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The Orcelle project – Towards Wind-Powered Ships for Deep Sea Cargo Transport

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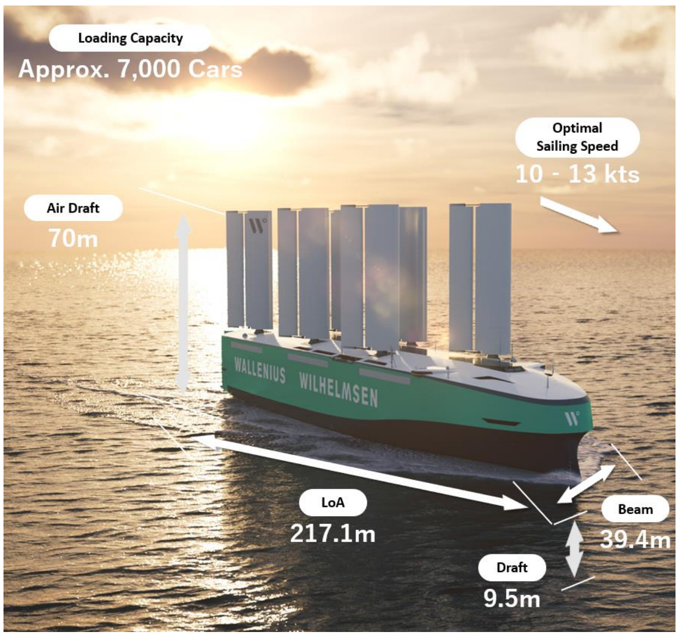

Figure 1. The Orcelle demonstrator

International regulations on greenhouse gas (GHG) emissions as well as strong market demand for zero-emission transport calls for a radical change in the shipping industry. Measures such as hull form optimization, use of alternative fuels and efficient machinery systems, new coatings, and smart routing have already improved the energy efficiency of the world fleet and to some extent its GHG emissions. However, it is far from enough. To make the drastic leap that we need in order to meet the climate challenges, we must turn to emission-free energy sources. One such promising and well-proven zero-emission propulsion system for shipping is wind propulsion. Using wind to power cargo vessels re-started on a commercial scale about a decade ago. Currently, there are 25+ wind-assisted vessels in commercial trade. They are equipped with technologies like Flettner rotors, wings or kites, which gives fuel reductions in the magnitude of 1-20 %. Although these are significant fuel savings, this is still not enough to effectively respond to the challenges for zero GHG emissions of the maritime industry. With the goal of demonstrating that even higher energy reduction and drastic reduction of emissions is possible, 11 representatives of the European maritime industry and research community have recently joined forces in the large scale EU-funded project Orcelle, led by Wallenius Wilhelmsen Ocean. The current paper will present the project's ambition, scope of work and expected outcome.

KEY WORDS: wind propulsion; GHG reduction; wing sails, decarbonization

INTRODUCTION

In alignment with the emission reduction goals set out in the United Nation's 2015 Paris Agreement, the International Maritime Organisation (IMO) agreed and regulated the cut of greenhouse gas emissions from shipping by at least 50% by 2050 and CO2 emissions per transport work by at least 40% by 2030 and 70% by 2050, compared to the 2008 level (IMO 2017). These international regulations, as well as strong demand from the market (Rehmatulla 2017), call for radical innovations in the frame of zero-emission maritime technology and shipping.

Various solutions are currently discussed in the maritime transport sector (Chou 2020). Bouman et.al. (2017) have recently studied the CO2 reduction potential of various improvement measures such as hull design, power & propulsion system, alternative fuels, alternative energy sources and operational measures. Out of many possible solutions, a promising and well-proven solution is wind propulsion.

Using wind to power cargo vessels re-started on a commercial scale about a decade ago. Currently, there are 25+ wind-assisted vessels in commercial trade (IWSA 2023). The main implementations in practice are so far:

Flettner rotors are rotating vertical cylinders driven by an electrical motor. When exposed to wind, the rotor generates a force perpendicular to the onset flow due to the *Magnus* effect, which can contribute to the ship's propulsion. In recent years, Flettner rotors were installed on *Viking Grace* (ferry), *E-Ship 1* (RoRo), *Maersk Pelican* (tanker), *Fehn Pollux* (general cargo), *Annika Braren* (general cargo) and *Copenhagen* (ferry). Rotors were recently also fitted to deep-sea ships: *Sea Zhoushan* (Bulk) and *Sea Connector* (RoRo).

