Policy and economic transition

Shipping is a highly strategic industry moving 90% of world trade and ships project military and commercial power around the world. This is as true today as it was in the 19th century – if shipping stops, the world economy stops.

The industrial revolution and adoption of steamships was supported by government intervention, from subsidies for mail services that made high-speed steamships competitive, to assisted migration programmes supplying large numbers of passengers and huge infrastructure support. The British government, for example, took a 44% stake in the Suez Canal in 1885 and reduced transit fees for mainly steam-powered vessels as wind vessels found it difficult to use the narrow channel and with expanding colonial power taking hold of strategic bunkering stations worldwide.

This framework is mirrored in today's shipping world – fossil fuels are heavily indirectly subsidised through the externalisation of environmental, security and health costs along with a favourable tax regime on marine fuel and no carbon price. These all impact the uptake of wind. However, environmental regulation from the IMO and elsewhere is picking up where the market has failed to drive change and with the development of an international level playing field, something that was wholly missing from the earlier transition away from wind. With the adoption of a full lifecycle carbon analysis of all energy sources, there will be further impetus for the adoption of direct wind energy as it is streaks ahead of everything on the market or in development.

Another key issue in the earlier transition was financial risk, early steam was costly and later wind vessels were progressively more financially risky as trades narrowed. Heavy capex financial models persist in today's shipping world, but these are starting to be challenged; wind propulsion technology supplied as a service has the potential to radically transform the adoption of wind systems. Pay-as-you-save models, leasing and even the development of modular systems could lead to 'payment by kWh' and shift the burden fully over to an opex model.

The market uptake of new steam vessels tied the industry to a commoditised fuel with all of the cost and supply challenges associated, the British Royal Navy was very conscious of these logistics issues and remained sceptical of steam during most of the 19th century. We see echoes of these issues in new debates around low carbon fuels with their projected high costs and supply issues into the foreseeable future. The solution then was a hybrid wind-steam vessel and while we are not seeing these alternative fuel-wind hybrid vessels in the market yet, they are on their way.

Wind-assist fossil-fuel hybrids are the first significant step and set the stage for wind propulsion being a facilitator for the uptake of those costly new propulsion systems and fuel. Wind taken along with operational changes and vessel optimisation across the fleet could reduce energy demand by up to two thirds, making it far cheaper and quicker to get alternative fuels into the market.

As we re-wind vessels, this opens up the possibility of a new paradigm in shipping, the fully wind-powered vessel. Not a rewind to engineless vessels but a fast forward to ships that can harvest the excess wind energy delivered to the vessel and convert it into zero-emissions fuel for use when there is little or no wind. The system design and development of these solutions are already underway. We hear much about autonomous shipping, or autonomy-in-control, but wind brings autonomy-in-operation too, just ask any clipper ship captain of old. *NA*

Making wind assistance into a commercial proposition

A recent study has helped to prove the viability for Flettner rotor-assisted propulsion solutions, explain Nico van der Kolk and Giovanni Bordogna of Blue WASP

As most are now aware, the maritime industry is under pressure to deliver change in line with decarbonisation trajectories laid out in the Paris Agreement (40% reduction by 2030 as per recent EU ETS regulations) and IMO's halving of CO_2 from the 2008 baseline by 2050. Unfortunately, the increasingly strict regulatory regime means the present fleet of commercial ships faces environmental obsolescence.

Wind-assisted ship propulsion stands apart among available energy transition technologies for commercial shipping. These 'steel sails' (some actually being composite) contribute to the propulsion requirement, thereby saving fuel and improving transport efficiency. Depending on wind conditions, large wind assisted propulsion (WASP) installations could help operators avoid frequent bunkering, mitigating – or even in some cases eliminating – their main operating expense.

But the barrier to broader market uptake isn't, as might first be thought, technological readiness. After all, it's not a new concept: several viable wind propulsors are already commercially available and significant examples of vessels equipped with these sails are presently operating on both inland and deep-sea routes. Rather, the main barriers appear to be a lack of experience and unwillingness to shoulder the risk accruing to early adopters.

