

# Rethinking transport

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## TrAM – Transport: Advanced and Modular

Evangelos Boulougouris<sup>a\*</sup>, Alexandros Priftis<sup>a</sup>, Mikal Dahle<sup>b</sup>, Edmund Tolo<sup>c</sup>, Apostolos Papanikolaou<sup>d</sup>, Yan Xing-Kaeding<sup>d</sup>, Christoph Jürgenhake<sup>e</sup>, Thomas Svendsen<sup>f</sup>, Morten Bjelland<sup>g</sup>, Aphrodite Kanellopoulou<sup>h</sup>, Geoff Symonds<sup>i</sup>, Torleif Stokke<sup>j</sup>, Patrick Bollaert<sup>k</sup>, Marie Launes<sup>l</sup>

<sup>a</sup>University of Strathclyde, Richmond Street 16, Glasgow G1 1XQ, United Kingdom

<sup>b</sup>Kolumbus, Jernbaneveien 9, NO-4005 Stavanger, Norway

<sup>c</sup>Fjellstrand yard, Omavegen 225, NO-5632 Omastrand, Norway

<sup>d</sup>Hamburg Ship Model Basin, Bramfelder Str. 164, Hamburg D-22305, Germany

<sup>e</sup>Fraunhofer IEM, Hansastradde 27C, Munchen 80686, Germany

<sup>f</sup>Hydro, Metallvägen, Vellanda 574 81, Sweden

<sup>g</sup>Leirvik, Storhaugvegen 130, NO-5416 Stord, Norway

<sup>h</sup>National Technical University of Athens, Heroon Polytechniou 9, Athens 15773, Greece

<sup>i</sup>MBNA Thames Clippers, The Studio, The O2, London SE10 0DX, United Kingdom

<sup>j</sup>Servogear, Brubakken 73, NO-5420 Rubbestadneset, Norway

<sup>k</sup>De Vlaamse Waterweg nv, Oosdijk 110, Willeborek 2830, Belgium

<sup>l</sup>NCE Maritime CleanTech, Meatjonnsvegen 74, NO-5412 Stord, Norway

### Abstract

Europe has taken a leading role in the international effort for a drastic reduction of greenhouse gas (GHG) emissions. Transport systems play a crucial role in this effort and the competition among the various transportation modes for the shrinkage of their environmental footprint, is mounting. Maintaining its focus on sustainability, Europe is seeking to produce transport solutions with a cost effective and environmentally friendly life cycle, integrated in its smart cities. This is what the H2020 funded project “TrAM – Transport: Advanced and Modular” aims to offer (<https://tramproject.eu/>). It is validating a concept for waterborne transport by implementing state-of-the-art “Industry 4.0” holistic ship design and production methods, for fully electrical vessels, operating at reasonably high speed in the vicinity of urban areas. The project will lead to significant lower construction costs and reduction in engineering hours for new zero emission fast vessels. Three different catamarans will be designed by implementing the developed methods, while one of them will be undergoing detailed design and physical model testing, prior to its construction and start of operation in Stavanger/Norway before the end of the TrAM project in 2022. The paper outlines the objectives, first R&D outcomes and the main challenges of the project.

**Keywords:** Industry 4.0; modular production; holistic ship design; zero emission transport; battery electric systems; electrically powered vessels

#### 1.1.1. Nomenclature

TrAM                    Transport: Advanced and Modular  
CAD                    Computer-aided design

\* Evangelos Boulougouris. Tel.: +44 (0)141 548 3875;  
E-mail address: [evangelos.boulougouris@strath.ac.uk](mailto:evangelos.boulougouris@strath.ac.uk)

CFD	Computational fluid dynamics
FEA	Finite element analysis
GHG	Greenhouse gas
MBSE	Model-based system engineering
SFI code	Classification system for the maritime and offshore industry introduced by the Ship Research Institute of Norway (SFI: Skipsteknisk Forskningsinstitutt)