Wing sails are vertically arranged wings with or without flaps. Several developers lunched patented wing sail systems in recent years (e.g., *Ayro of OceanWings*, *WindWings* of *BARTech/Yara Marine*, *Wisamo inflatable sails by Michelin*, *OceanBird of Alfawall, advanced in the Orcelle project*). Among the prototypes with wing sails, as of today, is the 121m long Ro-Ro cargo ship *Canopée*, delivered in December 2022. Its hybrid propulsion uses a combination of wing sails of *Oceanwing* type and traditional engines. The use of *Canopée* will ultimately halve the costs of shipping Ariane rocket parts from Europe to French Guyana and significantly reduce its environmental footprint. Also, in late 2022, the VLCC *New Aden* was delivered to China Merchant Energy Shipping, built by Dalian Shipbuilding Industry Co. and equipped with two pairs of new generation rigid wing sails, which were developed DSIC's R&D team, united CMES, CCS, Guangwei Composite Materials Co.

Suction wings installed on for example *Ankie* (general cargo), *Frisian Sea* (general cargo), and *La Naumon* (general cargo). A suction wing is a vertical wing with a very thick profile. A fan installed inside the wing sucks air through the permeable surface of the wings trailing edge to prevent it from stalling. In that way it can provide a high lift coefficient (*Ventifoil of Ecowind*, *Bound4Blue*).

Soft sails, *Neoline* (RoRo) and ***kites*** *Beluga* (Container), *AirSea* (RoRo) are less common and may have limited impact.

The wind propulsion systems, currently in use, deliver fuel reductions in the 1-20% range, by assisting ship's propulsion by its main engine, which is in general a diesel fueled engine (hybrid WASP: Wind Assisted Ship Propulsion systems). These are partly significant savings, but far from enough to reach the international GHG emission targets. There are a few built ships with wind as the main propulsion, in the segment of private yachts and very exclusive cruise, such as *Maltese Falcon* and *Black Pearl*, and many small sailing crafts, like fishing boats, but not yet any large vessels for deep-sea cargo transport driven primary by wind. The herein presented work aims to fill this gap.

With the goal of demonstrating that a drastic reduction of emissions from deep-sea cargo transport is possible, 11 representatives of the European maritime industry and research community have recently joined forces in the EU-funded project Orcelle (2023-2027). The consortium is led by Wallenius Wilhelmsen Ocean and includes Wallenius Marine, AlfaWall Oceanbird, RISE SSPA Maritime Centre, Royal Institute of Technology, StormGeo, National Technical University of Athens NTUA, DNV, Ghent University, Volvo Cars, and Maritime Cleantech. The project started on January 1, 2023 and will end by the end of 2027. The efforts aim to advance several technologies from TRL3-4 to TRL7, including the wing system and ship design, as well as simulation platform, safety regulation framework, business models and weather routing software. In the current paper we will present the project's background, ambition, scope of work and expected outcome.

THE ORCELLE CONCEPT-BACKGROUND

Target emission savings

The final goal of the consortium's efforts is to build and operate a primary wind powered ship, namely Orcelle. The concept design of the planned ship is already mature through background research and development work in collaboration between the partners. The concept vessel of Ro-Ro car carrier type measures 232 meters in length, 40 meters in beam and has the capacity to load approximately 7,000 cars or equivalent cargo. The optimal sailing speed with wind is between 10-14 knots. The vessel size and capacity are chosen in relation to the identified transport route and cargo flows. The evaluation of energy efficiency is performed for two different routes, a trans-Atlantic and a trans-Pacific route. The Atlantic route includes major ports on the EU-side, e.g., Zeebrugge and Bremerhaven, and Halifax and New York on the US east coast side. The trans-Pacific route includes ports in east-Asia e.g., Ulsan and Pyeongtaek and San Diego and Port Hueneme on the US west coast side. The great circle round-trip distances are 7.000 and 11.500 nautical miles for the trans-Atlantic and trans-Pacific routes, respectively.

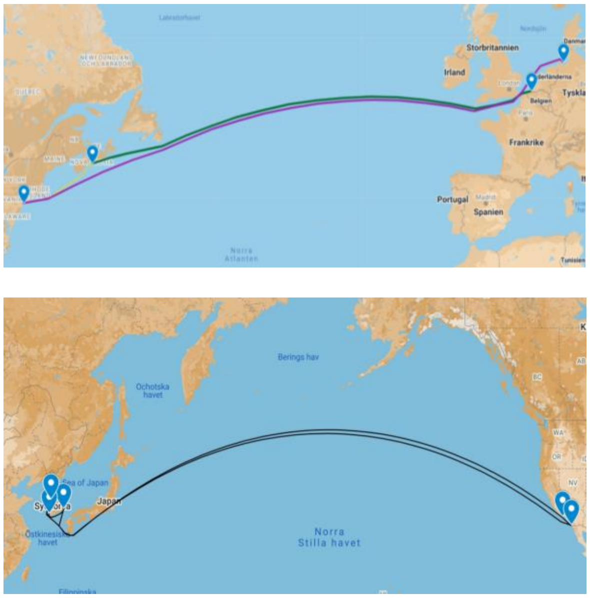

Figure 2: Routes considered in Orcelle's energy efficiency evaluation.

