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# Flettner Rotor for Ship Propulsion: Progress and Current Status

Akshay Lele and K.V.S.Rao
Department of Renewable Energy, Rajasthan Technical University, Kota, India.

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**ABSTRACT**

Shipping covers 90% of goods transport globally. According to current estimates presented in Third IMO GHG Study 2014, international shipping emitted 796 million tones of $CO_2$ in 2012, which is about 2.2% of the total global $CO_2$ emission. One of the methods of reducing $CO_2$ is by applying wind energy devices such as Flettner rotor for ship propulsion. Ships fitted with Flettner rotors are tested and simulated over various ship routes claiming a fuel saving up to 30% for average ship speed. In this paper the progress of Flettner rotor application exclusively for ship propulsion is reviewed and summarized.



## Introduction

Freight transport is the physical process of transporting commodities and merchandise goods and cargo. Global trade is fully based on shipping industry as it covers approximately 90% of the tonnage of all traded goods, as per the International Chamber of Shipping [1]. According to the United Nations Conference on Trade and Development (UNCTAD) the global shipping tonnage load has increased by 3.05% compounded annually from 2.6 billion tonnes in 1970 to 9.5 billion tonnes in 2013. According to current estimates presented in Third IMO GHG Study 2014, international shipping emitted 796 million tonnes of $CO_2$ in 2012, which accounts for about 2.2% of the total emission volume for the same year. Also by domestic and other water transports there is some emission. By 2050 this will increase further more by anything between 50% and 250%, depending on future economic growth and energy developments [2]. To reduce this much of carbon emission due to shipping, ship designers should include sustainable resources for efficient propulsion. Renewable energy sources like solar, wind, fuel cells, etc. can be a better option for this purpose. Amongst them wind energy is most abundant in shipping routes worldwide. So it is used as primary power source for earliest propulsion system in the form of sails. As the size of ship got increased and with the availability of newer fuels, new propulsion systems like diesel engine came into picture and that old method was disappeared. After the oil crisis in 1973, the focus was again diverted towards the renewable energy sources. Wing sails, Flettner rotor, Wind kite, wind turbine, etc. are examined by different researchers from different countries and groups. Many researchers suggested that Flettner rotor is the most satisfactory and plausible option in today's shipping scenario. Flettner rotor operates on the principle called Magnus effect. The development in ship propulsion using Flettner rotor that took place from 1925 to 2015 are reviewed and summarized.

## The Concept

Magnus Effect his principle was given in 1852 by German scientist named H.G. Magnus. According to this principle, when wind meets the spinning cylinder, the cylinder accelerates air flow on one side and restricts the air flow on the opposite side. The resulting pressure difference creates a force called Lift force that is perpendicular to the wind flow direction as shown in Fig. 1. The circulatory flow, created here by the skin friction, is the same phenomenon that creates lift for an aircraft wing. The same principle applies to rotating spheres and cylinders. This can also be observed for example in golf, tennis or football, where spinning balls follow curved path during flight.

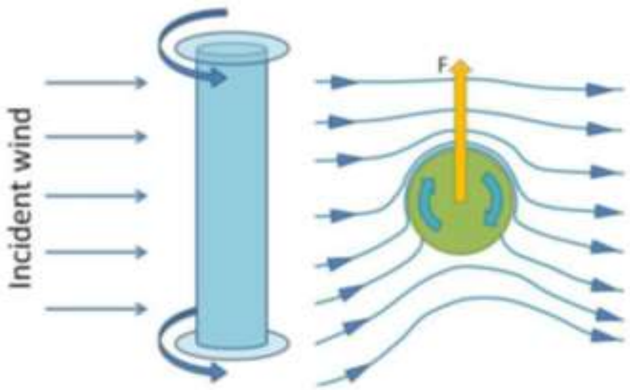


**Figure 1. Magnus Effect [3]**

Shipping Technology

The thrust induced by the Magnus effect can be utilized in ship propulsion by placing a cylinder on the open deck of the vessel and by rotating it around its main, vertical axis. An electric drive system that is powered by the auxiliary grid in the vessel is used for rotation of the Rotor.

## Reviewed Developments

In the 1920's German Engineer, Anton Flettner, constructed a hypothetical theory of ship propulsion using the Magnus effect of a rotating cylinder. He patented his study namely "Flettner Rotor ship Concept" on 16 September 1922 [4]. Flettner with his teammates A. Betz, L. Prandtl and J. Ackeret designed two cylinder shaped "sails" to propel the sailing ship "Buckau" in 1924 (shown in Fig. 2).

