Wind Propulsion for Ships

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The idea of turning wind into a propulsive force to assist the propulsion of ships has sailed a long way from the 5 masted clippers in the middle of the 19^{th} century to the early 21th century unmasted, automated, remote controlled kites pulled ships. In the meantime ambitious projects were to appear, disappear and reappear. For example, the flettner rotor technology invented by Anton Flettner based on the Magnus Effect was used on the german ship Buckau in 1923, with the collaboration of the pioneer of modern fluid dynamics Ludwig Prandtl

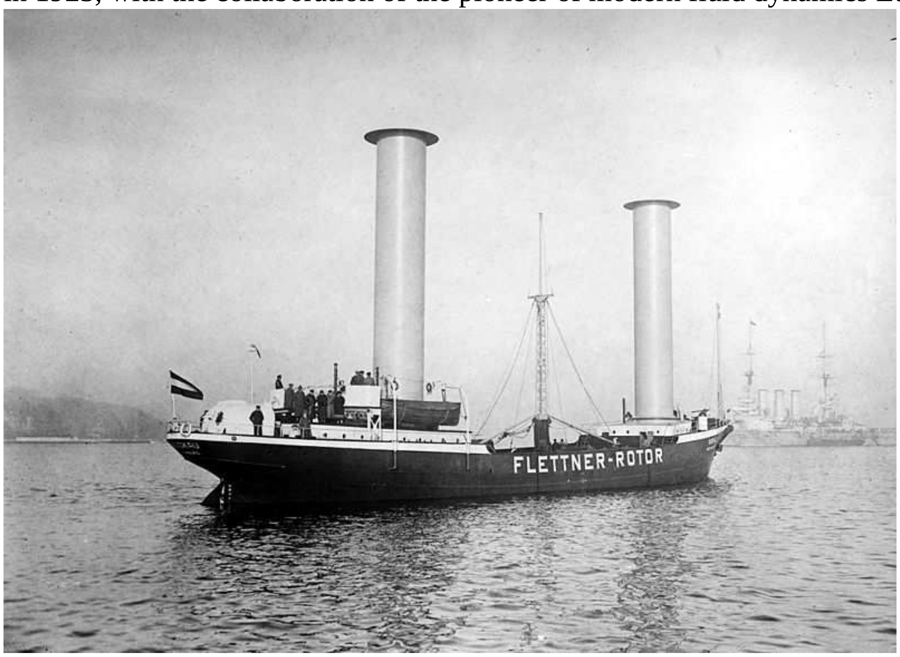


Figure: Ship using Flettner Rotors in 1923. Source Wikimedia.org

Less efficient than steam engines, the ship was dismantled. In the 1980's the French explorer Jacques Yves Cousteau had the Alcyone built with two flettner rotors, called then "turbosails"


Figure: Alcyone anchored in the US. Source www.starthrower.org

Most recently in august 2008, the E Ship 1 was christened in Germany, with 4 flettner rotors mounted on board to assist the propulsion of a vessel to be used to install offshore wind turbines.

Figure: Artist impression of the E ship from Enercon. Source gcaptain.com

These waves of interest for wind propulsion for ships are closely following the price of oil. Large research efforts were made in the 1980's when the oil prices went very high. Two conferences were held in the UK, presenting aerodynamic assessment of different wind technologies (Wellicome 1984), economic models of commercial sailing ships (Smulders 1985) and large hope for these technology to be soon wide spread in the shipping industry. However, the fuel prices dropped again in the 90's and the conservative, short term benefit oriented shipping industry moved on against the wind.

Fuel saving and reduction of emissions to air for the shipping industry

It is a very different context nowadays. The fuel price reached new record prices in 2008, the industry is still conservative and short term oriented but now faced with an unprecedented media and public focus on its environmental impact. The shipping industry carries 90% of the world wide freight, contributing to approximately 4% of the global CO2 emissions. The organisers of the next Kyoto conference to be held in Copenhagen in November 2009 announced their will to include the shipping industry in the CO2 emission trading schemes. The International Maritime Organisation has been urged by the European Commission to take action to reduce its emissions to air. CO2 efficient in terms of g CO2/ ton-mile[1], the shipping industry is much less efficient in Sulphur and Nitrogen oxides (SOx, NOx), as the largest part of Sulphur and Nitrogen contamination in coastal areas is not due to land based industry but to shipping.