Background hydro- and aerodynamic studies

The ambitious energy savings target is +50%. This has already been determined based on a set of analysis methods, developed by the consortium partners in the background research project "Wind Powered Vehicle Carrier", funded by the Swedish Transport Agency. The analysis methodology comprises of several modules. In the following paragraphs some of the main features of the approach are described.

***Hydro and aero modeling*.** Hydrodynamic modelling and analysis of the vessel hull while experiencing large leeway angles and variable propeller load is based on CFD (3D RANS). The employed numerical method has been validated using experimental tests in the towing tank of SSPA (Fig. 3) (Marimon 2021). The aerodynamic modelling of the wings and hull topsides, the interaction between the hull and wing systems, and interaction between the different sail systems on the hull topsides is based on a multi-fidelity approach mixing 3D RANS, 2D RANS and lifting line methods (Malmek 2023). Examples from the aerodynamic modeling are shown in Fig.4-5. The method has been validated using wind tunnel tests at SSPA (Marimon 2022).


Figure 3: Towing tank tests at SSPA of the Orcelle concept for validation of CFD based captive test.

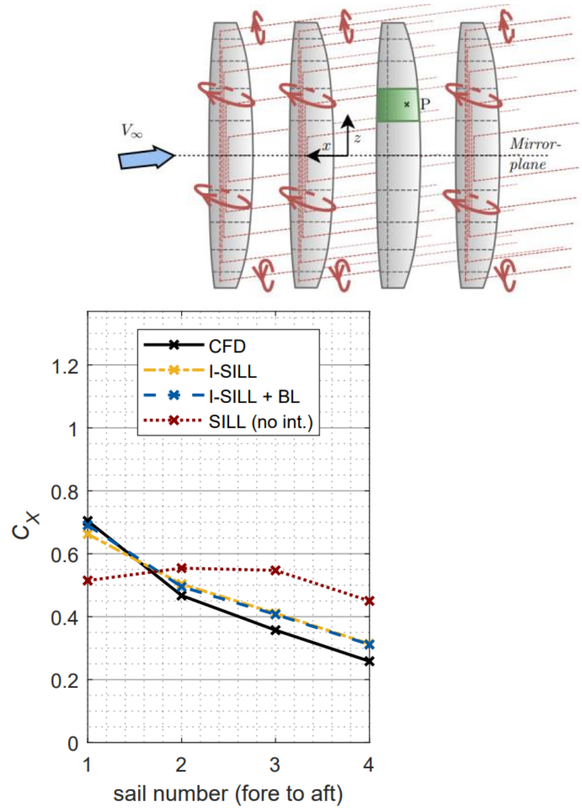

Figure 4: Examples from aero modelling. Multifidelity method for wing-wing interaction (I-SILL). (Malmek 2023).

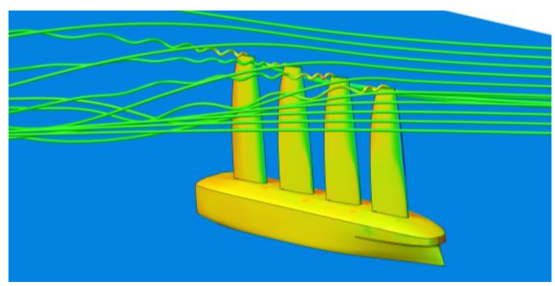
Figure 5: Examples from aero modelling by 3D CFD simulation of the Orcelle concept (early stages of development, with different rigs).

Velocity prediction A velocity prediction program VPP has been developed, where the non-linear systems of constrained force and moment equilibrium equations of the vessel system is solved to provide a large range of performance parameters given certain wind and wave conditions (Olsson 2020). An example of the output is shown in Fig.6.

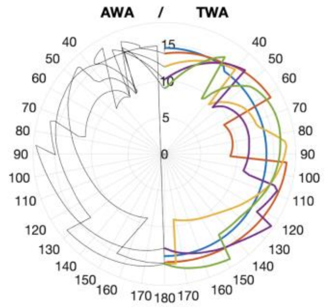

Figure 6: Result from VPP of an early version of the Orcelle concept. Radial axis shows ship's speed. Each colored curve represents the ship speed at a given wind speed. The staggered shapes of the curves are due to folding/not folding wing sails on deck.

Routing An optimal routing methodology, which enables the operational energy savings to be assessed on various trading routes across the globe, has been developed. The methodology considers the need for the vessel to fit into a logistics system regarding arrival time and lateness and considers ECMWF weather data captured during the last decade (Fig.7) (Werner 2021).

