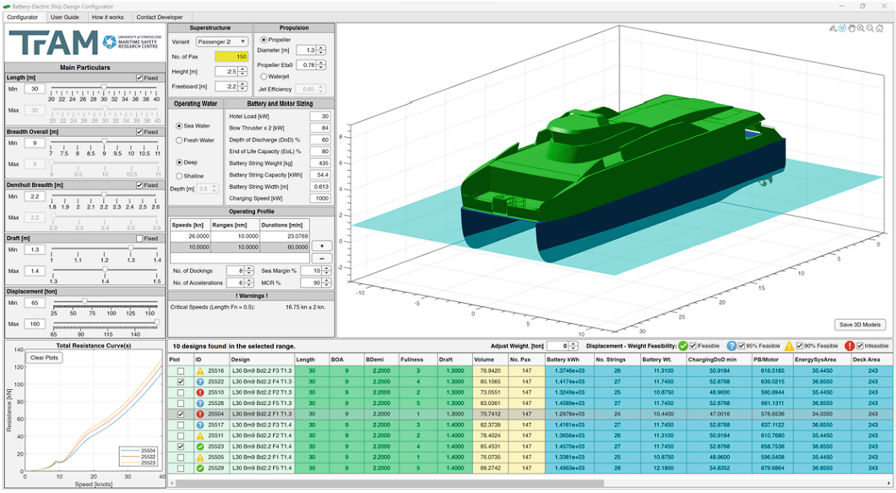

Fig. 2. Battery-Electric Ship Design Configurator Tool (MATLAB App)

3 High-Speed Catamaran Ferry Design Database

This section shows how the design database is generated using the particulars of the demonstrator high-speed catamaran ferry from the EU Horizon TrAM project [9] as a basic design. To generate hull forms of various dimensions and shapes a fully parametric hull model is first developed in CAESES software [10] as shown in Fig. 3. The parametric model is designed to ensure that the hydrodynamic performance of the generated hull is decent for the whole range of design variables.

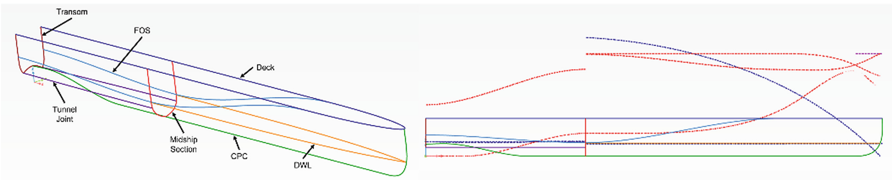

Fig. 3. Parametric Feature Curves and Function Curves (Sectional Area Curve (SAC), Tangent Curves, Section Fullness Curves, Waterline Entrance Angle Curve, etc.)

The four main dimensions used as design variables are length, breadth overall, demihull breadth, and draft. An additional parameter called *fullness* is added to create different shapes for the hull with the same dimension. The fullness value of 1 represents the V-shape midship sections while the fullness value of 5 represents the U-shape midship sections. For this particular database, a total of 51030 hull designs are generated, with displacement ranging from approximately 30 m^3 to 150 m^3. The design parameters and their ranges are provided in Table 1.

Each generated design geometry undergoes hydrostatic and hydrodynamic data calculations by connecting the CAESES to the Maxsurf Modeler and Maxsurf Resistance

Table 1. Design variables and ranges for design database generation

Design Parameters	Minimum	Step	Maximum
Length	20 m	1 m	40 m
Breadth Overall	7 m	0.5 m	11 m
Demihull Breadth	1.8 m	0.1 m	2.6 m
Hull Fullness (V or U Shape)	1 (V-shape)	1	5 (U-shape)
Draft	1 m	0.1 m	1.5 m
Displacement	~29 m^3		~151 m^3

[11]. Since the demihulls are slender, Slender Body method [12, 13] with the Molland form factor is used for resistance estimation. It was found that Slender Body method gives relatively accurate results, even though dynamic trim and sinkage are not considered. However, additional corrections are made using high-fidelity CFD and experimental resistance data of the basic hull model. The corrections for shallow water are also done using shallow water CFD resistance simulation results.