Further, development is also hampered by a poor understanding of complex physical phenomena: for example the interaction effects between wind propulsors, and the hydromechanics of a

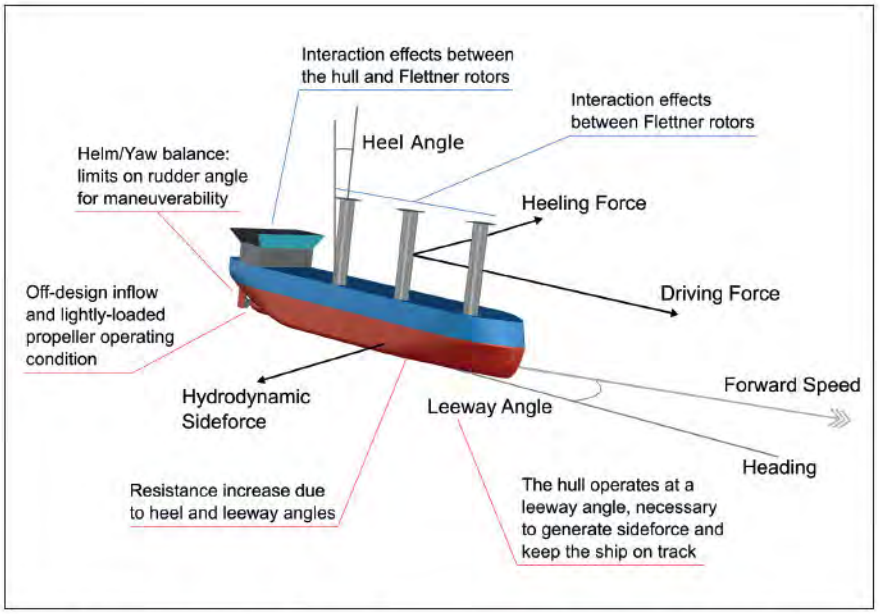


Figure 1. Vessel equipped with three Flettner rotors, showing key interaction effects

commercial sailing ship. For the shipowner or operator, this lack of experience introduces yet more uncertainty in a profoundly risk-averse sector. Moreover, for the regulator who wishes to promote the uptake of sustainable technologies, this knowledge gap could result in misdirected policies which both fail to advance the energy transition and further burdens owners.

Wind-assist efficiency

The underlying principle is superficially straightforward: to maximise the wind-assist contribution to the vessel's propulsive requirement. However, optimal operation requires careful consideration of knock-on effects introduced by WASP systems, where new (transverse) loading introduced by the sail plan will impact nearly every aspect of the ship performance.

The Flettner rotor – the object of this focus – is one of several high-lift devices being developed as auxiliary, wind-assisted propulsion systems for commercial ships. It creates an aerodynamic driving force using the Magnus effect: so, in exchange for limited absorbed engine power to turn the rotor, Flettners can still generate a significant amount of thrust despite a reduced sail area.

The lift and drag it generates is related to the rotor's rotation rate and the true wind speed (TWS). An optimal setting can be found for upwind and downwind courses, considering also rotor-rotor interaction effects and any vessel efficiency loss. As most wind-assisted ships are effectively hybrids, the overall performance depends on the wind contribution in combination with the efficiency of the drive train. Similarly to other types of hybrid, an off-design operating point will generally be detrimental for specific fuel consumption of the main diesel engine and propeller efficiency. Furthermore, the demand from the Flettner rotors has to be taken into account as an added load on the ship's electric grid.

To achieve the maximum benefit from sail thrust, the captain of a wind-assisted hybrid should operate the vessel differently. The course and engine setting (and corresponding ship speed) must be set considering the anticipated weather conditions along the route, where the vessel seeks to offset some portion of its propulsive requirement using available wind-assist power: PWASP. This wind-assist power will deviate from a theoretical value based on the energy in the wind stream according to the efficiency of the WASP integration with the vessel.

Economic penalty for delayed (or early) arrival must also be considered. This presentation is necessarily brief, but the optimisation described touches on aerodynamics, hydromechanics, engine modelling, weather routing, and economics.