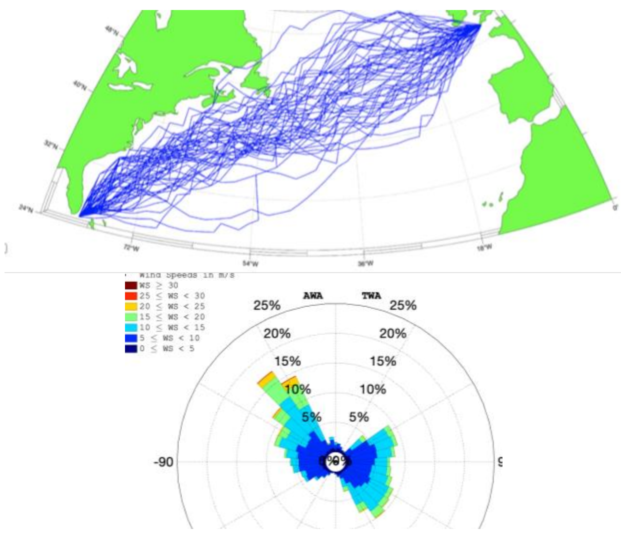

Figure 7: Results from the routing simulations. Alternative routes from UK to NY, and wind statistics on the route.

Combined analysis The above outlined methods together with the operational know-how of the consortium partners form the basis for the target energy savings potential of the Orcelle demonstrator vessel. The expected potential energy savings for the given trade scenarios shows that approximately 50% total energy savings is achievable at 14 knots and even increased savings as the trading speed reduces, compared to the latest generation car-carriers operating with same amount of cargo at 16 knots. Comparing energy savings at the same vessel speed gives a total energy reduction of approximately 40% at 14 knots and 45% at 10 knots only from wing system. The saving potential at 10 knots is even higher, namely savings of +70% compared to conventional propulsion at the same vessel speed of 10 knots is possible but requires carefully optimized auxiliary propulsion systems. We believe that a part of the challenge for wind propulsion is to develop operational models that allow for lower speed (and vessels designed for lower speed), which is a key to moving to the largest emission reductions using wind.

The wing sail propulsion

Wing sail technology is not in itself a novel technology; it has been in fact utilized for sailing for a century or more. However, as to its application to commercial shipping, wing sails have still not entered the market to any significant degree. The reasons for this are several, for example as highlighted by Nelissen (2016): access to capital for the development of wind propulsion technologies, incentive to improve energy efficiency/reduce CO2 emissions of ships, and verifiable information on performance, operability, safety, durability and economic implications of the wind propulsion technologies.

Development of wing sail technology has up until now to a large extent been focused on theoretical performance optimization and novel mechanical designs (Ouchi 2013, Nyanya 2021, Khan 2021). However, work related to practical operational optimization of wing sails remain scarce in public domain literature (Müller 2019, Vahs 2019). Compared to technologies such as Flettner rotors, wing sails have the advantage of being a passive technology, requiring very little power to operate and thereby enabling a full shift towards wind-powered vessels onboard ships (Ma 2019). Wing sails are also more efficient in generating propulsive force in the forward sailing quadrant, enabling an increase of the sailing operability window, drastically reducing carbon emissions (Juliá 2020). To develop wing systems, an understanding of long-term degradation is needed. Because of the stochastic nature of both the operational environment and material strength degradation, design practice is typically based on fixed and conservative design parameters to ensure the required level of system availability and safety (Stambaugh 2020). Maintenance management of (ship) structures typically includes optimal inspection strategies to detect fatigue cracks and updating structural reliability models (Xing 2017).

The wing sails solution for Orcelle, called *Oceanbird Wing* has been developed by the Swedish company Alfawall Oceanbird (Fig 8). It consists of a 40m tall main wing and a flap, which can both be rotated independently to provide optimum forces. The wings are made in composite shells, which provides the aerodynamical shape of the wing sail and transfers pressure loads to the main load-carrying structure. In unfavorable and extreme wind conditions and in port, the wings are folded down.

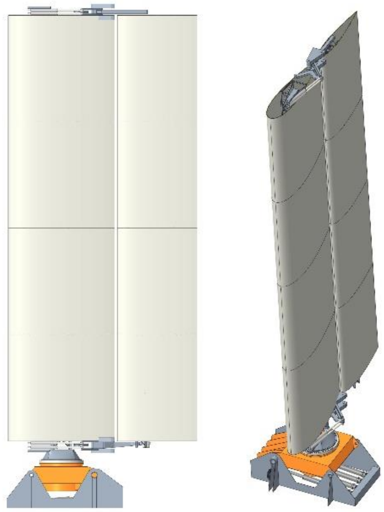

Figure 8. The *Orcenbird Wing* concept

Control, maneuvering and seakeeping

Course keeping and maneuvering in waves under sail were assessed with hybrid model tests at SSPA, where the sails were replaced by pulling fans (Fig 8). This confirmed that the maneuvering performance is sufficient, even when the driving force is primary from the sails and there is no propeller flow to the rudder.

