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WIND PROPULSION OF SHIPS TO DECARBONIZE MARITIME TRANSPORT

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ABSTRACT

The International Maritime Organization and the European Commission are demanding increasingly significant decarbonization efforts from shipowners, and maritime freight should be integrated into the EU emissions trading system. Several technologies exist for sail propulsion: the Flettner rottor, rigid panels made of composite materials, sails and in particular the kite, innovative in this field. Studies show that 3700 to 10700 ships could be equipped with sail propulsion systems by 2030. The release of 3.5 to 7.5 million tonnes of CO_2 *could thus be avoided in 2030. In this article, the fundamentals of the ship propulsion by the wind are presented: a credible, efficient technological proposition available today to ensure the sustainability of transport.*

Keywords: wind, sail propulsion, technologies, emissions

1. INTRODUCTION

Developing clean, carbon-free maritime transport is one of the major challenges of this decade to respond to the 2015 Paris Agreement: contain global warming to +2°C and if possible +1.5°C compared to pre-industrial levels. A value proposition is capable of triggering a virtuous cycle: systematically using wind energy to propel ships. Sailing has been practiced for over 7,000 years. It relies on a fully renewable energy resource that is widely available on the planet. Previously using all kinds of sails woven from flexible materials, the 21st century navy is reinventing merchant sailing with new technologies and new materials which even better combine the laws of aerodynamics with those of hydrodynamics. These technologies can be deployed on the majority of existing ships, and easily find their place in the design of new ships.

However, innovation plans in the maritime transport sector, are almost exclusively focused on the search for the green fuel of tomorrow which will power the engines of the ships in a business-as-usual system. This "monoculture" of the internal combustion engine effectively rules out any possible consideration of an alternative energy source, such as wind propulsion. Within this article, the fundamentals of the ship propulsion by wind will be presented: a credible, efficient technological proposition available today to ensure the sustainability of transport.

2. ENVIRONMENTAL IMPACTS OF MARITIME TRANSPORT

The lower greenhouse gas emitting mode per unit transported, maritime transport is nevertheless seeing its climate bill increase due to the intensification of trade. The cost of this transport is extremely low thanks to the mass deployment, deployed using large ships powered until now by a low-cost and tax-exempt petroleum residue, heavy fuel oil.

Today (2020), 98.140 vessels of gross tonnage, greater than 100, travel the oceans. This represents an annual fuel consumption of nearly 235 million tonnes of combustibles. Fuel expenses represent 20 to 35% of total annual costs for a shipowner.

Also, the total impact of the maritime transport is increasing overall as a percentage of anthropogenic emissions. International and national maritime transport is the source of 919 million tonnes of CO_2 in 2018, an increase of 8.4% since 2012. All maritime transport (international, national and fishing) represents 1076 million tonnes or 2.89% of global emissions.

At European level, the maritime transport emissions in 2018 represent more than 138 million tonnes of CO_2, or more than 3.7% of total European Union emissions, and 15% of total maritime transport emissions. This represents 44 million tonnes of fuel (including 70% heavy fuel oil), or almost 7% of the European Union's total oil demand.

3. WIND PROPULSION METHODS IN THE 21ST CENTURY

Practiced since Antiquity, sailing was undoubtedly the most significant vector of development. At the same time, the propulsion of the ships by a heat engine appeared in the 19th century. Steam engines were initially powered by coal, before the invention of the Diesel internal combustion engine. The appearance of turbines will favor steam: the tonnage transported by steamships exceeded that of sailboats in 1880.

Finally, three factors combine to lead to the disappearance of the sailing ships. On the one hand, the opening of the Suez Canal in 1870 reduced the advantage of clippers on long-distance journeys - especially since access to the canal (Red Sea) was unfavorable for sailboats due to lack of wind. On the other hand, the increase in ship capacity requires more sailors on board to manage the larger sail areas, therefore a greater cost even though crews are difficult to recruit. Finally, after significant destruction during the First World War, the crisis of 1929 completed the disappearance of the -large sailing ships, of which only 70 units remain in the world today.

The transition to diesel in the fishing fleet took place rather after the Second World War. All that remains is almost only the pleasure fleet that appeared at the end of the 19th century, a practice which developed to the point of today representing a real nautical industry, certain developments of which are the source of technological innovations which inspire propelled vessels. with the wind of the 21st century.

Very diverse solutions are now being studied and prototyped to allow navigation to reconnect with wind propulsion, under performance conditions compatible with the current constraints of maritime transport. Some of these innovations date back to the 1920s.