## 2. Introduction

### 2.1. The challenge

The transport sector is considered as one of the main polluters globally. The challenge to create solutions for environmentally friendly transport is reflected in public policy on a national, European and global level. There is a joint effort to mitigate climate change and introduce sustainable solutions and this indicated in the strategic plans on clean energy technologies implemented on means of transport, including infrastructure. The European Commission's 2050 Low Carbon Economy policy states that GHG emissions should be reduced to 80% below 1990 levels, done through making low carbon transition feasible and affordable (European Commission 2019a). In the EU Maritime Transport policy, maritime transport is recognized as “a catalyst for economic development and prosperity”, while stating we should “minimise the environmental impact” of maritime transport (European Commission 2019b). On Sustainable Transport the Commission writes that there should be “technical innovations and a shift towards the least polluting and most energy efficient modes of transport – especially in the case of long distance and urban travel” (European Commission 2019c). At the same time the Commission's economic policies states that it is important to create jobs, where lower cost through working smart will be key for the European shipyards to remain competitive while paying high wages (European Commission 2019d). This is further in line with UN sustainable development goals on Affordable and Clean Energy (7), Industry, Innovation and Infrastructure (9), Sustainable Cities and Communities (11), Responsible Consumption and Production (12) and Climate Action (13).

With regards to the maritime transport, European ship operators and city councils have already started taking measures against the climate change. In Norway, Rogaland County Council and its ferry operator subsidiary Kolumbus have planned their transition to zero emission waterborne transport. In the United Kingdom, Thames Clippers, one of the river Thames ferry operators is facing increasing pressure to move to more environmentally friendly propulsion alternatives. This needs to be accomplished with zero emission vessels without reducing their high operational speed for keeping competitive market services. In Belgium, De Vlaamse Waterveg, a major regulator of the country's inland waterways, sees modular zero emission transport as the solution to regain competitiveness on economic and environmental levels. Thus, there is a need for lower priced, environmentally friendly ships that may operate up to high speeds, depending on the transport scenario.

### 2.2. The solution

The Horizon 2020 European Research project “TrAM – Transport: Advanced and Modular” is a joint effort of 13 European maritime stakeholders that aims to develop and validate a concept for waterborne transport by implementing state-of-the-art “Industry 4.0” modular design and production methods, with a main focus on electrically powered vessels operating in protected waters (coastal areas and inland waterways). The structure of the project starts with a set of requirements from operators, use cases, industry processes and standards. It includes three work packages on methods development that are applied to and refined through the physically build demonstrator of what can become the world's first large zero emission fast ferry. The demonstrator will be an electrically powered passenger ferry that will service a multi-stop commuter route into the city of Stavanger in Rogaland County. The vessel will be innovative due to its modular design, all electric power system, reusability and the employed state-of-the-art design/CAD and optimisation methods. Use of the modular production concepts are also used on several replicators in the last phase of the project (Fig. 1).

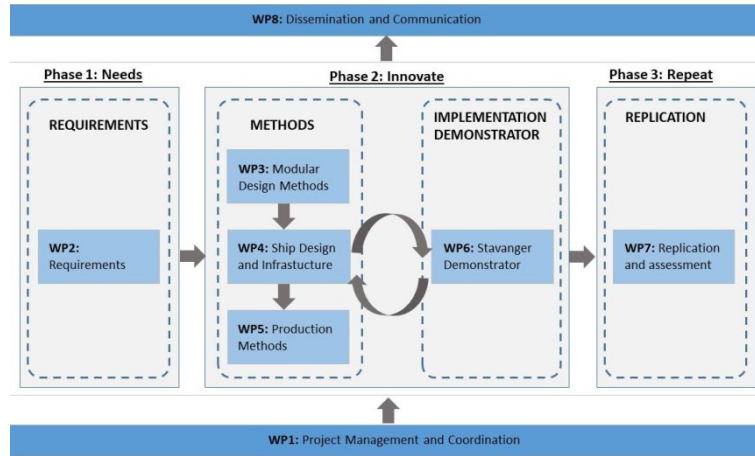


Fig. 1 TrAM project structure

The design for the demonstrator is being finalized in Q1 2020 and vessel build is due to start in Q3 2020.

### 3. The TrAM project approach

#### 3.1. Objectives

TrAM focuses mainly on the modular design approach and the introduction of zero emission, yet reasonably fast vessels. As far as the former objective is concerned, the development of cost-effective design and production methods is one of the main goals of the project. TrAM aims to decrease the design and production costs for electric vessels by applying a standardised modular approach and a deeper multi-modal integration of modules and a state-of-the-art parametric CAD software tool. Modular design approach offers the ability to design the various system components in such a way that they are reusable across vessel types. Such practice can lead to reductions in design and engineering hours, whilst versatility of the vessels is assured by verifying that a list of components and methods can be replaced after construction.

