Flettner Rotor: Paving the Road Ahead for A Cleaner Shipping Industry

Author: Snehadri Banik

Email id: banik.snehadritmi@gmail.com

Tolani Maritime Institute, Induri, Pune, India,

Abstract- Flettner rotors are vertical cylinders which spin and develop lift due to Magnus effect as wind blows across them. Flettner rotors need to be mechanically driven in order to develop propulsion power, and manoeuvrability is restricted by wind speed and direction. The force created inside the rotor cylinders generates the thrust. The Flettner rotors were first implemented by Anton Flettner on board a ship at the beginning of 1920's but not much advancements have been done in this technology. Flettner rotors can considerably reduce energy consumptions of a ship as an alternate propulsion system.

Keywords: Flettner Rotors, Magnus Effect, Savonious Rotor, Stabilizers, Thom Fences.

I. BACKGROUND

The shipping industry has witnessed some significant advancement since its advent. More than 90 percent of world trade is moved through the maritime commercial shipping industry. Subject to free market forces, this industry has achieved a high level of efficiency, which has contributed to the expanding global economy by enabling the low-cost movement of goods around the world. Worldwide seaborne trade has quadrupled in the last 40 years and now exceeds 6 billion tonnes per annum, with an annual growth rate of about 4 percent. In order to drive magnificent structures such as a ship, generally 3 types of oil are used. Heavy Fuel Oil (HFO), Low Sulphur Fuel Oil (LSFO) and diesel oil. Different countries have different rules for burning fuel when the ship is at that place.

With the natural resources being depleted day by day, humans are in search of cleaner and sustainable sources of energy which can be used in the seaborne trade for the upcoming generation. One such clean source of abundant energy available in the high seas is wind energy.

A. Wind

Wind is the movement of gas. On the surface of the Earth, wind consists of the bulk movement of air. In outer space, solar wind is the movement of gases or charged particles from the sun through space, while planetary wind is the out gassing of light elements from a planet's atmosphere into space. Wind moves from an area of high pressure to an area of low pressure.

C. Wind Energy:

Wind is one such source of energy which is available in abundant quantity in the seas, but this source of energy hasn't been yet tapped by the human race to its full potential. Wind happens to be one of the cheapest, most powerful, and greenest sources of energy on the high seas. If this source of energy can be made to use with the help of modern technology, then we can reduce the consumption of fossil fuels to a greater extent and can also help in creating a cleaner society.

Wind is caused by the uneven heating of the atmosphere by the sun, variations in the earth's surface, and rotation of the earth. Mountains, bodies of water, and vegetation all influence wind flow patterns. Wind power conventionally has been generated with the help of turbines in the past few decades. Wind turbines convert the energy in wind to electricity by rotating propeller-like blades around a rotor. The rotor turns the drive shaft, which turns an electric generator. The key factors which affect the amount of energy a turbine can harness from the wind are: wind speed, air density, and height.

D. Flettner Rotors

Flettner rotors (FR's) are a form of a wind based propulsion system that utilizes the Magnus effect shown by a spinning body in a fluid flow incident upon it. A Flettner Rotor typically comprises of a cylinder with an end plate affixed to it on the top. The rotating cylinder in an airstream generates a lift and a drag force that contributes to the propulsive need of the ship. The rotation to the Flettner Rotor is generally given by an electric motor.

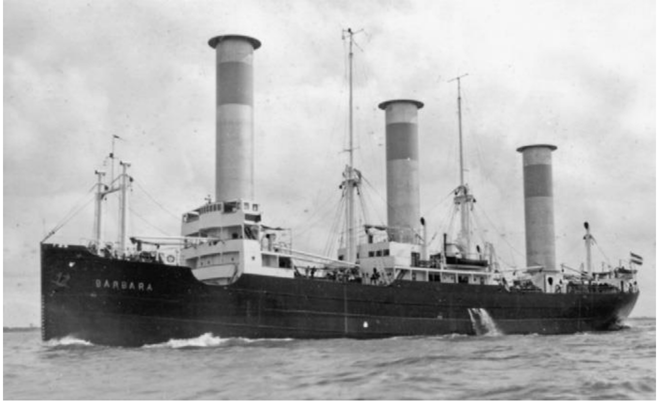

Fig 1: Rotor ship Barbara (Courtesy of Deutsches Schifffahrts museum Archive, Bremerhaven.)