One of the first modern solutions developed is that of the rotor, which uses the Magnus effect: rotating a metal cylinder on the deck of the ship generates lift. This solution was used in 1924 by Anton Flettner on the German schooner Buckau which, converted using two 15 m rotors, crossed the Atlantic. Another ship was used from 1926 to 1929 in the Mediterranean. These first experiments were not continued, because the very low price of oil did not justify investing in renewable energies. They were taken up much later, notably via the E-Ship 1 ship from the company ENERCON, which has been sailing since 2010.

In the 1980s, Commander Cousteau's team designed an aspirated profile called a "turbo sail" and installed it on a Moulin à Vent boat. The turbosail optimizes the flow of air through a suction system along the profile to create aerodynamic thrust. Le Moulin à Vent carried out the first crossings between Tangier and New York, between 1981 and 1983. CRAIN (La Rochelle) relaunched R&D around this principle of aspirated profile in 2015.

Competitive sailing and offshore racing also fuel innovation. Thus, it is the rigid articulated wing designed by the architectural firm VPLP which enabled the victory of the USA 17 trimaran (BMW Oracle Racing) during the 2010 America's Cup. This concept inspired the development of the thick profiles by the same naval architecture firm, to equip commercial ships, which then led to the creation in 2018 of the AYRO company dedicated to the design and manufacture of these wings. If boating gave birth to these flying wings called kites, aeronautics has played a big role in their adaptation to the merchant navy, thanks to its mastery of flight conditions and safety.

3.1. CLASSIFICATION ELEMENTS

There are five main families of technologies.

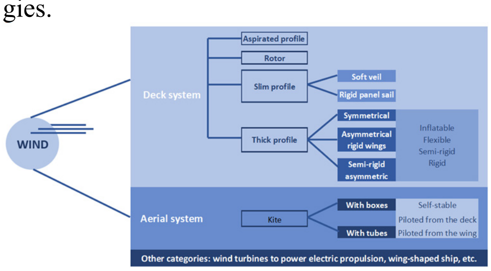

Fig.1. Classification of wind propulsion technologies

Four of them equip the ship on deck, that is to say on the deck, the kite being an exception. The kite has the advantage of not cluttering the deck, and of seeking stronger and more stable winds higher up. It functions optimally at downwind speeds.

The rotor and the aspirated profile, already mentioned, are very compact systems, but they need external energy to rotate, turn or suck in air. Their optimal performance is obtained for apparent wind ranges that are generally smaller than other systems.

Other deck technologies are similar to either sails or wings, with a thicker profile (seen in longitudinal section). Their aerodynamic properties vary depending on the thickness but also the camber or symmetry of the sail or wing. The thick profiles have good "aerodynamic finesse", i.e. high performance when it comes to going upwind.

The wings and sails also differ in their material and their rigidity. A flexible textile material is easier to lower or rig (reduction of sail) but wears out more quickly by exposure to ultraviolet rays and by faseying (sail beaten by the wind). Some textile membrane wings are made more robust thanks to inflation which stiffens them. Rigid systems rely on robustness and their ability to orient the wings optimally in relation to the wind.

Other characteristics can complete this categorization, such as the number of elements in the articulated wings, the type of articulation (slot, flap) etc.

Aspirated profile – the aspirated profile consists of a vertical cylindrical metal wing, equipped with a suction grille and a flap which optimize the lift of the system.

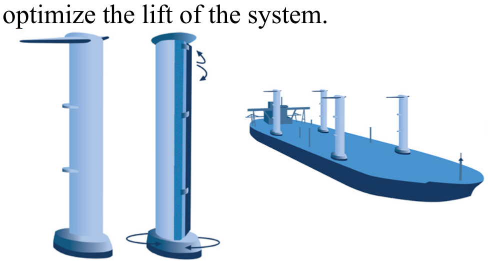

Fig.2. Integration of suction profiles on an oil tanker

Rotor - the rotor is a metal cylinder rotated by a motor. This rotation allows the cylinder to generate thrust by the Magnus effect. The rotors can be equipped with a tilting system to reduce their air draft.

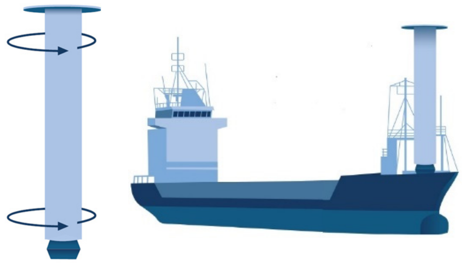

Fig.3. Integration of a rotor on a multipurpose cargo ship

Thin profiles - soft textile sails can be rigged in different ways. They are affable and ardorable. In some cases, the masts can be folded down to allow passage under bridges.