The fuel burned by the shipping industry is a low residue of oil called heavy fuel oil, releasing 3 tons of CO2 in the air for 1 ton of fuel burned, and a Sulphur content limited to 1% of the fuel mass. While the CO2 pollution of a ship is directly linked to the amount of fuel burned, the Nitrogen pollution depend on the fuel quality and how it is burned (temperature and duration of the combustion in the engine).

All in all, the shipping industry is now forced to improve its public image and comply with the emission to air quotas being set in place locally (in Scandinavia and on coastal areas in North America for example) and soon globally (CO2 emission trading scheme). The most efficient way for that is to reduce fuel consumption; it is for the shipping industry a great opportunity to reduce its running cost and avoid paying too much taxes on air pollution!

Available wind technologies and technologies in development

There are currently in early 2009 few commercially available technologies on the market: the autonomous kites from the german company Skysails[2], which are being used on on two small multi purpose ships, and the rigid sail covered with solar panels from the Australian company SolarSailor[3], fitted on a 100 passengers ferry for transport in the bay of Sidney.

However other technologies are being developed to enter the market.

The wingsail technology from Shadotec (http://www.shadotec.com/commercial.html) in United Kingdom has been fitted to a small multi purpose cargo ship in 1986. A recent study by the Norwegian shipowner Wilhelmsen to fit it on a seismic vessel is showing promising results.

The flettner rotors are back on the E Ship 1 as mentioned in the introduction. More research is being carried out by the Greenwave project (http://www.greenwave.org.uk/GreenwaveBrochure.pdf) and there is no doubt the flettner rotors are going to be seen very soon on other ships.

Potential of these technologies: Risk, Cost and Benefit analysis.

For a ship operator to decide to step into wind propulsion there is more to do than only reading articles on internet. Such an investment represents a double risk to be examined with care;

Operational risk: ship strength (risk to damage the ship structure), stabiltity (risk to capsize), schedule integrity (risk to arrive late at destination, miss the unloading slot at the terminal, pay a fee for late delivery), crew safety (physical harm), compliance with existing legislation

[1] quantity of CO2 released to ship one ton of freight on the distance of 1 nautical mile, 1852 m

[2] see full description in Sysails website: www.skysails.com

[3] www.solarsailor.com

in several areas (port and flag authorities, crew labour standarts, navigation regulation: risk of being denied the right to operate the ship).
Financial risk: cost of purchase (CAPEX) and maintenance (OPEX), reliability of revenue, length of the return on investment.

The operational risk can be analysed by risk methods of HAZOP type: Hazard and Operability Study, which can be described as the succession of the following actions:

1. List all the components and sub components of a system
2. Find all the possible failure modes of each component
3. Find the causes of each failure
4. List the safeguards in place that could prevent a failure to happen
5. Rank the risk of each failure
6. List the possible risk reducing measures

The risk is ranked as followed: low risk is negligible, medium risk is acceptable and high risk is not acceptable ("Show stopper"). The goal of a risk reducing measure is to shift a high or medium risk into a low risk. A system is then seen as safe when all the listed risks are ranked as low.

Applied to the Kite propulsion system, the HAZOP method gives the following results:

- Main Risk: kite or cable in the wind assisted ship propeller or the propeller of a ship passing nearby
- Main Failure Mode: kite falling in water
- Main Cause: loss of control of kite
- Safeguards in Place: redundancy (back up) of any control system. If the system is to fail, it should fail in a safe mode:
- Missing safeguard: electronic nautical charts are now compulsory on board ships. An attention zone around a ship flying a kite would help the other ships navigating in the same area to keep their distances and avoid a collision with the kite. This concept is inspired from the aviation industry (see description of 3D Attention Zones http://research.dnv.com/hci/3daz.html and their application to kites[4]).