II. PRINCIPLE

The principle on which the Flettner Rotor works is that of Magnus Effect. **Magnus effect** is defined as the generation of a sidewise force on a spinning cylindrical or spherical solid immersed in a fluid (liquid or gas) when there is relative motion between the spinning body and the fluid., It is responsible for the "curve" of a served tennis ball or a driven golf ball and affects the trajectory of a spinning artillery shell.

Named after the German physicist and chemist H.G. Magnus, who first in 1853 experimentally investigated the effect is that of a force generated by a spinning object traveling through a viscous fluid. The force is perpendicular to the velocity vector of the object. The direction of spin dictates the orientation of the Magnus force on the object. The orientation of the force can change or it can be changed but it is important to remember that it is always perpendicular to the direction of fluid.

A spinning object moving through a fluid departs from its straight path because of pressure differences that develop in the fluid as a result of velocity changes induced by the spinning body. The Magnus effect is a particular manifestation of Bernoulli's theorem: fluid pressure decreases at points where the speed of the fluid increases. In the case of a ball spinning through the air, the turning ball drags some of the air around with it. Viewed from the position of the ball, the air is rushing by on all sides. The drag of the side of the ball turning into the air (into the direction the ball is traveling) retards the airflow, whereas on the other side the drag speeds up the airflow. Greater pressure on the side where the airflow is slowed down forces the ball in the direction of the low-pressure region on the opposite side, where a relative increase in airflow occurs.

The force of the Magnus effect can be calculated with the following equation:

$$\boxed{F_m = S\,(w \times v)}$$

Where:
F_m =the Magnus force vector
w= angular velocity vector of the object
v=Velocity of the fluid (or velocity of object, depends on perspective)
S= air resistance coefficient across the surface of the object
Once Fm is found we can use the basic kinematic equations to predict the characteristics of spinning objects in flight.

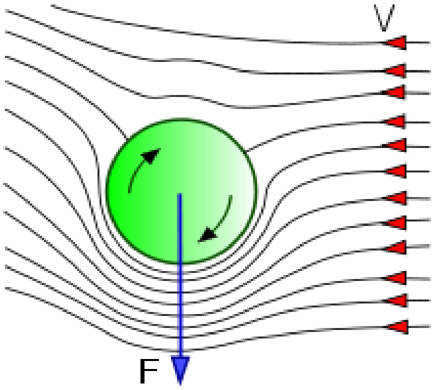

Fig. 2: Pictorial representation of Magnus Effect

III. IDEAS AND VISIONS

A. History

Anton Flettner's spinning bodies are vertical cylinders, which as specified before was to use Magnus effect. Anton Flettner was assisted by Albert Betz, Jacob Ackeret, Ludwig Prandtl and Albert Einstein, Flettner constructed an experimental rotor vessel, and in October 1924 the Germania werft finished construction of a large two-rotor ship named Buckau.

The vessel was a refitted schooner which carried two cylinders (or rotors) about 15 metres (50 ft) high, and 3 metres in diameter, driven by an electric propulsion system of 50 hp (37 kW) power. Following completion of its trials, the Buckau set out on her first voyage in February 1925, from Danzig to Scotland across the North Sea. The rotors did not give the slightest cause for concern in even the stormiest weather, and the Flettner rotor vessel could tack (sail into the wind) at 20-30 degrees, while the vessel with its original sail rig could not tack closer than 45 degrees to the wind. On 31 March 1926, the Buckau, now renamed Baden-Baden after the German spa town, sailed to New York via South America, arriving in New York harbour on 9 May.

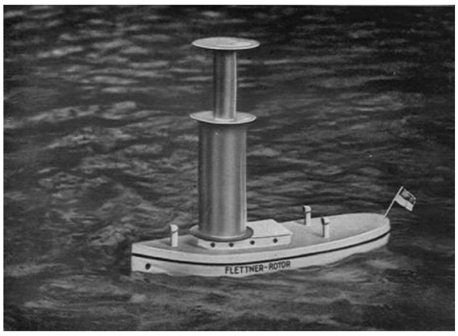

Fig 3: Rotor ship Buckau

IV. COMPONENTS AND WORKING

The Flettner Rotor can be used on board for two major applications:

- *Rotor Ships:*
  Rotor ships use mast-like cylinders for propulsion.
- *Stabilizers:*
  A Flettner rotor mounted beneath the waterline of a ship's hull and emerging laterally will act to stabilize the ship in heavy seas. By controlling the direction and rotation strong lift or downforce can be generated. The largest deployment of the system to date is in the motor yacht Eclipse.