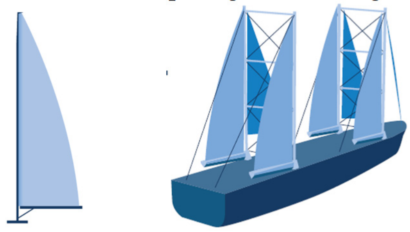

Fig.4. Integration of sails on a Ro-Ro ship

Thin profiles - the sail is made of movable fiberglass panels. It deforms under aerodynamic pressure without faseyer. It can be mounted on a balestron rig which is oriented independently of the windward angle of the ship to control the forces depending on the wind.

Fig.5. Integration of panel sails on a cruise ship

Thick profile - the symmetrical wings are made of textile, inflated and equipped with a telescopic mast, which can be retracted.

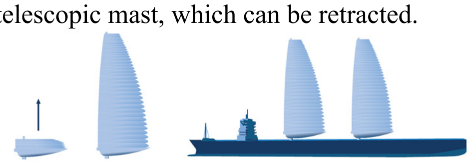

Fig.6. Integration of inflatable sails on a bulk carrier

Thick profile - the asymmetrical rigid wings are made of composite materials like a wind turbine blade. They can unfold in one direction or the other to invert and orient themselves optimally.

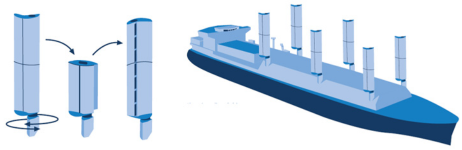

Fig.7. Integration of rigid wings on an LNG carrier

Thick profile - the semi-rigid asymmetric wings are made up of a classic sail equipped with flexible plates and an inflation system to avoid faseyement.

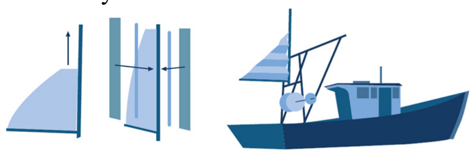

Fig.8. Thick profile, asymmetrical, semi-rigid wing on a fishing vessel

Thick profile - the multi-element wings feature a semi-rigid composite structure and a textile covering. The whole assembly is collapsible and arrisable.

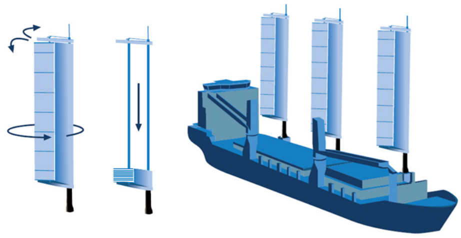

Fig.9. Integration of multi-element wings on one multi-purpose cargo ship

Kite - the kite is a wing which provides lift and traction for the vessel via one or more lines. The kite operates upwind in static flight (at the same speed as the ship) and downwind in dynamic flight where it describes figures of eight which increase its apparent wind and therefore its efficiency per unit area.

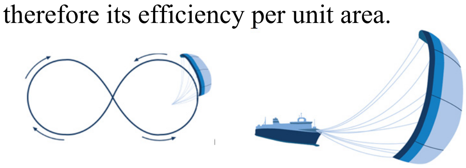

Fig.10. Example of kite integration on a Ro-Ro ship

The propulsive power provided by the wind propulsion system depends on:

- real wind speed
- the speed of the ship
- the angle that the wind makes with the ship
- the propulsion surface exposed to the wind
- the technology used.

The propulsive power reaches its maximum when the wind perceived by the ship (apparent wind) arrives within certain angle ranges, which are determined by the technology concerned. Generally, this maximum is encountered for apparent winds between 50° and 100° relative to the axis of the ship.

It should be noted that the propulsion power also depends on the surface area of the propulsion system exposed to the wind, which means that, to have high propulsion power, it is necessary to be able to install a large system.

Therefore, for each ship, a compromise to be found which must take into account:

- The planned navigation area and the type of navigation (oceanic, coastal, etc.);
- The size of the vessel and its expected commercial speed;
- Space available to install a wind propulsion system;
- Optimization of the vessel in terms of hull shapes and anti-drift.

This search for a compromise often requires several iterations, and makes it possible to establish the elements to arbitrate in favor of this or that wind propulsion system, and to determine the importance of the contribution of wind in the energy mix of the ship.