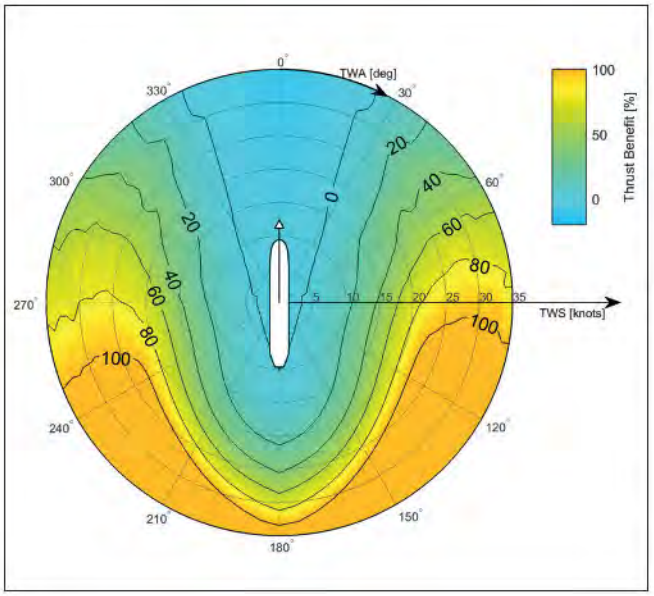


Figure 2. Sailing performance metric Thrust Benefit (TB) on a polar diagram. The ship is sailing directly into the wind at TWA = 0° (resulting in negative TB due to the added air drag of the Flettner rotors), and with the wind astern for TWA =180°

WASP case study

An interesting WASP retrofit design of a 20,000dwt tanker (a representative tonnage for regional operation) has been developed: taking into account the sail-carrying capacity along with structural and operational considerations, the solution consisted of three 30m Flettner rotors arranged in-line along the starboard deck edge.

This allows the structural foundation of the Flettner rotors to be tied into the vessel's frame. Further, cargo handling challenges from the sizeable towers were

mitigated as this configuration also yields full deck area access when the vessel is berthed against its port side.

Vessel performance

Besides the thrust contribution, a balance of forces and moments for the remaining degrees of freedom (sway, roll, and yaw) is a necessary condition for WASP vessels. The desired wind-generated driving force is generally accompanied by a transverse aerodynamic force, known as the heeling force in sailing yacht nomenclature. As a result, the vessel will adopt a steady heel and leeway angle (known as drift in the maneuvering field), or the 'sailing condition': unfortunately, these give rise to increased resistance.

As a hybrid vessel, the benefits of aerodynamic thrust generated by the wind propulsor must be considered against any increase in hydrodynamic resistance: neither should vessel maneuverability or vessel stability be compromised. Therefore, a 10-degree limit was adopted for heel, based on cargo handling requirements and deck immersion while underway.

This effect and others limit the operating points of the WASP vessel and therefore the available wind-assist power. The vessel is restricted in this sense by its the sailing characteristics, a condition for which modern commercial ships were not intended.

Thrust Benefit (TB) represents the contribution of the wind-assist devices to the propulsive requirement, including any increase in resistance caused by the 'sailing condition'. Ship performance for light wind conditions is crucial as, for example, the global wind scatter diagram defined for the IMO EEDI calculation has the majority of wind conditions TWS<20knots. Considering the service speed for this ship, the wind angles experienced will be predominantly upwind. A good WASP vessel must be able to generate adequate thrust at these low wind speeds efficiently to realise any significant savings on aggregate.

The remaining propulsive thrust required to achieve a desired ship speed is delivered by the main engine. The operating points within the engine envelope show that the engine SFC for WASP concepts is highly dependent on the wind condition.

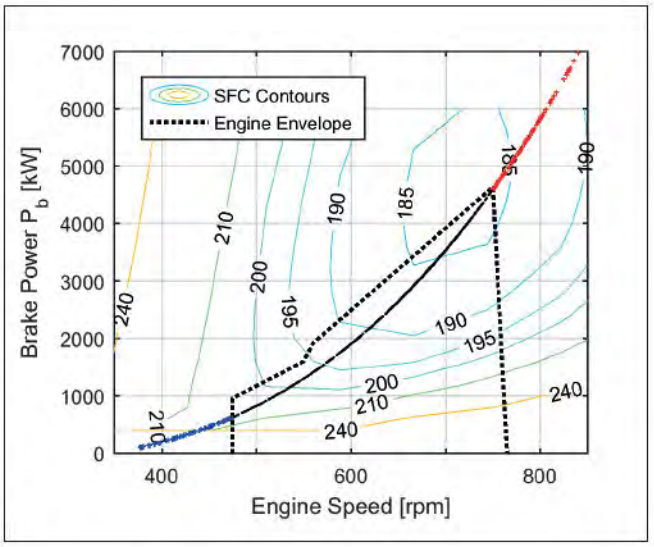


Figure 3. The engine setting needed to achieve the EEDI design speed (12.4knots)