A. *Driving a Magnus rotor*

A Magnus rotor is usable as a lifting device as long as it is spinning. In case of the rotor ship, the rotors are powered by an electrical drive system. One reason for this solution is the flexibility in selecting the spinning direction according to the wind direction and the desired moving direction. In order to reduce system complexity and increase system safety, other technologies may be developed to drive the rotors. For example, Flettner proposed a Savonius-rotor, which is known as an auto rotating wind energy converter, to drive the Flettner-rotor.

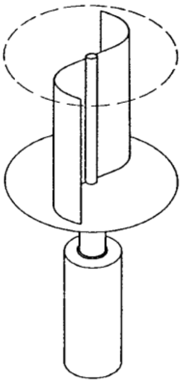

Fig 4: Savonious Rotor

B. *Flettner Rotors*

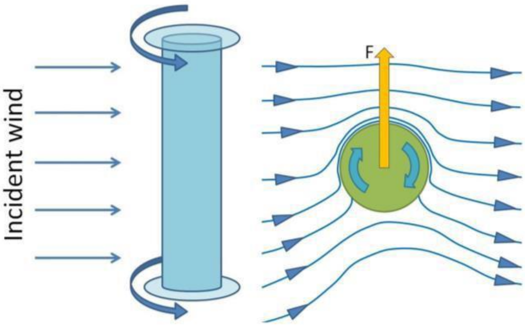

Fig. 5: Magnus effect applied on Flettner Rotor

a. *Rotor Design*

A standard Flettner Rotor is a basic cylinder shape, with an endplate mounted at the top in order to improve the lift/drag ratio. It can include 'Thom fences', additional plates spaced evenly along the length of the cylinder which can also increase the lift coefficient at the cost of greatly increased power requirements, named after Dr Alexander Thom who initially proposed their use in FR design. The basic structure and major characteristics of the rotor must be defined in the technology options file prior to use within the model. As the model is generic in order to be used with a number of different ships with different sized rotors, the rotor design will automatically be generated based on the particulars of the test ship if it is not pre- defined.

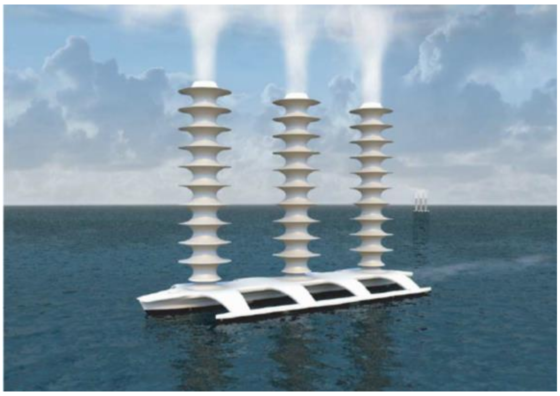

Fig 6: Thom Fences

b. Height of Rotor

The Flettner Rotor height is defined as the vertical distance from the weather deck to the top of the ships tallest mast, so as not to increase the existing air draft of the ship. The diameter of the cylinder is defined based on a fixed aspect ratio of height/diameter, with a lower aspect ratio for the endplates.

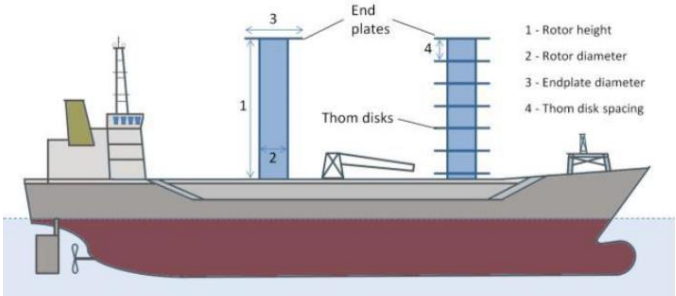

Fig. 6: Components of Flettner Rotor

C. Ship Selection

When beginning an assessment for the potential retrofit of Flettner Rotors on a ship, it must first be ensured that the candidate ship is physically well suited to accommodate them. The ships particulars are used to define the initial dimensions and locations for FRs, and depending on the type of ship, a different logic is applied.
Initial requirements are as follows:

- Sufficient clear deck space.
- No immediately adjacent structure.
- Suitably strong mounting points.