Through this project, research is carried out regarding the hydrodynamic optimisation of the hull form and use of lightweight materials by applying “first principles” design methods. Therefore, energy consumption can be reduced. The latter is also achieved through the introduction of new propulsion and hull solutions related to the concept of electrically driven vessels. The complex issue involving the high-power demand of a high-speed ferry in conjunction with the implementation of a zero-emission vessel is tackled in TrAM. The optimisation of the hull shape for minimum power requirements and reduced wave wash, the careful weight control of structure and the innovative technologies regarding batteries and recharging methods/plan contribute to the achievement of the aforementioned goals.

Finally, the integration of electrically powered vessels with land side interfaces forms another goal of the project. The introduction of smart city infrastructure will ensure co-modality with other transport modes, such as bikes or other means of public transport, promoting eco-friendly solutions and seamless integration with transportation services. The challenge of fast battery charging at the ferry terminal is also addressed in TrAM.

#### 3.2. Concept and methodology

The project’s methodology is divided into three main phases; (a) the identification phase during which the requirements and needs for the demonstration cases are set, (b) the innovation phase which includes the development of modular design and production methods and their application to the Norwegian/Stavanger demonstration case and (c) the replication phase, assuring that the results of the second phase are applicable to broader cases.

TrAM is based on four major principles;

- modularity

- zero emission
- high speed operations
- reuse and reconfiguration.

### 3.2.1. Modularity

At the core of the new production and design concepts to be developed in this project, are new modular design methods derived from systems engineering. The modularity approach combines standardisation and flexibility. Standardisation allows us to produce using the same components and interfaces, which may be used in various applications. This lowers the cost of tasks, including responding to a tender, designing and engineering a ship, dealing with sub-contractors, and constructing the vessel. At the same time, flexibility is needed. Hull, propulsion and energy systems are arrangements that must be designed and configured differently depending on the operational profile of the vessel (Fig. 2).

In recent years, there has been theoretical work on advanced modularity in the maritime industry, but the commonly used method is a hierarchical system with one-dimensional dependencies among modules, typically based on functional modes (e.g. the “SFI code” used in the Norwegian maritime industry). Moving to more advanced methods, allowing better understanding of how modules fit together, the project will build on experience from other transport industries. In the automotive industry, modular construction is mature, with very advanced and efficient modular methods in use by world renowned car manufacturers. In our project, this experience is brought by Fraunhofer IEM, with a long history working with Volkswagen and other car manufacturers. Fraunhofer IEM will work with the industry partners and maritime R&D institutions to couple the SFI matrix (and similar one-dimensional approaches), describing ship components, with more advanced engineering concepts such as MBSE. This will give a much deeper multi-modal model of how components fit together, and simultaneously prepare the maritime industry for future possibilities like “Industry 4.0” concepts. The project further builds on modular production methods from the railway industry, where project partner Hydro is a major component provider. Combining experiences and theories across domains enables the project to leapfrog development stages and implement a modular design system for the maritime industry (Gausemeier et al. 2013, Kaiser et al. 2013).

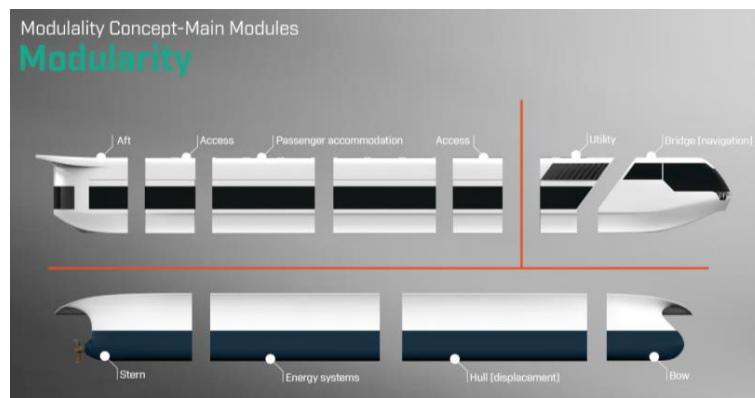


Fig. 2 High level modules

The modular approach applied to the production methods is closely related to the ship design methodologies applied within the project. University of Strathclyde, HSVA and National Technical University of Athens bring their expertise on holistic ship design optimisation in TrAM to combine the newest methods from parametric ship design with the modular production approach (Papanikolaou 2010, Papanikolaou et al. 1995, Zaraphonitis et al. 2003). The introduction of parameterisation has allowed researchers to perform optimisation studies on ship design. Optimisation enables designers to identify preferable solutions in the design space, based on specific needs and requirements. When many objectives are incorporated in an optimisation study, there is always a dilemma in choosing between high fidelity tools such as CFD or FEA, which increase the required resources in computational time and power, and empirical methods which provide less accurate results but in short time. Uncertainties and changes in future operational requirements also need to be considered as part of the ship design process and life cycle design optimisation. Risk-based design is applied, introducing a probabilistic approach to tackle this issue.