For the weight estimations of hull and superstructure, a detailed parametric structural model is first constructed in CAESES as shown in Fig. 4. However, generating variants of the detailed structural model for the whole database is computationally expensive and time-consuming. Therefore, polynomial surrogate models are constructed using only a limited number of structural design variants. Other parts of the weight estimation are derived from the basic design which has the detailed weight estimation data.

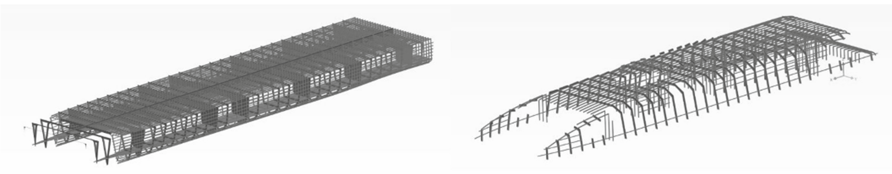

Fig. 4. Parametric Structural Models for Hull and Superstructure Weight Estimation (Source: Authors)

4 Discussion

The developed configurator tool with the catamaran hull database has been tested and verified through feedback from the partners from TrAM project [9], including ship operators, shipyards, and research institutes. The capability of the tool is demonstrated in the designs of two replicator vessels from the TrAM project, one coastal deep water passenger ferry in Belgium and one river bus in shallow London's Thames River [9]. Although the current database is constrained to small catamarans with dimensions given in Table 1, it can be easily extended to other vessel types and sizes by developing additional design databases and suitable weight estimation models. This design automation tool is expected to expedite the transition to zero-emission battery-electric vessels by aiding decision-making processes for ship operators and designers, considering their unique operational requirements. The web version of the tool is available at tram.myozinaung.com [14].

References

1. IMO (International Maritime Organization): Revised GHG reduction strategy for global shipping adopted. https://www.imo.org/En/MediaCentre/PressBriefings/Pages/Revised-GHG-Reduction-Strategy-for-Global-Shipping-Adopted-.Aspx. Accessed 10 Oct 2023
2. Wartsila. Full electric vessels. https://www.wartsila.com/marine/products/ship-electrification-solutions/full-electric-vessels. Accessed 10 Oct 2023
3. TrAM Project. https://tramproject.eu/2022/07/14/the-worlds-first-zero-emission-fast-ferry-is-ready-for-operation. Accessed 10 Oct 2023
4. InsideEVs. World's Largest Electric Ferry Now Operational in Norway. https://insideevs.com/news/491590/largest-electric-ferry-norway-oslo. Accessed 10 Oct 2023
5. Yaya. Yara Birkeland. https://www.yara.com/news-and-media/media-library/press-kits/yara-birkeland-press-kit. Accessed 10 Oct 2023
6. Pratt, J.: Battery Electric and Hybrid Vessels in Norway and Denmark: Ampere, Vision, and HH Ferries (2016)
7. The Fjords AS. Our boats. https://www.thefjords.no/our-boats. Accessed 10 Oct 2023
8. E-ferry Consortium. E-ferry final presentation. http://e-ferryproject.eu. Accessed 10 Oct 2023
9. TrAM Project Home Page. https://tramproject.eu. Accessed 10 Oct 2023
10. Friendship System. CAESES. https://www.caeses.com/products/caeses. Accessed 10 Oct 2023
11. Bentley. Maxsurf Naval Architecture Software. https://maxsurf.net. Accessed 10 Oct 2023
12. Tuck, E.O, Luzauskas, L., Scullen, D.C.: Sea wave pattern evaluation. Part 1 report: primary code and test results (Surface Vessels). Applied Mathematics Department, The University of Adelaide, 30 April 1999
13. Couser, P., Wellicome J.F., Molland, A.F.: An improved method for the theoretical prediction of the wave resistance of transom-stern hulls using a slender body approach. Int. Shipbuilding Progress **45**(444) (1998)
14. Aung, M.Z.: An initial design tool for high-speed pure battery-electric catamarans. https://tram.myozinaung.com. Accessed 10 Oct 2023