WIND-AIDED PROPULSION IN THE FORM OF ROTOR SAILS

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Abstract: Ships were indeed one of the greatest applications of mankind's scientific knowledge. As time passed by, their strategic importance grew and today these ships have become lifelines of World trade. Since their invention, water transportation became irreplaceable and countries allotted huge amounts of its available energy resources to keep them functioning. We have used several energy resources to power these mega-machines. It all began with wind sails, but with the advent of fossil fuels, ships began using pollution-emitting oils as its fuel. It was a smooth ride until the world realized that we are running out of oil supplies and the pollution caused due to it in the past decades is taking a toll on the environmental balance. As threat to our planet increased, the quest for cleaner fuels began. Many of the environment friendly options were not really "economy-friendly", so their implementation was avoided. Now ship-makers are going back in time and once again analyzing the possibilities to power the ships using winds. Once such technology that could enable wind-aided propulsion could be of ROTOR SAILS or the FLETTNER SAILS. This paper explains the working principle of rotor sails (the magnus effect), its possible application on the existing as well as new ships and also discusses its contribution in cutting annual Carbon emissions caused by shipping industry.

Keywords- wind, renewable, Magnus effect, rotor, alternative fuel.

1. Introduction

Ships are world's most efficient transportation agents today, but are also acting as massive contributors to the air-borne emissions posing threatening implications such as global climate change, ocean warming, sea-level rise and also acidification of the seas. The global community now has to think of a comprehensive solution that helps retain profitability of ships and also strides in the environment-friendly direction. Initializing a change towards avoiding more pollution is to opt for Hybrid applications, or using two or more technologies for power-generation. It can be a combination of a fossil-fuel and an alternative renewable source. One such alternative, a greener solution, which can help in cutting down a ship's carbon emission is of the Rotor sails. The origin of shipping came from wind-assisted propulsion, albeit at lower scale before it was taken over by the fossil fuels, beginning with coal and then oil-based technologies such as Marine Diesel oil (MDO) or Heavy Fuel Oil (HFO) which are currently exercising their monopoly over the ships. The rotor sail's technology was previously proposed in early 20th century by a German engineer, Anton Flettner. Flettner described it as "Blue-Coal". But it was the time when the shipping industry hadn't gained momentum, fuel prices were extremely low and ship-makers absolutely had no environmental concerns. So, this technology was never taken into consideration. But its need is felt massively in today's time, with oceans carrying 90% of the total transported goods. The effects of its environmental damage are now becoming evident as the Sulphur and soot emitting fuels are giving their major contribution to global threats. The industry now feels obliged to incorporate ways to reduce the pollution.

2. Magnus Effect

The working of Rotor sails is governed by a scientific phenomenon called the Magnus Effect. It was discovered by a German physicist Heinrich Gustav Magnus.

In this effect, whenever a cylindrical/spherical spinning object is bought in contact with relative motion of fluid it produces a sidewise force. Consider a ball spinning amongst the air flow-

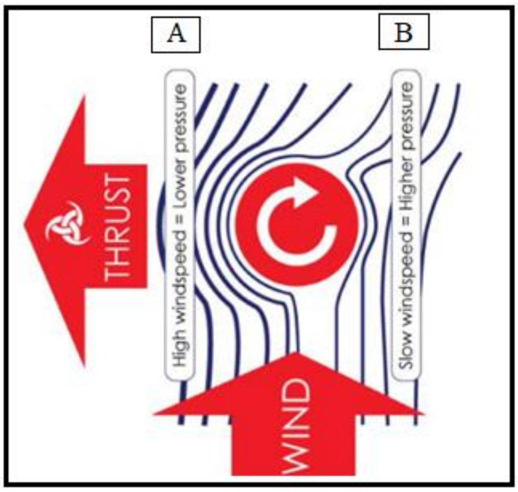

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Figure 1-Explaining Magnus Effect

If we focus on PART A particularly, this half of the ball is spinning with the direction of wind flow. Thus, velocity of the air flow increases and the pressure in this area decreases. Now if we see PART B, this half of the ball is opposing the motion of airflow. Thus, the velocity of air flow is retarded due to opposition imposed by the ball and pressure in this area increases. It is an extended application of the Bernoulli's principle, where velocity increases when pressure decreases and vice versa. We see that a pressure difference is generated. So, the ball experiences a force from the higher-pressure side (B) to the lower-pressure side (A). Another approach to it suggests that, in PART A, due to the frictional surface of the ball the air is dragged in the downward direction. In PART B, due to the opposition faced by the air, it is not deflected upwards. So, if we consider the net impact on the airflow due to its interaction with the ball it is clear that the airflow experiences a net downward deflection, i.e. the ball exerts a net downward force on the airflow. Now, as per the Newton's Third Law of motion- every action has an equal and opposite reaction. So, in the form of a Reaction force, the airflow exerts an upward force on the ball, which is termed as the Magnus force. In practical scenarios, the net results of this air-ball interaction are-

- A Lift force- "Magnus Force" generated in the direction perpendicular to the wind flow.
- A Drag force- Frictional force opposing the relative motion between ball and the wind, generated in a direction opposite to that of the wind flow.