These requirements ultimately mean that a candidate ship must be of a type that has an open area of deck, without extensive superstructure that would inhibit air flow, or deck gear/cranes which may be obstructed by the presence of a Flettner Rotor.
As there will be considerable forces transmitted to the structure of the ship, the mounting sites must be carefully chosen to ensure that the forces can be safely transferred to the ships structure. For an initial assessment, areas that already have deck reinforcement for cranes or capstans etc. are assumed to be an appropriate site. Where this is not possible, sited directly over a bulkhead that can accommodate extra stiffening is an acceptable alternative.
Vessel types such as dry bulk carriers and tankers represent an ideal platform for the installation of Flettner Rotors. Their open decks and relatively slow steaming speeds, alongside favourable operating profiles make them a more attractive proposition for the use of Flettner Rotors.

The operating profile of the ship and the ships speed in different sea states are also key factors to the feasibility of installation, as Flettner Rotors are more effective for ships travelling at slower speeds in medium/higher winds. The best fuel-saving benefit is for ships that spend the majority of their operational time at a constant cruising speed instead of manoeuvring, such as anchor handlers.

V. RESULTS & DISCUSSIONS

A. Aerodynamic Data

The only dynamically controlled variable of the FR is the rotational speed, which consequently affects the velocity ratio, which is defined as the ratio of the cylinder surface speed relative to the air speed as shown below:

$$\boxed{V_{rat} = {}^{N \cdot R_{fr}}\!/_{V_{app}}}$$

Coefficients of lift and drag vary with the velocity ratio; therefore, FR performance is dependent on the background data used to calculate the coefficients of lift and drag, and the subsequent forces that are generated. Accurate data regarding the coefficients of lift and drag was limited to a maximum velocity ratio of 8, taken from early experimental results based on the work of Jakob Ackeret. This data is illustrated in Fig. 7.

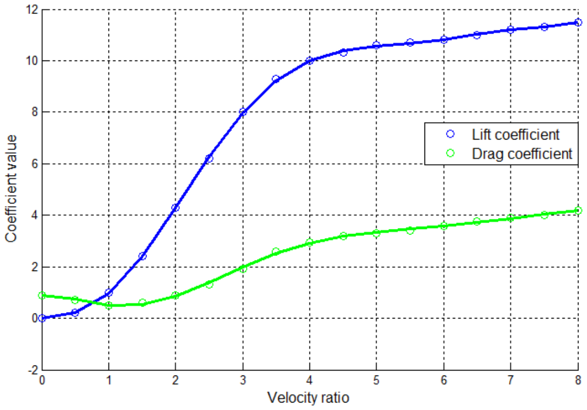

Figure 7: Ackeret values for CL and CD

B. Wind and Forces

The wind force and direction experienced by the ship as it moves forward will be the resultant of the ‘induced wind’ (the airflow felt due to the ships forward motion) and the ‘true wind’ (the direction of the wind were the ship to be stationary) to create the apparent wind.

It is the apparent wind incident upon the ship that is the wind speed used for calculating the velocity ratio. The apparent wind varies in strength and direction for every combination of ship speed, true wind speed and true wind direction.

As the model is intended to be generic there is no wind routing performed, therefore each instance of true wind direction is assumed to be equally likely to occur.

The resulting lift and drag forces from the Flettner Rotor are then broken into their components and summed to give the net force for that scenario. The apparent wind and forces are illustrated in Fig. 8.

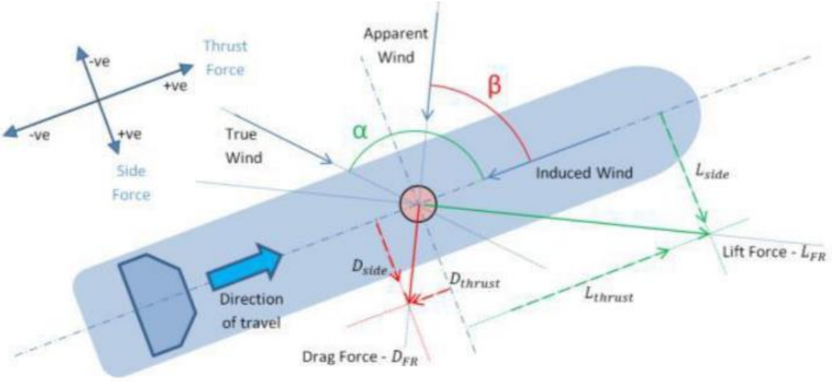

Figure 8: Apparent wind and forces.