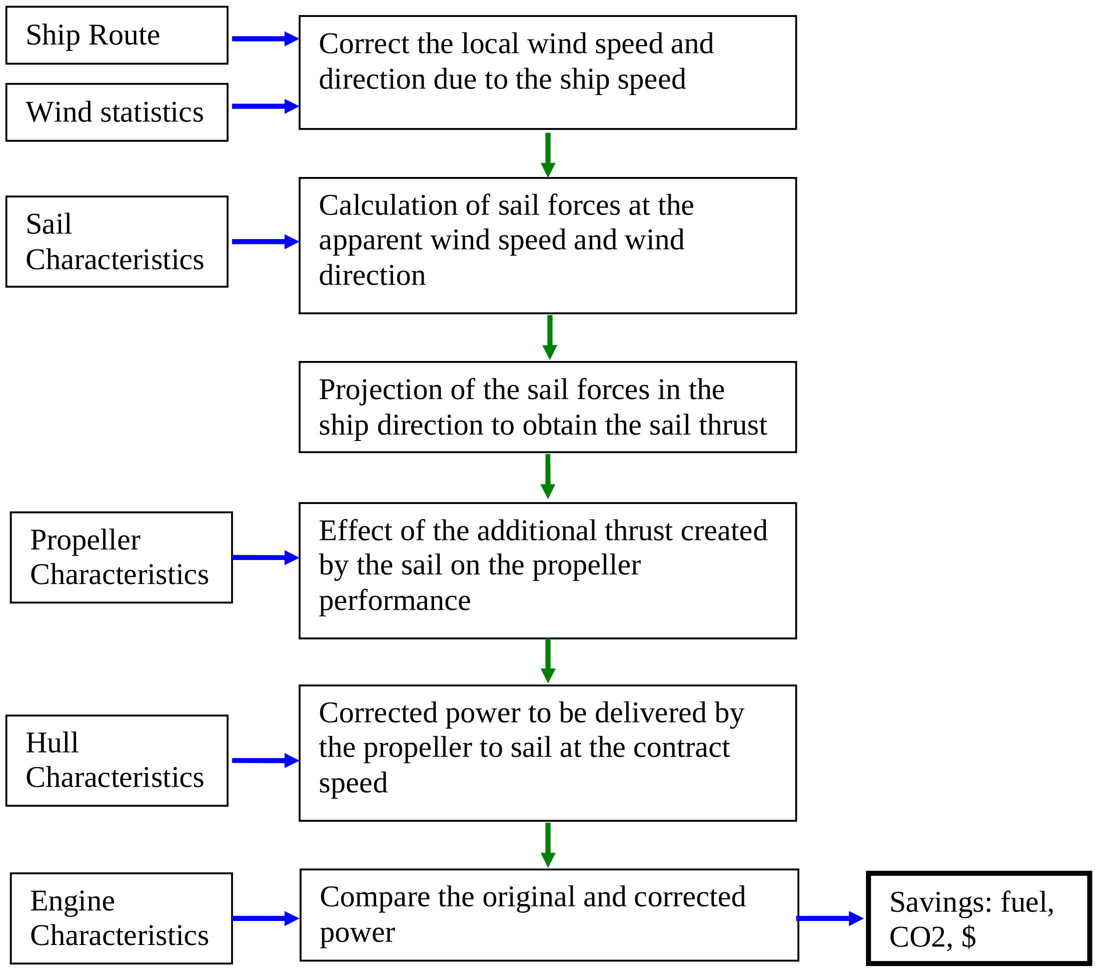
Simulations of a ship powered with the assistance of a sail are carried out to assess the financial risk. The different input parameters of the simulations are:

- The route (also called trade) the ship is sailing on: ship speed and direction (heading). The speed is usually agreed on before the trip on a contract, also called contract speed.
- The wind conditions met on this route (speed and direction) possibly associated with a probability of occurrence. The wind speed and direction seen on the ship will be different because the ship has already its own speed. A ship sailing at 10 knots straight into a wind blowing at 10 knots will feel a wind of 20 knots.
- The ship hull, propeller and engine characteristics to express how much energy (power in kW) is needed to move the hull at a certain speed, how this amount of energy can be transmitted by the propeller to the water, and what is the fuel consumption of the engine when delivering the required amount of energy.
- The characteristics of the sail used to assist the propulsion of the vessel, in order to calculate its performance in any wind condition. The performance can also be measured for example in a wind tunnel and given in the form of a table giving the thrust created by the sail as a function of the wind speed and direction.