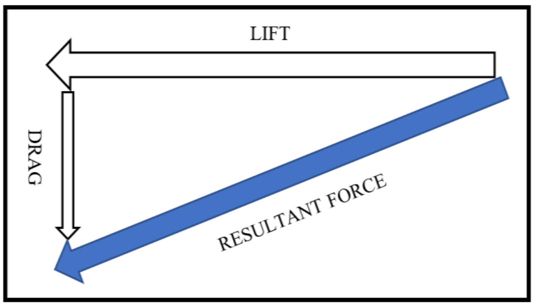

Figure 2-Direction of Resultant Force

The mathematical computation of lift force is done in the following way-

$$\text{Lift} = \rho\ A\ V^2\ C_L$$

Where,
ρ= Density of air
A= Surface area of rotor
V^2 = apparent velocity (vector addition of wind speed and ship's speed
C_L= coefficient of lift.

2.1 Working And Installation

The Rotor Sail installed on the ships will also use this principle to harness the wind energy and generate supplemental thrust to propel the ship. It is a relatively simpler technology to extract energy from renewable sources in terms of construction and operation. Rotor Sails are tall cylinders (range of 18-30m) with an approximate diameter of 5m rotating continuously at an expense of low voltage electrical power supply given to each sail Height of the sail is generally taken from the weather deck to the tallest mast of the ship to avoid any increment in the air draft. It is constituted by a cylindrical-shape, it implies we don't have to adjust the angle of attack, or the stall angle every time the wind changes its direction even slightly to maximize the output. The sails have a disc fitted on the top which serves dual purpose. First one being, maintaining the pressure difference generated by the wind flow. Secondly, it is known that a part of induced drag is due to formation of permanent tip vortex, a similar phenomenon which occurs in the wings of an air-craft. This drag is reduced by a higher aspect ratio (ratio of length of disc to its chord) wings or tip fins. This was the reason Flettner installed discs over the sails.

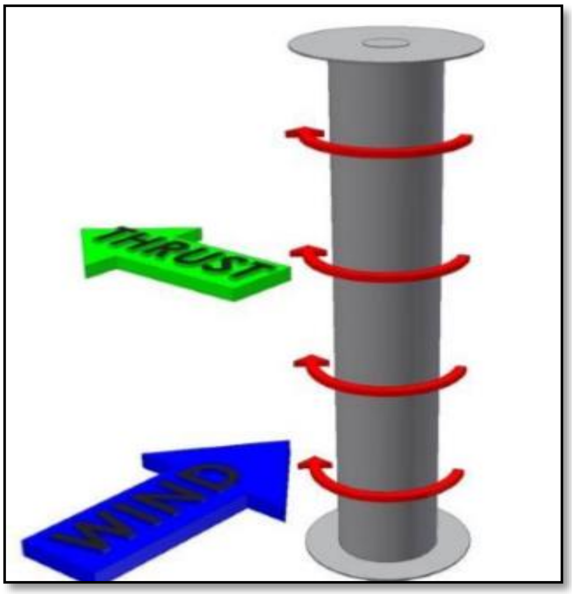

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Figure 3-Working of a Rotor Sail

Number of sails required by a vessel depends on various factors, like speed and size of the ship, its working conditions, etc. In favorable wind conditions, it will generate a forward thrust and allow the main engine to throttle back, resulting in lesser consumption of fuel. Some technological advances have been made in this simple technology. Now the Rotor sails are also equipped with an automatic control system. The sails can be operated from the bridge and the crew just has to initiate the power supply. It will sense when the wind speed is sufficient to produce fuel savings and the sails will automatically begin their operation. No extra crew or attention is required. It is a technology that can be constructed in new ships, but can also be retrofitted in existing ships which satisfy certain criteria. Its installation is possible on the vessels having free-deck space. The deck shouldn't have any considerably large superstructure which will obstruct the air-flow through the sail. The deck should also have a strong mounting point on which the large cylinders can be mounted. The mounting sites require a careful analysis to make sure that the sail placed in that location will generate thrust in such a way that the force will be transferred to the ship structure without disturbing its other operations. First option for suitable mounting sites is usually deck reinforcements for cranes or capstan. It is made sure that the rotors are definitely not mounted directly above the bulkheads which can cause extra stiffening. It can be proven efficient for tankers, Ro-Ro vessels, Gen. Cargo, Bulk carriers as well as cruises and ferries. It is indeed an old technology, but it has been improved with some fundamental changes. The rotor cylinder is constructed using modern materials like Carbon and Glass Fibers that cut the weight by a factor of 3, making it light-weight and more efficient. The two most commonly used materials are GFRC and CFRP. GFRC or Glass Fiber Reinforced Concrete is an amalgamation of Portland cement, aggregates, acrylic, copolymer and Glass fiber reinforcement. Appreciated qualities of GFRC include high tensile strength compared to any concrete counterpart, lightweight, durability and ease of molding it in desired shapes. The other one is Carbon Fiber Reinforced Polymer Composites, CFRP. It contains carbon fibers for strength and a binding polymer like Epoxy to keep the fiber together, maintaining its light weight nature. In most sails, CFRP is sandwiched between GFRC to get a light and strong structure. For the technology to benefit the propulsion, it should encounter favorable wind conditions.