Figure 8. Hybrid sea keeping model tests at SSPA, where the wing sails are modelled by pulling fans.

The wing sails affect the induced roll motions in waves, as they provide substantial damping. Therefore, seakeeping simulations by use of a program based on non-linear potential flow and the aerodynamic modelling from the VPP program were integrated to assess the motions in the waves. (Fig 9).

At the Royal Institute of Technology in Stockholm, a large 7-m prototype model was built and used intensively in open air/sea testing to study a variety of operational effects, like control systems in real environment (Fig 10.). (Hillenbrand 2021)

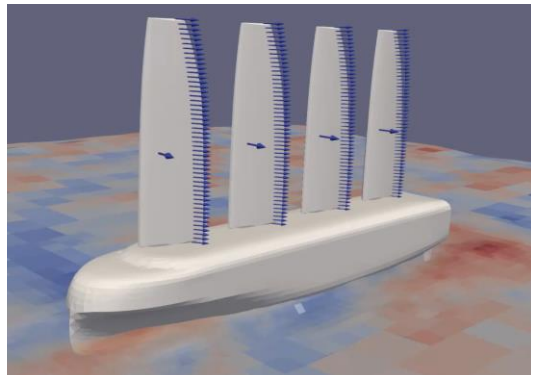

Figure 9. Seakeeping simulations with the code Shipflow. Motions integrated to the aerodynamic model SILL.

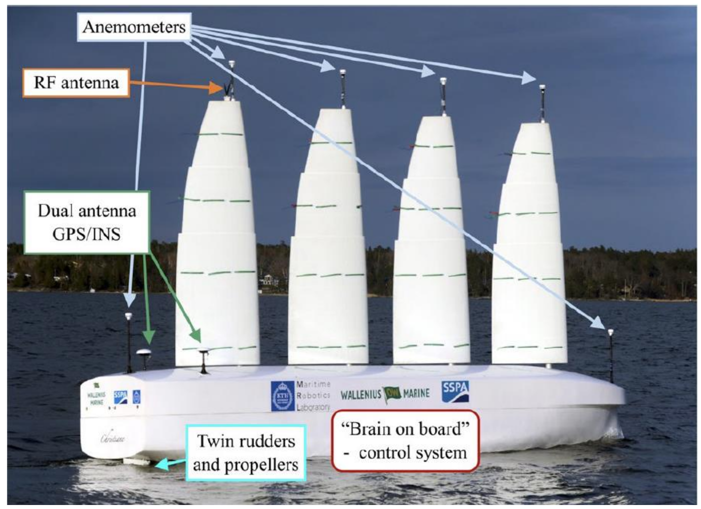

Figure 10. A 7-m long demonstrator of the early concept of Orcelle was used to study control systems and manouverabulity.

PLANNED RESEARCH AND DEVELOPMENT

The EU funded, 5-year Orcelle project will involve research and development in a range of areas, while also including the demonstration of a retrofitting and a newbuilding use case. An overview is given below.

Wing solution

Control and automation strategies and systems will be further developed. The research involves the algorithms for the control of a multi-wing configuration, where the fluid-mechanical interaction between the wings sometimes is substantial. A large portion of the effects that needs to be accounted for in this respect is difficult to predict even with todays most sophisticated methods. Experimental techniques coupled with machine-learning and AI might turn out to be the most effective solution (Yo 2013).

Advances need to be made regarding the safety standards for wind power technology. This will be done by a series of large-scale demonstrators with integrated condition monitoring, thereby increasing adoption potential through risk reduction.

Safety standards for wind propulsion technologies are continuously advanced, however the limited number of full-scale installations, especially for full wind propulsion, limits the available data and thereby makes assessment of the actual safety levels difficult. At present (among others) DNV has a regulatory framework for wind assisted systems (e.g., using Flettner rotors), but to our knowledge there exists no developed framework for approving ships in large-scale international trade with wind as the main propulsion. A major concern here is operation in adverse weather conditions. Extreme wind loads of 50 m/s should be considered, including measures to handle such winds through prediction systems and operational procedures to lower the sails (which is the planned operational strategy). This involves a combination of challenges: at what wind angles are you able to both lower the sail and get incoming sea waves at favorable encounter angles.

To gain insight in the real-life structural integrity of the wing system, i.e., to allow early detection and identification of malfunction and degradation of its critical mechanical components, a structural health monitoring framework for data-driven evaluation of the integrity of the wing system will be developed.