Coloured markers, as seen in Figure 3, are flags for the routing algorithm: red flags correspond to a reduced vessel speed (the EEDI calculation is performed based on a 12.4knot reference speed). In fact, the added resistance in waves and windage loads for a 'wind from ahead' situation increases the propulsive requirement, exceeding the installed vessel power for this speed.

In this case the vessel (both the WASP design and a reference case) is obliged to reduce speed. The blue markers in the 'wind from astern/beam wind' condition indicate that the required engine speed is less than the minimum engine speed. Normally an engine would run around a minimum RPM, allowing the ship speed to increase slightly, or the engine would be switched off and the ship would sail more slowly.

The region in the TB polar diagram (Figure. 2) where TB>100 in the 'wind from astern/ beam wind' condition indicates that the sails by themselves deliver sufficient thrust to achieve the vessel speed without engaging the engine. In this situation, the WASP concept will accelerate the vessel to a higher speed, where a new balance is found between resistance and aerodynamic thrust.

Design and engineering

A point of diminishing returns was identified, after which further investment in WASP propulsors gave marginal improvement for expected fuel savings along the route. This result was linked to operational constraints placed on vessel heel and leeway angles and on aerodynamic interaction effects occurring for close Flettner rotor spacing.

Several design and engineering effects are highlighted here:

- Optimal settings for the Flettner rotor velocity ratios can mitigate detrimental aerodynamic interaction effects between rotors. It is possible to de-power the Flettner rotors when the transverse stability or course-keeping ability of the ship are compromised.
- The need for rudder correction due to the destabilising Munk yawing moment generally increases with aerodynamic thrust, but the rudder will become less effective as the main propeller thrust is correspondingly reduced.
- The engine selection for WASP vessels must be made with care, considering the variation of the engine operating point within (or without) the engine envelope.

Business case

This model offers a robust method of assessing the viability of technologies on specific vessels and trade routes, a result that can be used to create a business case for financing. Rotors are relatively simple to retrofit and applicable to a wide variety of existing tonnage, which could provide an attractive solution to avoid stranded assets in a carbon constrained future.

As with all energy-efficiency investments, the payback period projection only holds when considering an owner-operator

scenario. Other chartering models introduce the split incentive barrier where there is a disconnect between the party that takes the risk of the investment and the party that benefits from it. Thus, on the charter market, owners need to recoup costs through higher charter rates, making them less competitive and favouring less efficient vessels.

In order to assess the economic viability of the WASP technology in a commercial perspective, the Net Present Value based on the Capital Expenditure (CAPEX) and discounted cash flow projection from the WASP installation is used to determine an expected payback period. Fuel savings are estimated by running a Monte Carlo simulation over each month considering the varying weather conditions on outbound and return journeys, generating monthly values over a 1,000-year simulation to obtain a range of savings to be expected.

The fuel savings display significant fluctuations depending on month with average of over 50% in both January and December (see Figure 4). A consequence of using fuel-optimised routing, where the ship strays away from the shortest-distance path in search of advantageous weather conditions, is a potential increase in the total voyage time of each journey.

Given the length of each leg and allowing port operations, it is assumed that the vessel is on a regular schedule running 3.5 return journeys per month with most of the route in a designated ECA in the North Sea using 0.1% low-sulphur fuel. Alongside this, the carbon intensity of the vessel transport work is calculated for each case, expressed as the Energy Efficiency Operational Indicator (EEOI) for an individual voyage and an entire year, being tied to diverse Green Port incentives at both Rotterdam and Trondheim harbours.