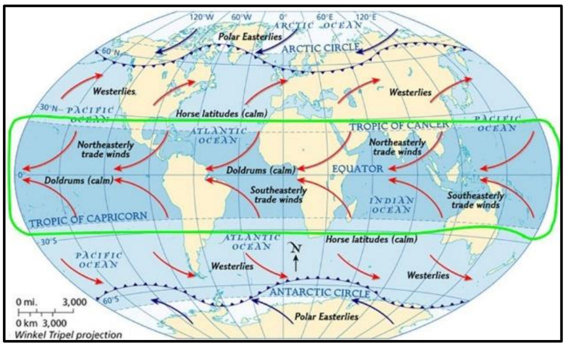

Figure 4- Wind Zones of the Globe

The wind should be flowing at least with a speed of 18 km/hr. (approximately 10 knots) and it should be flowing across the bow at an angle of at least 20^0.

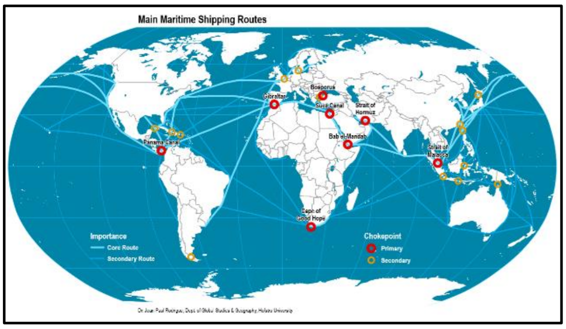

Figure 5- Most Frequent Shipping Routes

Ships are likely to encounter such wind conditions in the north Pacific and northern Atlantic shipping routes. So, if we judiciously coordinate with the wind cycle of the nature, we can harness the benefits of wind energy. In a storm-like scenario, where the wind speed causes excess heeling of the ship in the transverse direction, the presence of rotor sail can prove to be beneficial to counter the heeling force caused by the wind. As the wind speed increases, the drag force which is produced on the rotor surface also increases proportionally which acts in the direction opposite to the direction of the wind flow and hence reducing the net transverse force which is responsible for excess heeling. So, the ship+rotor system can be termed as a virtually "storm-proof" system.

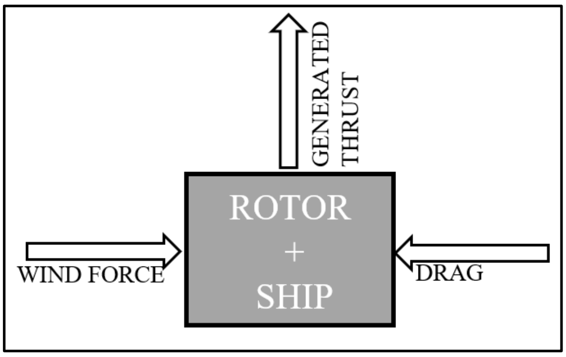

Figure 5- Ship-Rotor System

2.2 Testing The Technology

A Finnish company, registered in the name of NORSEPOWER, is now heading on to industrialize Rotor sails. To further verify its capabilities, it installed Rotor Sails on 3 commercial vessels of different types which includes-

1. Bore's Estraden (It was fitted with one more rotor sail) a 9700 dwt Ro-Ro carrier.
2. Viking Line Viking Grace, an LNG fueled cruise ferry.
3. Maersk Pelican, a 109,647 dwt Product Tanker.

The most interesting collaboration is the Norsepower- Maersk for the tanker Pelican. The tanker was fitted with the largest Rotor sail ever made, 30m tall and 5m in diameter, and was installed on the port of Rotterdam. It aimed cutting down fuel consumption by 10%. The tanker's performance was analyzed between a 12-month period, from September 2018 to September 2019. To generate an impartial data about its efficiency, a team from the Lloyd's Register (LR) is been appointed to scrutinize its performance aspects. The vessel delivered expected results, saving 8.2% of overall fuel consumption under normal wind conditions. Estimations show that this has avoided emission of 1400 tons of Carbon Dioxide. The Rotor sail added one more feather in its cap in February 2019 when it received first-ever type approval design certificate granted to an auxiliary wind propulsion system onboard a commercial ship by the classification society DNV GL after it assessed rotor sails functioning on Pelican. This signifies that any ship having Rotor sails is technically capable of safely navigating all operational and environmental situations.

3. Conclusion

Today shipping finds itself in turmoil while balancing between maintenance of its economic efficiency and the share of pollution that it has been creating. The job in hand is to bring up solutions which will maintain the "low-cost" identity of shipping and also reduce the environmental torture caused by maritime industry. Rotor sails can be a technology contributing towards cutting down fuel consumption by a fraction. All it is going to require is the willingness of this community to give environmental protection priority status.

Author's Biography

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