Development of optimized manufacturing and installation techniques to reduce the capital expenditure barriers and enabling scale-up for the wider shipping market, both regarding smaller drop-in solutions and full wind-power installations. Knowledge will be increased on manufacturing, logistics and commissioning during the onshore pilot, the retrofit ship installation, and the full-scale newbuilding ship installation to develop efficient manufacturing and installation methodologies for wind power technology. Thereby we address one of the main barriers in the wider adoption of wind power technologies for shipping namely to increase the cost efficiency and thus reducing the initial investment for the shipowners.

Simulation platform

Accurate, validated, and feasible methods for simulating the energy efficiency and operation at design stage are vital for the industry. Methods for performance predictions of wind assistance ships, i.e., ships with a small to moderate portion of wind propulsion, are currently being developed in several European research initiatives (WASP, WiSP). Effects that are to some extent already described in literature are the resistance due to leeway (van der Kolk 2019), how leeway angle affects the propeller performances (Schot 2019), how CFD can be used to derive the maneuverability coefficients for static performance prediction force balance (Simonsen 2003) and how sea keeping performance can be assessed in model tests (Eggers 2019)

Further research is needed on simulation methods applicable to ships with a large portion of wind propulsion (exceeding 30%). For these ships, phenomena that can safely be disregarded in the evaluation of wind assisted ships needs to be accounted for. The project partners RISE SSPA and KTH have through R&I activities during the last years started to develop simulation methods for powerful wind ships. This includes tools for simulating the effect of side-force and drift angle on hulls with multiple rudders and appendages (Marimon 2020), aerodynamic interaction between multiple wings (Malmek 2020), maneuverability of wind powered ships in time-domain simulations as well as experiments (Gerhardt 2019), weather optimized routes (Werner 2021) and the effect of waves in fatigue analysis of wing sails (Kjellberg 2022). The Orcelle project's research activities will continue the development of these techniques and advance them further. Several knowledge gaps that the project aims to solve have yet not been described in scientific literature, nor in industry praxis: the non-linear interaction between the ship motion in waves and the aerodynamic forces, the unsteady effects of wind gusts and variations in the atmospheric boundary layer, fast methods for the aerodynamic interaction between the ship hull and the wind propulsor.

Ship design & system design processes

The design of conventional motor ships is traditionally described as the design spiral, where the various disciplines contributing to the ship design are developed and improved separately in an iterative chain. However, a system design approach (which means considering all sub-systems of the ship together, and not one by one) is gradually finding its way into the yard industry. This was also demonstrated in the recent H2020 HOLISHIP project on a holistic approach to ship design, where the various disciplines of ship design and associated tools are processed in parallel by integration of tools on a design platform, rather than sequentially (Papanikolaou 2020). However, for conventional ships to a large extent this may not be needed in practice, since the yards and designers rely on experience, data and gradual advancements of known concept generations. For wind powered ships, we cannot use this background knowledge. A true "system design approach" for wind powered ships is essentially a simulation-based design approach that needs to include not only all relevant physical aspects and all sub-systems, but also all operational conditions, all weather conditions, crew, logistic and safety aspects. Recent studies have been presented in open literature covering mainly the variation of operational conditions and economic implications of wind propulsion (Bentin 2016, van der Kolk 2019), or specific engine sub system (Ghorbani 2022) but no complete holistic design approach has so far been presented.

The Orcelle project will meet the challenges by introducing a simulation-based design approach with two fundamental processes: Multi-physics (or multi-disciplinary) system design and Multi-stakeholder collaborative ship design. A multi-physics system design approach is developed by using simulation tools that model the complete ship system including relevant sub-systems. This will be achieved though systematic R&I activities, as planned in the Orcelle project, to overcome todays knowledge gaps on:

- Optimum energy management onboard including new energy sources such as sun, wind power, power generation from propeller, energy storage and alternative fuels.

- Mapping of the physical phenomena that is required in the design process.
- Deriving multi-fidelity simulation models with the right mix of high fidelity and low fidelity models.

Weather routing and voyage planning

The shortest route between two sailing points is not necessarily the most beneficial in terms of fuel efficiency due to environmental influences (wind, waves, shallow water and currents). State-of-the-art weather routing algorithms optimize the route from one port to the next based on graph, gradient, or genetic optimization techniques considering weather effects on the vessel as well as safety, regulatory and business constraints like traffic separation zones, environmental protection areas and required time of arrival. The industry practice today includes: i) Advanced onboard weather analytic solutions for the captain to analyze the weather along the planned route, as well as to get predictions of weather-related effects to the vessel such as speed loss, fuel consumption and vessel motions (Walther et al, 2016, Liu et al., 2020). ii) Shore-side weather routing services to provide ongoing weather safety advice as well as analytics to monitor and keep the vessel compliant towards charter party terms. iii) Web based platforms for the commercial operator to align the onboard and shore-side route plans with the commercial targets of the voyage. Safety and compliance are the overriding priorities, followed by higher level commercial targets such as e.g., ETA and charter party alignment and only at a third stage, fuel optimization becomes a priority. The components in voyage optimization, when used ideally, do allow for significant fuel savings (3 – 10%), but for this to be achieved, a perfect workflow between stakeholders must be maintained in real time.