Stochastic optimisation can be utilised to address the uncertainty in ship design, by creating alternative future scenarios and assigning probability distributions respectively.

### 3.2.2. Zero emission high speed operations

The development of zero emission, all electric vessels for inland waterways is now an established technology, to which the project partners have been strong contributors. For instance, Fjellstrand yard built the world's first all-electric car ferry "MF Ampere". TrAM goes one step further in introducing the high-speed electric vessels, which is a radical step ahead, disrupting the impression that an electric ship must be inherently slow due to limitations in battery technology and recharging facilities.

It is important to demonstrate the possibility and the ability to offer a low cost, zero emission alternative for fast ferries through application of new production methods. Electric vessels are a good fit for a modularity strategy, since the ability of electric systems to be updated is of great importance due to the rapid technological progress. Also, a high-speed inland ferry needs to run with low wave wash due to its potential impact on the onshore environment, including the safety of people.

### 3.2.3. Reuse and reconfiguration

The project allows operators of electric powered vessels to extend their business horizon with longer term depreciation of investments, achieved through securing the possibility to adjust and adapt the vessel's configuration, including its energy system, to changing needs over time. Further, by implementing eco-design principles, we maximise reuse opportunities after the vessel's projected life cycle.

## 4. Stavanger demonstrator

To verify and validate the applicability of the project the partners will apply the proposed methodology and develop a 1:1 proof of concept in terms of a demonstrator for Norway's case. By doing so, the developed results can be evaluated and further developed. In this way, possible corrective measures can be identified within the framework of demonstrator development. A suitable route for the demonstrated operated by the mobility provider Kolumbus (Rogaland County Council) has been identified. The demonstrator will be a cost-efficient transport alternative compared to diesel operation for a up to 12 stops, 20-minute route between Stavanger and Hommersåk, operating at a service speed of 23 knots and able to transport 147 passengers and 20 bikes. The vessel will be fully operated by batteries and leave zero emission to air and sea.

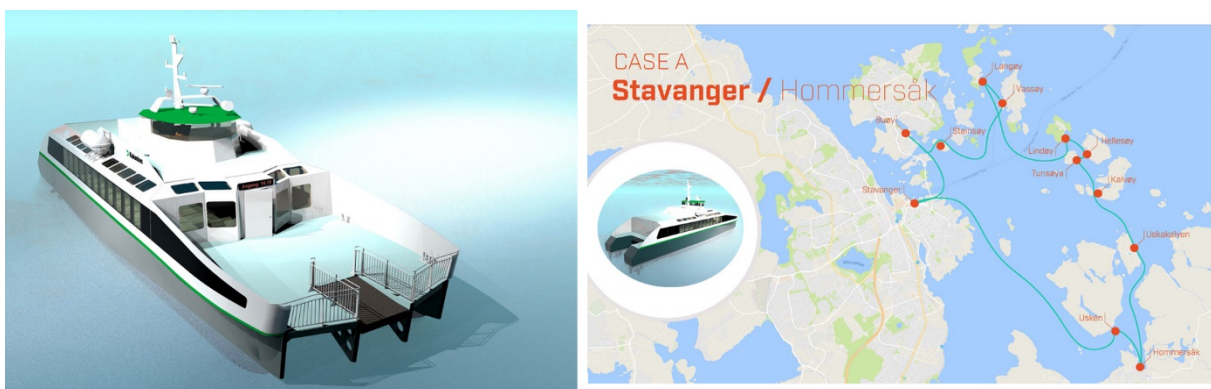


Fig. 3 Stavanger demonstrator

### 4.1 Hydrodynamic Hull Form Optimisation

A two stage optimisation procedure has been applied for the hydrodynamic optimisation of the catamaran's hull form with respect to calm water resistance and propulsion. It consists of a global optimisation leading to optimal

ship main dimensions/characteristics (length, draft, demihull beam, separation distance, integral hull form characteristics) and a local hull form optimisation of mainly the ship's stern area. The latter includes the optimisation of the ship's transom stern and propeller, as well as rudder and propeller shaft arrangements. Some details of the applied procedure are outlined in the following.