Tele: +91-9680386524
E-mail address: akshayanandlele@gmail.com

In 1926 Backau is modified to Barbara having three cylinders. But it got accident in 1929 [5].

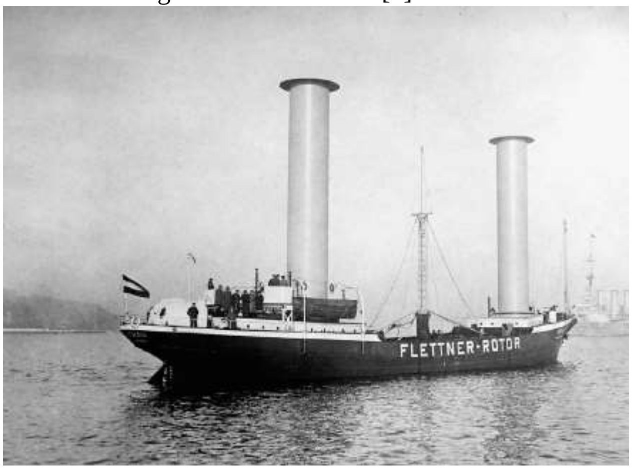


**Figure 2. 1924 "Buckau" (LOA approx. 54m) First Trails by Anton Flettner 2 Flettner Rotors 18m/2,8m [6].**

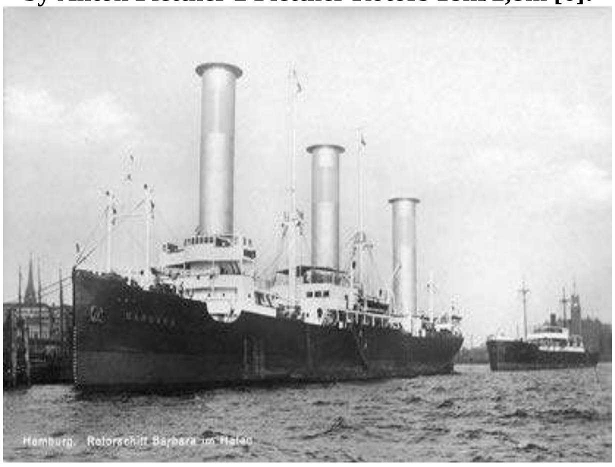

**Figure 3.1927 "Barbara" (LOA approx. 90m) Second Trails by Anton Flettner 3 Flettner-Rotors 17m/4m [6].**

Due to the cheap prices of fuel and the loss occurred in crash of Barabara (shown in Fig. 3) shipbuilders were not attracted for manufacturing new kind of ship. Meanwhile some simultaneous developments took place like discs used by Alexander Thom in 1934 [7].

Dr. Wellicome from Southampton University (1985) was one of the earliest researchers in recent times who reviewed different aspects of wind energy technology for marine transport. He bifurcated devices in active and passive mode. Aerodynamic characteristics and coefficient of maximum forward drive force of those devices were calculated. He concluded that Flettner rotors are the most efficient devices for wind assisted transportation [8].

Bergeson and Greenwald in 1985 presented their intensive study on wind propulsion for ships. Wind Ship of 20,000 dead weight Tonne was developed and tested at sea with a 3,000 $ft^2$ soft sail cat rig. They also designed a 3,000 $ft^2$ Wing Sail based on the principle of feathering. Wind Ship was also extensively tested a 90 $ft^2$ Magnus Effect rotor at sea (shown in Fig. 4). The rotor system was fabricated by Windfree, Inc. in California and shipped to Massachusetts for installation. The barrel (rotor) is 45.5 inches (1.16 m) in diameter, 284.5 inches (7.22 m) high, and weighs 180 lb. Comparing average performance at 6 knots, the wing sail saves 32%, the cat rig 26%, and the rotor 20% (after deducting the fuel for spin drive power) rather rotor has ten times less projected area as compared to other two. Also Rotor gave maximum lift coefficient with respect to all other devices [9].