[4] http://research.dnv.com/hci/3dAZ/ShipKites_TheMotorship2007.pdf

The output of the simulations is how much power can be saved by using the assistance of a sail and how does this translate to fuel, CO2 and dollars savings.

The architecture of the simulation can be modelled as follows:



Different mathematical models have been published to predict the aerodynamic performance of a kite with various degrees of accuracy. The kite can be considered as a type of wing plane with a lift and drag properties. The canopy shape of the kite and the presence of lines (bridles) to control the kite make the lift and drag properties to vary on the trajectory of the kite when it is manoeuvred. Experiments in wind tunnel are required to measure the drag properties of the kite, whereas the lift can be calculated using computational fluid dynamics (CFD) programs. Advanced research on kite trajectories to maximize the driving force the kite can deliver to the ship is being carried out (Williams et al 2008, Houska 2007) using control theory.

The Effect of the additional thrust created by the sail on the propeller performance is fundamental for the simulation. When the assistance of a sail is used, the operation of the propeller is shifted outside its design point and the efficiency of the propeller is modified, as well as the power to be delivered by the engine to move the ship at the contract speed. It would be too bad to end up with an increased demand of power when using a sail! Hopefully, the sail has usually a beneficial effect on the propeller efficiency, as a reduced load (less thrust to produce) on the propeller results in a reduced torque, which is equivalent to a reduced power demand.

Pilot Projects

Two multi cargo ships are flying autonomous kites from Skysails: M/S Beluga SkySails and M/S Michael A. They are used as pilot projects to calibrate the automatic control of the kite, and collect full scale measurement of kite forces to improve the kite trajectories. The first ship is sailing across the Atlantic, investigating new routes in the Atlantic north to find more wind. The other one is sailing along the west European coast and in the Mediterranean Sea. A computer on the ship bridge is analyzing the weather conditions and gives advice whether using the kite or not, and for how long it is safe to fly it. The kite has no rigid parts and is stored in a box in the foredeck, folded like and accordion. It is lifted by a telescopic mast and filled by the wind until it gets its flying, solid shape. It is then slowly released by an electronic winch that constantly controls the tension of the cable linking the kite to the ship. The kite starts its manoeuvres when high in the sky, at 200 to 300m altitude and can reach up to 100km/h. The whole launching operation is automatic and takes between 10 and 20 minutes. The recovery of the kite is exactly the same procedure in reverse order. The main problem experienced is the air turbulence at the fore deck: the air stream over the sea surface suddenly meets the fore part of the ship hull and crawls over this obstacle in a non-uniform flow, creating air turbulences that make the kite difficult to launch even if the wind conditions are favourable. Skysails will publish full scale measurements in 2009 and equip more ships with bigger kites. The kites currently flown have a surface of 80 to 160m2, and the plan is to increase to 320 and 640m2. Their design is inspired from space shuttle parachutes. The larger surface the more towing force, but the more difficult to launch (it becomes heavy!) and to control (it becomes unstable!) so the research effort is lead towards optimised trajectories, aerodynamic efficiency (lift and drag properties), and material strength: the kite fabric is made of Polyester very sensitive to UV rays. The kites need to be replaced every 6 to 12 months depending on their utilization.

Future Projects showing the way ahead

Kites can also be used to produce electricity, harvesting the very high altitude winds that conventional wind turbines cannot reach. A kite is attached to a cable reeled around a drum. When the kite flies up and reels the cable out, the drum is rotating and produces electricity like a bicycle dynamo. A part of this electricity is used to rotate the drum on the opposite direction to reel in the cable in and start again. Smart trajectories are used to produce as much lift as possible on the reeling out step and as less as possible drag on the reeling in step. The electricity produced can be transferred for a example to an electric ship engine. As the kite is flying in three directions, the ship can sail head into the wind without any problem.
See http://www.ockels.nl/ for more info.