#### 4.1.1 Parametric Model of Hull Form

Both the global and local hull form optimisation are based on the development of a parametric model for the catamaran's hull form, allowing the systematic variation of the hull form within certain limits of the ensuing design parameters. This parametric model of the catamaran vessel was developed by use of the CAESES® software (Harries and Abt, 2019). CAESES® allows the use of built-in methods of parametric surface modelling and is also used as the general process integration and design optimization environment (PIDO), utilizing the coupling mechanisms to set up process chains for automated optimization studies. A set of four (4) design variables for the ship's main dimensions (length at the waterline, demihull's beam, initial design draft and transom width), as well as of six (6) local hull form parameters for the shape of transom and bow area were defined. Based on the specified values of the design parameters, a grid of parametrically defined curves was created, consisting of a set of principal curves and on a set of parametrically defined sections and diagonals. Subsequently, a series of meta-surfaces and lofted surfaces was generated, as shown in Fig. 4. After the hull definition, a Lackenby transformation is used in order to adjust the prismatic coefficient and the longitudinal position of the centre of buoyancy of the hull to the specified values.

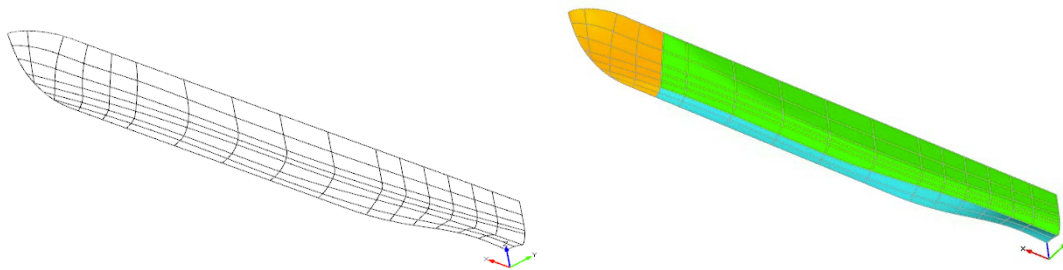


Fig. 4: Parametric hull form model of Stavanger Demonstrator by CAESES  
left: Grid of Control Curves and right: Generated Lofted Surfaces

#### 4.1.2 Global Optimisation of Main Dimensions for Minimum Resistance

In the frame of the global optimisation, the calm water resistance of the parametrically varied catamaran hull form was calculated by use of HSWA's 3D panel code v-Shallo (Gatchell et al., 2000). A series of response surfaces (*surrogate models*) was created in CAESES® by applying a Design-Of-Experiment (DoE) sampling procedure; this enables the very fast and sufficiently accurate estimation of the calm water resistance for hundreds of generated design variants. Based on this, a global optimisation was performed by the use of the NSGAI genetic algorithm to identify the optimum combination of the main design variables for the Stavanger demonstrator, while assuming the overall length and beam (as specified by ship's deck arrangement) fixed. The objective of the study was to minimize the calm water resistance of the demihulls considering the effect of wave interference between two demihulls. As the shipbuilder and operator were interested in obtaining a hull form with superior characteristics in a range of displacements and speeds, a multi-objective optimisation was conducted considering the resistance for three different speeds (21, 23 and 25 knots) and three displacement volumes ( $\Delta_1 < \Delta_2 < \Delta_3$ ), while the weighted average of the calm water resistance was the criterion for the final selection of the globally optimised hull form. A set of constraints was also applied, in order to verify that each feasible design alternative disposes sufficient space for the installation of the battery racks and the fitting of a large propeller diameter in the tunnelled transom stern area.

In Fig. 5 some representative results of these optimization studies are illustrated, noting that shown resistance data are non-dimensionalised by a fixed reference value (confidential). Out of 1,000 generated designs, the 824 proved feasible, whereas 176 violated the set constraints. Based on the obtained results, the overall optimum design

(marked with green circle) corresponds to a very slender hull form with a length at WL close to the maximum, a demihull beam close to the set minimum and an increased draught. In addition, as can be observed from the figures, for the lightest displacement  $\Delta 1$ , hull forms with the smaller beam at WL are those having lower calm water resistance, whereas for the heavier displacement  $\Delta 3$  at 25kn, hull forms with a larger beam at WL are exhibiting lower calm water resistance values.