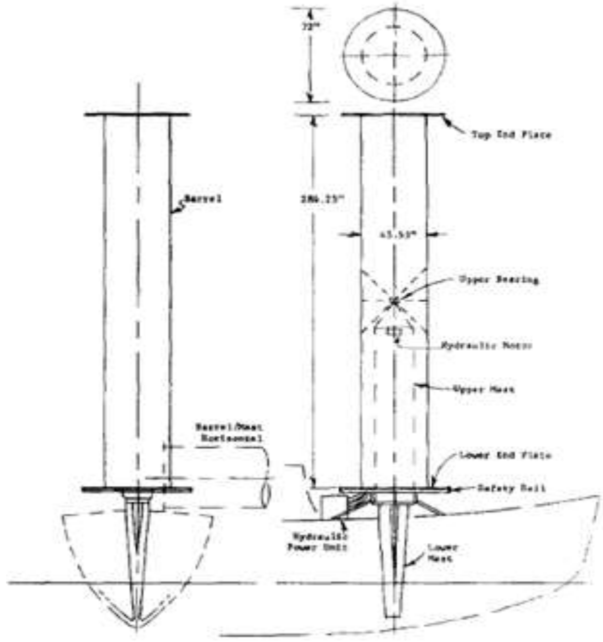


**Figure 4. Experimental Magnus Effect Rotor General Arrangement [9]**

In 2006, a number of students from the University of Flensburg under the guidance of Professor Lutz Feisser built a Flettner rotor driven proa. The vessel was named the Uni-Kat Flensburg. Feisser and his students used this proa as a demonstration piece to show the abilities of a vessel fitted with a Flettner rotor. The small proa housed a solar-powered electric motor to rotate the single cylinder a top the vessel. The team concluded the efficiency of the Flettner rotor was an improvement by a factor of ten over the conventional sailing rig. [10].

In 2008, Enercon, a wind energy company, designed and began construction on a Flettner powered cargo ship, named the E-Ship 1, which is shown in Fig. 5, to transport wind turbines among other products the company manufactures. This ship has four individual 25 metre tall Flettner rotors, two fore and two aft, to utilize the wind energy. The original construction was done by Lindenau Gmbh shipyards but in the early part of 2009, the ship was transferred to Cassens Werft to finish the job. The ship was completed in April 2010 and successful sea trials were completed by the end of July 2010. E-Ship 1 completed its maiden cargo carrying voyage to Dublin, Ireland on 10 August, 2010. The rotors are used to assist the diesel engine, also aboard the E-Ship 1, and cut fuel consumption by approximately 30%. The E-Ship 1 has undergone an intensive utilisation and trial phase over the last two years, during which it has covered more than 150,000 nautical miles in commercial operation [11].

**Figure 5. ENERCON E-SHIP 1 [6].**

Silvanius from KTH centre for naval architecture produced a study on wind assisted ship propulsion for PCTC fedora ship in 2009. He has done a mathematical matlab simulation for three different systems namely wing sail, wind kite and Flettner rotor. Mathematical equations for horizontal and vertical axis wind turbine for ship propulsion are also presented. PCTC Fedora ship has length of 220 m, breath of 32.2 m, height of 34.7 m, and a frontal area of 1171 $m^2$.
This ship then implemented with different systems using maximum possible sizes, i.e. kite 620 $m^2$, height of rotor 12.5 m with aspect ratio of 6, height of wing 12.5 m with chord of 6 meters and compared on the basis of (a) power per square meter from systems ($kW/m^2$) and (b) actual power from systems (kW) and presented graphically for four different wind speeds of 5 m/s, 10 m/s, 15 m/s, 20 m/s and different ship speeds of 15 knots, 20 knots. Flettner rotor delivered maximum power ($kW/m^2$) and performed better at low true wind speed amongst these three options. An economic analysis was also done by considering a sea route wind data and saving of fuel, return of investment was estimated. In case of Flettner rotor, it has lowest payback time of 1.7 and 1.0 years for 15 knots and 20 knots ship speed respectively. It saved fuel cost by 5.8% and 4.0% of total fuel cost for 15 knots and 20 knots ship speed respectively. But according to the author wing is preferred over kite and rotor as it has low payback period and less complicated installation [12].

Craft et. al. (2012) from School of Mechanical, Aerospace & Civil Engineering, University of Manchester published a paper on Flettner-Thom rotors for marine propulsion. They had examined the performance of the spinning rotors proposed by Flettner as well as the spinning rotors with discs distributed along the cylinder as proposed by Thom (1934) by Computational fluid dynamics in URANS code. According to these computations they found that spinning rotors performed well as compared to cylinders having discs as their application in marine transport [13].