The formula for drag is the same but with the corresponding drag coefficient.

$$Lift = \frac{\rho_{air} \cdot A \cdot V_{app}^2 \cdot C_L}{2}$$

It is assumed that the rotor will always rotate in the direction that will provide beneficial thrust and at the highest beneficial rotational speed; where that is not possible the rotors are turned off to minimize drag and power consumption.

C. *Net Power*

The power consumption of a Flettner Rotor was taken to be the sum of the motor power required to overcome the aerodynamic resistance and the resistance from the bearings. Aerodynamic power is calculated by treating the endplate and cylinder as separate entities and summing the required powers. The relevant equation for each is given below:

$$P_{disk} = Cm_{disk} \cdot \rho_{air} \cdot N^3 \cdot R_{disk}^5$$

$$P_{cyl} = \frac{1}{2} \cdot Cm_{cyl} \cdot \pi \cdot \rho_{air} \cdot N^3 \cdot R_{cyl}^4 \cdot L_{cyl}$$

$$P_{bearing} = \frac{k_{bearing} \cdot F_{bearing} \cdot D_{bearing} \cdot N}{2}$$

In order to ensure the operation of Flettner Rotors provides a net benefit in a particular scenario, the total power required to drive a rotor is compared against the equivalent main engine power its thrust replaces. In the event the thrust from the Flettner Rotors does not justify their added power requirements, the rotors are turned off.

D. *Negative Effects*

There are other factors that affect the overall performance of a FR fitted ship, and demonstrate why an early appreciation of ship type and layout are important. Factors considered within this model are:

- Increased heeling moment from side forces;
- Extra rudder drag from increased yaw;
- Forced vibrations (Resonance).

The sideways (sway) forces as illustrated in Fig. 8 can become very large when the apparent wind angle (β) is nearly dead ahead or astern.

This large sideways force when combined with the vertical lever arm of a Flettner Rotor creates a large heeling moment on the ship and will thus increase the angle of static heel, just as with a sailing yacht. The increase in static heel angle must therefore be calculated to ensure it does not exceed safe levels and to quantify its effect on the sea keeping of the ship.

Moments are equated around the vertical centre of gravity (VCG) and basic geometry allows for a calculation of static heel angle, shown in Fig. 9.

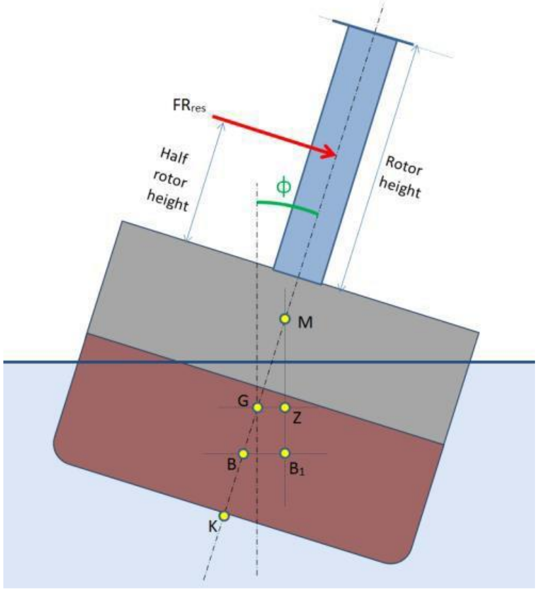

Figure 9: Angle of static heel

From the calculated angle of static heel, the change in the wetted surface area on the hull can be calculated and thus any resultant change in drag taken into account. It was researched and found to have negligible effects (<1%), as the static heel does not exceed any roll angle normally experienced by the ship, thus the effects of static heel were not routinely calculated unless expected to be unusually high for that scenario.

Another potential effect of large sway forces is the ability to create unbalanced yaw moments around the ships Longitudinal Centre of Gravity (LCG). This yaw moment must be countered by applying increased rudder angle which will increase drag and reduce the benefit from the Flettner Rotors. As part of this problem, there is a maximum yawing moment the rudder can exert for a given ship speed, and at reduced ship speeds and higher winds this could result in the ship losing steerage. This scenario is illustrated below in Fig. 10.