Due to the peculiarities of the design of primary wind powered vessels (ratio of hydrodynamic to aerodynamic forces), it is necessary to implement an accurate digital twin for the purpose of weather routing as the usual mixed data driven and engineering models are not fit for the purpose. This digital twin enables an accurate modelling of the vessel's performance based on first order physical principles and the required level of data exchange between the affected stakeholders. The current voyage simulation is evolved to cover the hydrodynamics of the ship´s hull, the conventional propulsion system and the maneuvering devices as well as the aerodynamics of the wind propulsion system and the interaction between these (Krüger et al, 2018, Papanikolaou et al, 2016). The hydrodynamic and aerodynamic models are represented by surrogate models to keep the computational effort manageable for complex optimization tasks under constraints -like in weather routing- where a large amount of solution candidates need to be evaluated (Papanikolaou et al, 2020). As the dependency on the weather of the vessel performance becomes more pronounced for vessels equipped with wind assisted propulsion, compared to standard vessels, the inaccuracy of the midterm weather forecast has a more serious impact on the optimization result. To deal with this, ensemble forecasts or Monte-Carlo-simulation should be considered to quantify the confidence level of route prediction (Hinnenthal 2008).

Logistics and business models

Research on wind-powered shipping has so far focused mainly on efficiency potentials and the technical development. Research findings stress the challenge in lack of business models for successful wind-power technology applications (Köhler 2021). There is a large need for designing new business models as well as taking a higher management perspective on the organizational transformation (Chou 2021). Key questions relate to financial incentives and if business models should be changed (Köhler 2021). Research highlights the challenges related to logistics design issues in wind-powered shipping for maximizing the CO2 emission savings and limiting the operational costs, such as how to handle lower speed, uncertainties in arrival time, changed route with less port calls, and larger volumes handling in ports (Santén 2021). To reach a successful commercial way forward, shipping companies with a focus on wind-powered shipping need to find a way to attract customers and ports to adhere to the new innovative and sustainable solutions where the traditional logistical cost and service model must be reviewed. As vessels with wind systems as main propulsion do not exist on any large deep-sea ship today, the studies of the challenges in logistics and business modelling are not mature and therefore there is a must to include such development for successful realization phase.

The Orcelle project will develop new logistics and business solutions for wind-powered shipping, that are differing from today's operational system. To ensure that wind-powered ships can be used as an integrated part of a commercial value chain, the project will create an understanding of market conditions and their influence on the business case, involve key stakeholders (shipping operator, cargo owners and ports) perspectives to identify and assess logistics and business scenarios as well as ICT potentials, which serve as major input to the multi-stakeholder realization process to be developed. From the perspective of the operator, the following issues will require attention in a future logistics set up: a) how to integrate a wind-powered ship into an operational schedule combining traditional ships with wind-powered vessels (with challenges such as differences in voyage time and cargo requirements, b) how to design the specific routing including the selection of port calls, c) how to attract sufficient cargo volumes through selected ports in a route, and d) how to handle limitations in ports. The project will handle these operational challenges by the creation of new understanding across all the main stakeholders (port, cargo owner, ship owner/operator) and new ICT systems that will provide a deeper integration across the partners in the logistics chain (allowing the new characteristics of the operational profile). Based on previous research results of the early design phases of the wind-powered vessel concept a logistics requirement model including costs, delivery service, damages of goods, route and environmental impact elements (Santén 2021) will be the structure for the in-depth understanding of multi-stakeholder logistics criteria in the realization process of wind-powered shipping. Further, as an important part for the development of such realization path, is the project focus on creating a knowledge link between new and future market conditions and the framework for business modelling of wind powered shipping.

FULL SCALE DEMONSTRATION

How to a approve a viable solution at large scale

The lack of verifiable data for the energy efficiency and fuel savings potential is reported to be one of the key barriers for market uptake of wind assistance technology (Rehmatulla 2017). A few demonstration campaigns of wind assistance technologies have been described in published literature: m/v Viking Grace (Paakkari 2017), m/v E-Ship 1 (Comer 2019), m/v Maersk Pelican (Paakkari 2020), and m/v Fehn Pollux (Vahs 2019). However, these lack in consistency and transparency, as they are based on scattered operational data, and often written by the technology providers. In 2021, a new procedure for sea trial assessment of wind powered ships was developed in the EU Interreg project WASP and applied to m/v Copenhagen (Werner 2021), m/v Frisian Sea and m/v Annika Braren (Werner 2022). The new sea trial procedure has shown to be useful for independent verification of fuel savings potential of wind assisted ships. It has never been applied to primary wind powered ships, though.