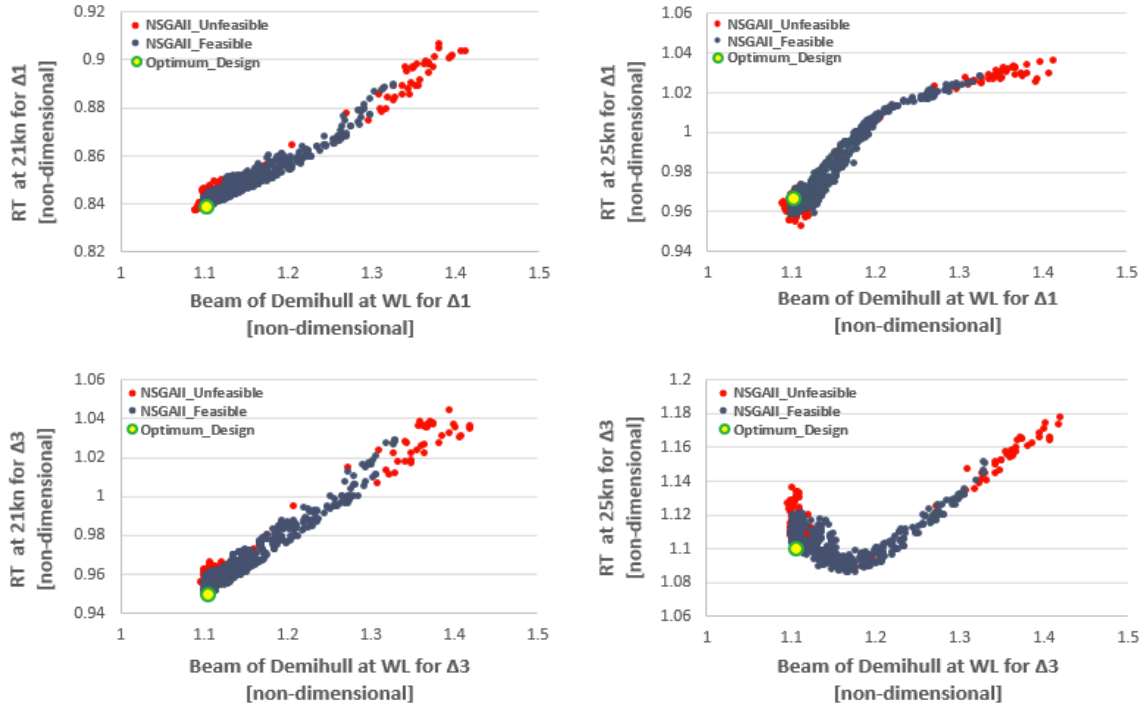


Fig. 5: Calm water resistance against Beam at WL at 21 knots (left) and 25knots (right)

#### 4.1.3 Local Hull Form Optimisation

The criteria for the selection of the final design for the local hull form optimisation included next to the calm water resistance comparative performance, issues of the easiness of hull construction and the outfitting/maintenance of the main equipment. The local hull form optimisation focused on the propeller tunnel area, which was mathematically captured by six design local parameters. In addition, five parameters related to the propeller characteristics, such as propeller diameter, position and shaft inclination were included in the optimisation thus eleven parameters in total. The Dakota Optimisation Toolkit of Sandia National Laboratories disposed in CAESES® has been utilized. This toolkit allows excellent exploration of the multi-parametric design space by use of proper sampling methods, such as Latin hypercube sampling, orthogonal arrays, and Box-Behnken designs. In total nine design constraints were eventually specified, mainly for reasons of seamless fitting the propeller, its shaft and brackets. Generated designs were evaluated by use of a RANS-QCM coupling method (Xing-Kaeding et al. 2017), where both the HSVA in-house RANSE code FreSCo+ (Hafermann, 2007) and the propeller panel code QCM (Chao and Streckwall, 1989) are coupled through the actuator disk method at an iterative basis to evaluate the hydrodynamic performance at self-propulsion condition. In this procedure, the free surface, free sinkage and trim of the catamaran are being considered as well. The numerical mesh applied has 5.3 Mil cells in total, including a refinement around the free surface region and the propeller/ship transom stern region.