Assessing the promise of wind-assist

The average fuel savings for the WASP concept vessel over two years of operation was 29.5%, corresponding to CO_2 savings of 3,330tonnes annually. Given current prices the potential monthly savings should come to between US$7,900 and US$13,000, with a payback period of 9.7 years, excluding other environmental incentives. When Green Port incentives at both harbours are included, this figure drops to 6.7 years.

However, both the IMO and the EU are in ongoing discussions leading towards a carbon intensity-based metric and mandated improvements in transport efficiency across the fleet. A form of carbon pricing, which IMarEST concludes could fall anywhere between US$100 and US$500/tonne, appears to be on the horizon for the shipping industry. The payback calculation for wind-assist devices would be completely upended should any such price come to pass.

Simple payback economics should soon be augmented by strong regulatory leverage, making a compelling business case for investing in WASP technologies. The 30% improvement in transport efficiency demonstrated here will help shield this vessel from becoming stranded on the banks by environmental obsolescence: conferring a measure of resilience against future environmental regulation.

Investment – not just in wind-assist, but in the ship integration – will pay back. It is time to embrace the promise of wind-assist. It's a compelling short-term intervention alongside the de-powering of fossil-fuelled engines, and going forward, will be an essential part of the power mix for the new zero-carbon fleet. *NA*

About the authors

Nico van der Kolk is an experienced engineer with a broad background in experimentation and numerical simulation. He holds a PhD on the sailing behavior of wind-assisted ships from TUDelft. Giovanni Bordogna holds a PhD on the Aerodynamics of Wind Assisted Ships from TUDelft, in the Netherlands. He is a goal-oriented engineer with a strong passion for green technology and entrepreneurship.

About the company

Blue Wasp is an engineering consultancy specialising in wind-assisted ship propulsion. With 10 years of research experience specific to the topic at TUDelft and core expertise in both aerodynamics and hydromechanics, the company is uniquely positioned to help realise the economic and environmental benefits that wind assist delivers.

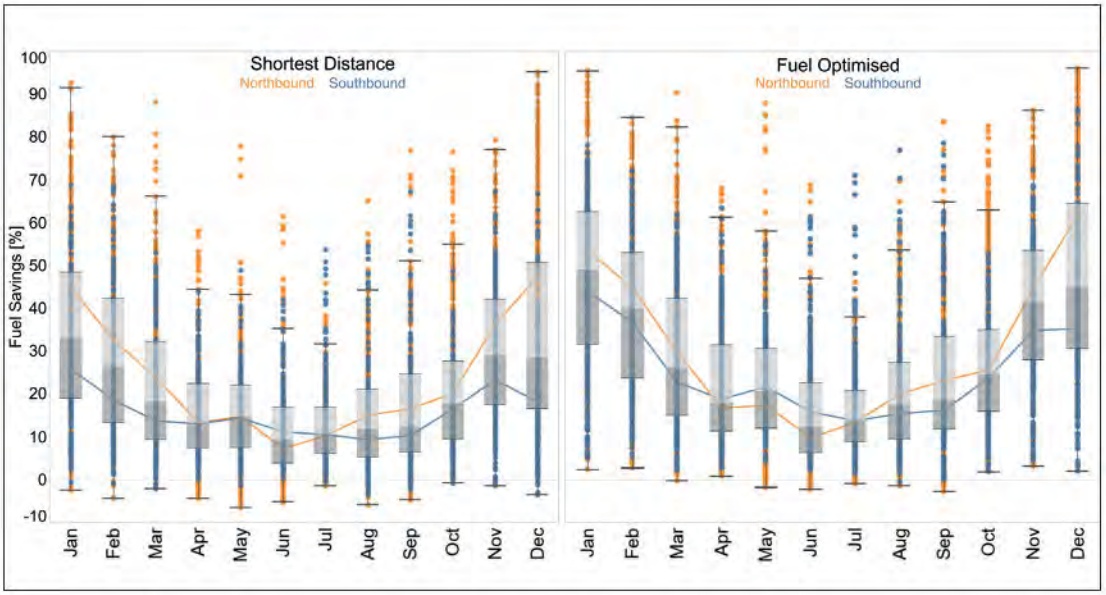


Figure 4. Monthly fuel savings of the WASP vessel operation between Trondheim and Rotterdam