Wind technologies are used on ship as assistance to the main engine because the power produced by the wind alone is not enough to move the ship at the contract speed. Combining wind and other clean energy sources could improve the solution. The Australian company Solar Sailor and the chinese shipping company COSCO are designing a tanker that uses rigid sails covered with solar panels, in order to harvest both wind and solar energy. The sails are made of very light composite materials and produce mechanical thrust when the wind is favourable. The solar panels produce electricity that is stored in batteries when the sun is favourable. The electricity can be used for the on board needs (electronics, ventilation, cooling, boilers to warm up the fuel, crew accommodation) and replace the need of auxiliary engines. It can also be directly used for the main propulsion if the engine is electric. Small ferries using this technology are sailing already in Sydney harbour and soon in other cities. They use natural gas as fuel for the main propulsion to complete the wind and solar power, making their emission levels very low.

Orcelle is a concept ship designed by the norwegian ship owner Wilhelmsen. It combines wind, solar and wave energy, has no ballast tanks (hence reducing the waste and avoiding the need to treat the ballast water[5]., meant to be a zero emissions ship. It is only a concept and the way ahead is quite long but it shows the feasibility of the concept.
See http://www.2wglobal.com/www/environment/orcelleGreenFlagship/index.jsp

Future research: sailing robots
Recent progress has been made by a French researcher from the Mads Clausen Institute of Sønderborg university in Denmark. Associate professor Jerome Jouffroy is applying the knowledge and experience of the automated industry into modern sailing. The trajectories of the movement of the robots used in the factories are now very efficient, because the physical possibilities of the robots (degree of freedom, speed of reaction, etc) and the constraints of the environment are integrated in the loop planning their trajectory. Why not designing sailing ships which can automatically sail from a point A to a point B taking into account the capabilities of the ship and the sails and the constraints from the wind and the waves? Jouffroy and his team are designing algorithm which will be used on sand sailing vehicles, small dinghies and yachts, being able to "read" the wind and tack without any human pilot. Modern weather routing of larger ship could benefit from this robotic approach.
More information on http://www.hca-sci-tech.dk/default.asp?id=1&more=102

Conclusion
Wind technology for ships is again in a promising development period. The economical and societal context makes it favourable. More actors in the logistic chains are demanding cleaner transport solutions: Toyota sells hybrid electric cars to demanding customers and has demanding requirements when these fuel effective cares are to be shipped all over the world. The part of fresh, perishable fruits shipped across the world and the rest of the freight could be shipped with much slower ships. It is even said to be beneficial for some, the wine for instance, being shipped on sail boats from Bordeaux to Ireland and North America by the CTMV: Compagnie de Transport Maritime a la Voile, http://www.ctmv.eu/

Now that a few technologies are available and more coming, the question is for the ship operators to find out which technology suits best a different type of ship and trade.

"The present situation is as if the steam engine, the petrol engine, the diesel engine, the gas turbine and the electric motor had been invented simultaneously, and we were faced with the proponents of each urging the merits of their favoured system for all applications [...]. No doubt someone who knew nothing about any of these power sources and had never seen a washing machine might be delighted in the first instance on being sold one driven through the wall by a diesel in an outhouse, especially if it was explained to him how great had been the success of the diesel in other fields. But he would hardly retain his pleasure if the following day along came a man offering one powered by a self-contained electric motor."

[5] : ballast water treatment is a huge challenge for the shipping industry. Pumping in water at one place and pumping it out in another place of the planet can release exotic species that can contaminate coastal areas, not to mention the exotic species growing inside the ship water tanks. Ballast water treatment is now regulated by an IMO convention and many technologies are available on the market.

This quote is from Captain C Nance opening the International Symposium on Windship Technology I n1985. With a closer collaboration between academic research, propulsion manufacturers and ship operators, the situation will hopefully evolve quickly in a positive direction.

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