To illustrate the power of a system with classic flexible sails: a medium-sized cargo ship (11000 tonnes displacement) and between 130 m and 140 m in length requires approximately 1100 kW (hull effective) to be propelled at a speed of 11 knots. If it is equipped with a rig of 4000 m² of sails, the rig will deliver on an annual average an effective propulsive power of:

- 850 kW on a transatlantic route, or approximately 77% of the propulsion requirement.
- 550 kW on a major European coastal route, or around 50% of the propulsion requirement.

The power developed thanks to wind propulsion can thus be sufficient to propel the majority of cargo ships.

4. FEEDBACK FROM EXISTING PROJECTS

Oil tankers, ro-ro, bulk carriers, ferries, cargo ships have been equipped thanks to retrofit operations since 2018, with the exception of Enercon's E-Ship 1 equipped since 2010. The technologies implemented are rotors, suction profiles and thick profiles (rigid wings). These large ships range in length from 80 to 340 meters. Half of them have a gross tonnage ranging from 4.000 to 10.000, and the other half, from 64.000 to 325.000 (ore carrier equipped for the VALE company), which represents in total a little more than 1 billion tons of deadweight. This capacity is expected to double by 2025.

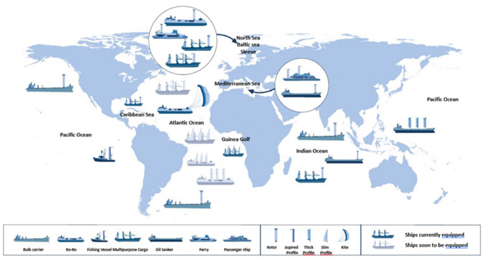

Fig.11. Fifteen cargo ships equipped with wind propulsion in the world

Around twenty other smaller vessels are also equipped with wind propulsion, and the fishing sector is starting to take an interest in it.

The fishing sector is the subject of new installations – a test is underway on the Oceania gillnetter of around ten meters in Quiberon, with a thick profile used to stabilize the vessel and improve its seaworthiness when running as in fishing, thus generating fuel savings – or the installation in June 2021 of a thick, rigid profile, 12 m high on a fishing vessel, the Balueiro Segundo, 41m long and 593t, a system approved by Bureau Véritas.

It is from the end of 2022 - 2023 that newly built and specifically designed for wind propulsion will be launched. But already, the testimonies of the first navigations using a rotor are interesting. E-Ship 1 has traveled more than 1.1 million nautical miles since entering service, equipped with auxiliary wind propulsion. It transports components all over the world. Wind propulsion allows it to save 20% fuel per year on average, or 920 t of fuel per year (for an average speed of 13 knots).

The Maersk Pelican equipped in 2018 served as a performance test platform for 1 year and shows a saving of 8.2% in fuel consumption for the year, or an equivalent of 1400t of CO_2. These performances have been validated by the independent company Lloyd's Registers.

These first results on prototypes are encouraging for future projects, which aim for different savings depending on the scenario (retrofit, new ship, main or auxiliary propulsion) and at a level higher than these first performances, thanks to different technologies.

Very regularly, new concepts of wind-powered ships are proposed in each segment of maritime transport, such as the bulk carrier of the CHEK project supported by the European Union, the container ship MELTEM, the tanker equipped with the Wind Challenger, regularly acquiring approvals principle of classification societies, such as the Trade Wings 2500 container ship (with a capacity of 2500 TEU) equipped with thick profiles.

6. CONCLUDING REMARKS

The technologies immediately developed and completely convert wind energy into propulsive energy without loss of intermediate efficiency. This clean energy makes it possible to avoid any polluting emissions on the propulsion part provided, and therefore to limit the overall polluting emissions linked to the propulsion of the ship.

Wind energy does not need to be stored on board. The propulsion system, however, occupies a space on the deck, more or less important depending on the type of technology chosen.

The use of wind energy is silent, releases no pollutants and does not add any particular major risk, for example explosion or fire.

If the wind is widely available and predictable, it is also variable. This is why, depending on the targeted navigation speed and the route envisaged, it can be used as a main source of propulsion or as a complement - thanks to a hybridization of propulsions.

Furthermore, one of the great advantages of most of these systems is their possibility of installation and uninstallation without major structural changes to the hull, and without a long period of downtime, or even without drying out. This means that a large part of the existing fleet can be quickly retrofitted.

Wind-assisted propulsion is one of the few technologies potentially offering double-digit fuel savings today.

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