Due to the many specified design constraints, only 8 (eight) out of 1,000 generated designs proved feasible. The identified best design with respect to the required delivered horsepower (DHP) was further fine-tuned to minimize the risk of air suction in the propeller tunnel. For the selection of the best hull form, a range of displacements and speeds were evaluated to assess the performance of the hull variants at various off-design conditions. Figure 6.1 shows the computed wave field of the best hull form at different speeds (21, 23, 25 and 27 knots) viewed from the bottom, while the propeller body force disk and rudder can be also seen. The propeller is simulated via the body force method, where the three-dimensional blade forces coming from the panel code QCM are incorporated, as can be better observed in Fig. 6.2.

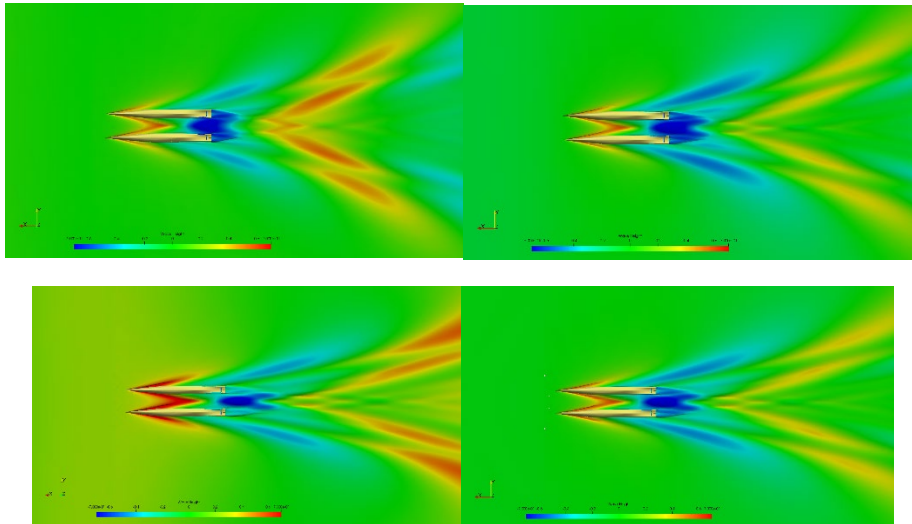


Fig. 6.1: Free surface deformation at 21 knots (upper left), 23 knots (upper right), 25 knots (lower left) and 27knots (lower right); view from bottom

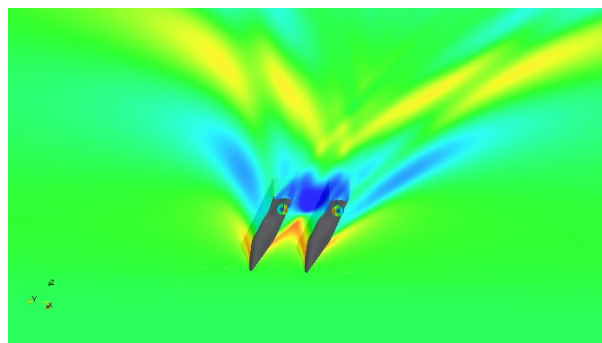


Fig. 6.2: Wave field and propeller body force distribution at 23 knots

#### 4.1.4 Speed Power Prediction

The calculated speed-delivered horsepower predictions for the three different displacements can be seen for the optimised hull form in Fig. 7. Pending the verification of the obtained numerical results by physical model experiments at HSVA's towing tank in December 2019, it proves that the Stavanger demonstrator can achieve the required service speed of 23 knots with the planned e-propulsion installation and battery recharging plan. Margins for higher speeds at the light displacement seem also feasible, even more when battery weight and space requirements are likely to decrease in the future.

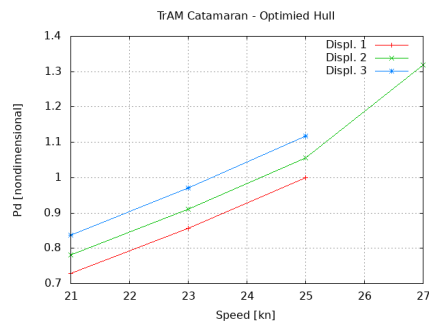


Fig. 7: Numerical power-speed curve for the optimized hull at three displacements



## 5. Replicators

To make sure that the production system developed in the TrAM project applies to a wide set of use cases, the refined modularity concept will be also applied to two replicators in the last phase of the project.