The Orcelle project will realize two full scale demonstrator ships, namely one retrofit wind-assisted vessel at the early stage of the project and one newbuilt vessel at the project's end. The two demonstration campaigns have several purposes: to provide data for verifying and improving the simulation tools, to improve the next generation of the wing technology, and to prove that the solution is viable in commercial shipping. The retrofit demonstrator installation will be performed on an existing Pure Car and Truck Carrier (PCTC) vessel of the Wallenius Wilhelmsen fleet. The planned newbuilding will be a PCC carrier with a capacity of 7,000 cars, bound to the Transatlantic route from Europe to the North-East Coast of USA. (https://www.walleniuswilhelmsen.com/news-and-insights/highlighted-topics/orcelle)

Figure 11. The Orcelle project will realize two full scale demonstrator ships: one retrofit wind-assisted vessel pictured here, and one newbuilt vessel shown in Fig 1.

A first adaptation of the developed weather routing system will be implemented onboard the demonstrator vessel to enable crew feedback and training as well as develop strategies for optimal onboard usage. The energy savings on retrofit market segment will be proven through dedicated sea trials as well as by analyzing fuel consumption over longer periods of operation. Sea trials means tests over a short time period (1-2 days) where the environmental conditions, the ship's speed and power consumption are recorded carefully while the ship is driven alternatively by engine and by sails.

The energy efficiency saving will be published, including all relevant measurements and methods, expressed in terms of transport efficiency, EEDI and CO2 saved compared to today's operation for the equivalent transport work.

The new built vessel Orcelle ship (Fig 1) will be in commercial operation from day one. The viability will be proven throughout all aspects of ship operation from emissions, safety, crew aspects to logistics and cargo owners' perspective. Such holistic demonstration campaign goes beyond anything publicly known in this area. For the verification of energy efficiency, the Orcelle project will advance the newly developed sea trial procedure further to make it applicable to large ships in fully sailing condition. This will pave the way for open and transparent verification of all future wind ships.

The crew aspects will be included in the demonstration. Qualitative feedback from crew on operations, safety and comfort will be collected through workshops and interviews, led by human factor specialists throughout the full campaign.

FURTHER APPLICATIONS

To show that the *Oceanbird* wing solution is a viable option for a wide range of applications, feasibility studies will be carried out for a range of other ship types than the ro-ro car carrier Orcelle. At least four generic ship concepts (tanker, bulk carrier, containership, ferry) will be developed in close contacts with the shipping industry. Design concepts that are based on a logistic and an operational profile, will include the ship's hull form, wind propulsion arrangement, machinery power and propulsion plant, cargo and other main arrangements. The validated simulation tool kit will then be used to evaluate the CO2-saving potential compared to conventional ships and demonstrate viable business models.

CONCLUSIONS

A number of cargo ships have already adopted wind assistance solutions to reduce GHG emissions. However, for deep-sea shipping with large cargo vessels, wind solutions have so far been limited to systems providing yearly energy efficiency reductions of 1-20 %. Moving from 1-20% to our target of +50% (yearly reduction) on a large scale, requires a radical shift in ship design. The Orcelle project will design, build, and operate a ship that is optimized for wing propulsions at all levels. This requires solving a combination of research and innovations challenges:

- More efficient wing systems for main propulsion, and safe automated ways to operate them.

- Improved simulation platforms covering wind propulsion and operation, that allows combining advances in modelling and data capture to safely design and operate new vessels in different segments.
- New ship design and design processes that handle the complexity of new wind systems.
- New weather routing systems, that handle the added complexity of new wind systems.
- New logistics solutions, that allow for some reduction of speed and (in our case) some more limitation on the cargo the ship carries that requires additional planning solutions.

In the project the feasibility of the concept will be demonstrated using two full scale vessels. The first vessel will be retrofitted with 1 wing and achieve savings of 5-10%, i.e., similar to existing wind assisted vessels. The second demonstrator vessel (newbuild) is expected to reach +50% savings in commercial operations, with the potential for moving to even higher values at lower speed.

The Orcelle project is expected to deliver a cost-efficient approach to reduce emissions and energy use with +50% (estimated for all energy used in operations) and further room to improve this through operational optimization or slower speeds. The emission reduction is achieved through energy efficiency. This means that alternative fuel approaches become more cost-efficient, making the two solutions complimentary. We also foresee a significant scientific impact of the project in areas such as multi-fidelity performance prediction methods, control systems based on machine learning, and novel design processes. Finally, we expect an impact on the traditional business models by involving the cargo owners from the start of our journey.

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