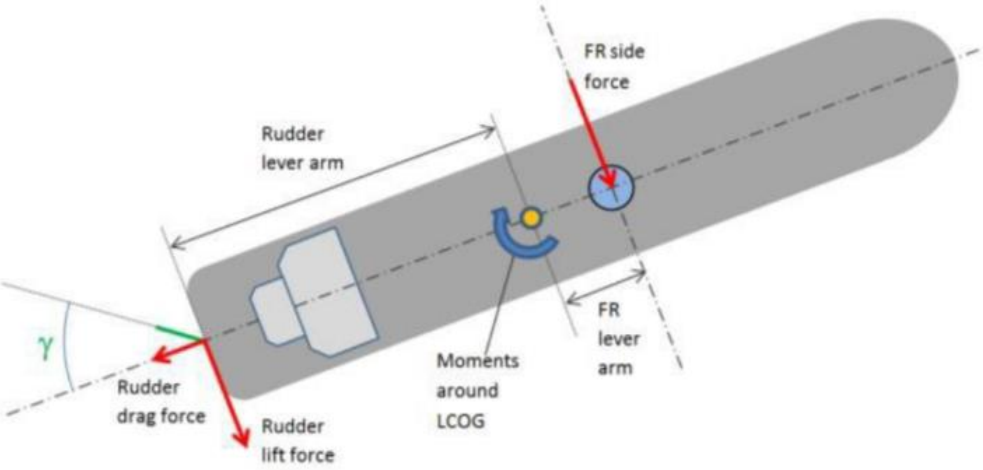

Figure 10: FR yaw forces.

VI. **CONCLUSION**:

It can be thus concluded from this technical paper that Flettner rotors are an alternative supportive propulsion system which are possible to be integrated on existing vessels. It works on the principle of Magnus Effect and taps in the power of wind energy to propel the ship in the desired direction. It consists of rotating cylinders, these cylinders mainly generate forces in the horizontal plane, forward plane and sideway forces. To make sure the seagoing properties of the vessel remains good, it must be prepared and planned because the healing movement influences the stability and the strait of the cylinder foot must be properly supported as it is subjected to high stress. The vessel needs to have a sufficient free deck surface. At the same time no objects should block the accessibility of free wind and operational height limitations must be taken into account. The German wind turbine manufacturer "Enercon" has constructed a new ship the *E-Ship 1*, which incorporates four large FRs as auxiliary propulsion and has operated successfully at sea in 2013, yet a lot changes and advancements need to be done.
The range of cost of Flettner Rotor is quite high but with further technological and material science advancements, the Flettner rotor can eradicate the problem of pollution, provide fuel savings and ensure reduction potential from 3-15% on main engine fuel consumption depending on vessel size, segment, operation profile and trading areas.

ACKNOWLEDGMENT

I would like to thank Tolani Maritime Institute, Induri for providing us with an opportunity to do a research project on "Flettner Rotor: Paving the Road Ahead for a Cleaner Shipping Industry".
I wish to express our sincere gratitude to Prof. Arun O. Mahajan, Prof. Puja Achawat and Prof. Nilima C. Joshi for their constant guidance and encouragement in carrying out this research project.

REFERENCES

1. J. Seifert. A Review of the Magnus effect in Aeronautics. Progress in Aerospace Sciences(2012)
2. http://ffden2.phys.uaf.edu/211_fall2010.web.dir/Patrick_Brandon/what_is_the_magnus_effect.html
3. http://glomeep.imo.org/technology/flettner-rotors/
4. ENERCON GmbH. Rotor sail ship *E-Ship 1* saves up to 25% fuel, Enercon Press release, 29th July 2013.
5. http://www.maritimejournal.com/news101/comment-and-analysis/wind-rotor-for-ships
6. M. Traut, P. Gilbert, C. Walsh, A. Bows, A. Filippone, P. Stansby, R. Wood, 'Propulsive power contribution of a kite and a Flettner rotor on selected shipping routes'.
7. Mandar Gadkari, Varun Deshpande, Sumant Mahulkar, Vishal Khushalani, Shubham Pardhi, Dr. A.P. Kedar, 'To study Magnus Effect on Flettner Rotor'
8. Snehadri Banik, Sudhanshu Sagar, 'Sky-Sail:Generation of Power from Wind'.