### 5.1 London replicator

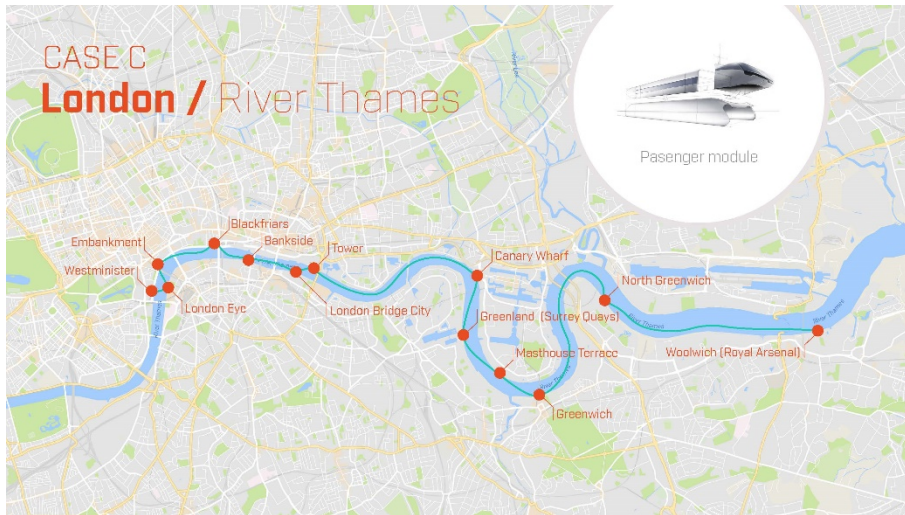


Fig. 8 London passenger ferry

This replicator, operated by project partner Thames Clippers, was chosen because it stretches the limitation of zero emission alternatives to an inner-city operation. Compared to the Stavanger Demonstrator, this replication case needs to more carefully take into account wave wash effects. Work on this replicator is planned for 2021 and it may be assumed that at that time considerable improvements in battery systems will allow even greater flexibility in design and operation.

### 5.2 Flanders replicator

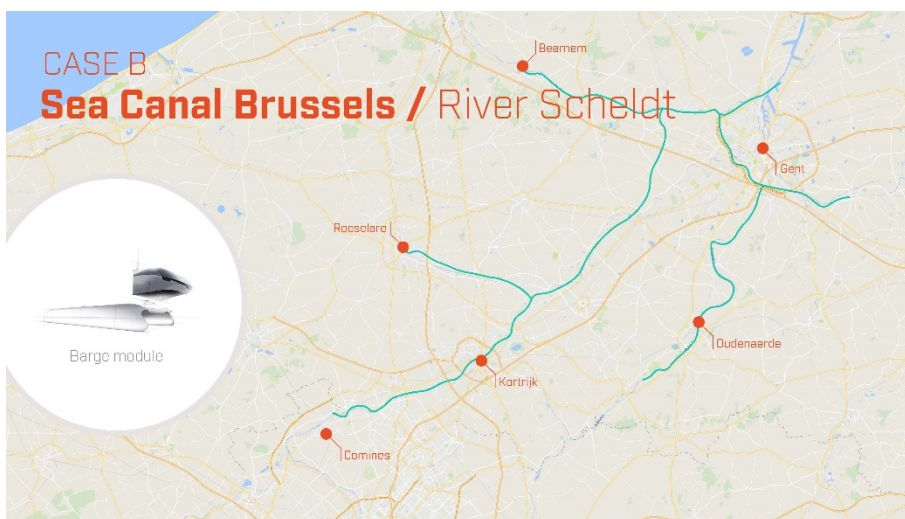


Fig. 9 Flanders inland waterways passenger ferry

This replicator is run by project partner De Vlaamse Waterweg, that is in charge of the inland waterways in Flanders. It was chosen because of unique challenges, namely developing transport systems operating with few or no crew (autonomous), which means that a full electric energy-power system needs to be automated to the largest extent possible.

## 6. Conclusions

The challenge to create environmentally friendly, marine transport solutions at low cost is reflected in public policy on national, European and a global level. In TrAM, leading European research and industrial companies are developing and validating a concept for waterborne transport by implementing modular design and production methods, with main focus on electrically powered vessels operating at high speed in protected waters (coastal areas and inland waterways). TrAM clearly moves beyond state-of-the-art in waterborne transport, with considerable innovation potential, by developing a new design concept for modular production of vessels while at the same time expanding the capabilities of electrically powered vessels to higher speeds of operation.

## 7. Acknowledgements

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