Traut et. al. (2012) from University of Manchester, United Kingdom analysed Flettner rotor numerical model along a route from Tubarao (Brazil) to Grimsby (UK). The selected route was 9319 km long. Further a typical 50,000 dwt bulk carrier serving that route, equipped with three Flettner rotors. The average power contribution from the Flettner rotors is 16% in this setup was found, varying between 7.6% and 31.4% at locations along the route from Tubarao (Brazil) to Grimsby (UK) and between 7.3% and 33.0% on the return trip i.e. it can save the fuel of 16% of total main engine needed [14].

Pearson (2014) a naval engineer from UK presented a paper on the application of flattener rotors in efficient ship design. A software model for the use of flettner rotor on common ship types the UK fleet was given. The analysis described within this paper is intended to provide an initial ‘first stage’ assessment of the viability of installing Flettner rotors to ship. The ship selected to demonstrate the Flettner Rotor model is a chemical tanker of approximately 14,700 tonnes deadweight. In this model Flettner rotors of both type (plain cylinder and with thom discs) are placed on the selected ship (shown in Fig. 6). Considered simple Flettner rotor has endplates 1.5 times the cylinder diameter, and a fixed aspect ratio of 5. The ship used in this study saved up to 10% of its annual total fuel consumption with the installation of two Flettner rotors [3].

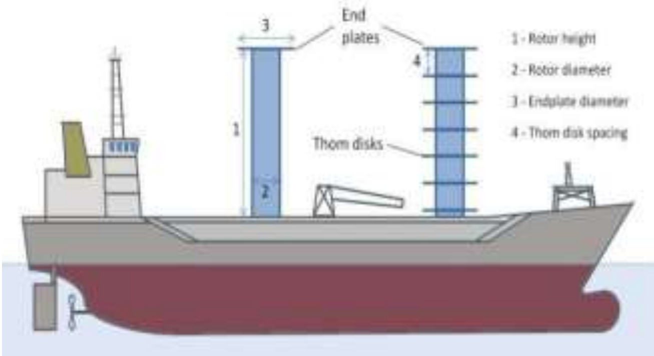


**Figure 6. Flettner rotor installed model ship by pearson et. al. [3].**

Traut et. al. (2014) from University of Manchester had held a study regarding numerical models of two wind power technologies, a Flettner rotor and a towing kite. The rotor was a plain cylinder, without end plates, and it has a vertical cross sectional area A of 175 $m^2$ with a height of h = 35 m and diameter d = 5 m, and the spin ratio (the ratio of the rotor surface speed and the apparent wind speed) of $\alpha = 3.5$. The defining parameters are the lift, drag, and moment coefficient, are selected as $C_L = 12.5$, $C_D = 0.2$, and $C_M = 0.2$. The average wind power contribution on a given route ranges between 193 kW and 373 kW for a single Flettner rotor [15].


**Figure 7. Ship constructed by norsepower [16]**

A company from Finland namely, Norsepower has constructed a ship fitted with Flettner Rotor. VTT (Technical Research Centre of Finland) used Norsepower’s Technology to build a ship and claimed 2.6-percent saving in fuel consumption for one Flettner rotor. Norsepower has estimated that the vessels could achieve an approximately 20-percent saving for vessels running with multiple rotors and in favourable wind conditions. The payback time for this kind of system was estimated to be four years. A ship constructed by norsepower is shown in Fig. 7 [16].

Peter Kindberg from University of Michigan in 2015 has done a study on wind-powered auxiliary propulsion in cargo ships. In this study he compared kite, Flettner rotor, and Dynarig with respect to fuel consumption as well as $CO_2$ emission at different wind angles and wind speeds. The reference ship used is from the University of Michigan a 600-footer ship, which has 18,544 dead weight tonnes (DWT) as load on two sea routes namely Helsinki – Rostock and London – Marseille. The results of the comparison shows that Flettner rotor system has maximum fuel saving and steady performance with respect to other two in turn and saved maximum money for both routes [17].

## Conclusions

- Flettner rotor driven ships cannot provide the full-required propulsion, but as the EU has set a target on 2050 to cut the emission levels with 40 percent from the 2005's levels, it is plausible to fulfil these requirements.
- It can be an interesting topic for researchers as fuel consumption can be reduced from 5% to 30% without depressing the operating speed of the vessel.
- The Flettner Rotor technology can be utilised more productively at lower ship speeds rather than higher ship speeds.
- As wind parameters such as speed and turbulence etc. are route specific, the fuel saving depends on the route, size of ship, operating speed of ship, etc.
- To estimate the accurate savings in fuel consumptions etc, it is essential to do further research by simulating and testing the ships fitted with Flettner rotor for different routes.

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