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Vertical Axis Wind Turbine-Flettner Rotor Integration As Hybrid Propulsion Power On A Model Ship

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***Abstract*—Natural energy is something that can be utilized as an alternative energy besides fossil fuel energy. Considering that the need for fossil fuel energy is decreasing, the purpose of this research is to propose a utilization of natural energy in the form of wind. The implication of the use of this alternative energy in the hybrid power function is that the integration of vertical axis wind turbines and Flettner rotors is chosen as the main driving energy of the model ship that fully utilizes wind energy. The performance evaluation stages in this experiment include design and simulation for the turbine-Flettner rotor, and trials on a model ship using a monohull type hull. The objective of this research is to obtain the optimum performance of the combined vertical-axis wind turbine-Fletner rotor in supporting hybrid propulsion power on a model ship. The power required by Flettner is 0.695 Watt and the turbine rotate at a minimum angular velocity of 40 rpm. The highest contribution of the Flettner rotor at ship service speed 1 knot and ship total resistance of 0.01 kN reached 26,20%.**

Keywords— Flettner rotor, hybrid, vertical axis wind turbine

I. INTRODUCTION

Wind is a potential renewable energy that can contribute significantly to Indonesia's electrical energy needs. Wind energy is natural resources that are abundant and their availability is guaranteed throughout the year. Currently, many ships in operation still use fossil fuel engines that are increasingly limited in availability. This result in ship operating costs continuing to increase in price, besides the impact of using fossil fuels also causes environmental damage. So that currently a breakthrough in ship propulsion technology is needed that can utilize wind energy in its operation.

Flettner rotor is a technology that utilizes the wind in nature to help the ship move. This tool is cylindrical and rotates along the y-axis in the air fluid flow to produce a fluid dynamic force due to the Magnus effect, where this technology was invented by Anton Flettner in 1920. This tool was first carried out on the Buckau Ship in 1925 which crossed the Atlantic with one or more Flettner rotors mounted on the ship's deck vertically and rotating using a motor, which when rotating can act as a sail to push the ship under wind power.

On a 205 m long tanker, thrust has been evaluated at the maximum Spin Ratio simulated in the study (SR = 3.0) and refers to a Flettner rotor of 4.0 m diameter and 28.0 m height. Tests of this ship towing tank show that the drag at speeds of 10 kn and 12 kn are 354 kN and 500 kN, respectively. In varying wind angles, some Flettner rotors can provide thrust that is up to 30% of the ship's drag in the operational speed range [1]. The use of a Flettner rotor on a container carrier with a DWT of 4000 tons takes into account the RPM value for analysis based on the results of the largest thrust force, namely when the Flettner rotor is rotated at 400 RPM, it produces a force of 736 N. The benefits of Flettner rotors on ships can save 10% to 30% fuel and depend on the shipping route [2]. The implication of the Flettner rotor on the Ferry Ship has dimensions of 5x1 meters with a lift coefficient (CL) of 3.647 and a lift force (Fl) of 2,980 kiloNewtons. While at a wind speed of 15 knots and a ship speed of 15 knots, the Flettner rotor contribution shows KMP. DBS I by 18.11%, KMP. DBS III by 11.27%, and KMP. SN 92 by 5.45% [3].

The research on a 100,000-ton oil tanker proposes a new type of rotating cylinder and its installation method that is on the superstructure and the Flettner rotor organically combined with a diameter of 40 m is designed. Through numerical simulation, the maximum effective power that the Flettner rotor can provide is about 2,240 kW. When the maximum effective power appears, the effective power of the Flettner rotor can reach about 75% to 85% of the thrust it generates [4]. In the study the fuel economy performance of three wind-assisted ship propulsion technologies namely Flettner rotor, DynaRig, and wing sail on Aframax Oil Tanker was simulated and compared in two voyages. The results show that the three sail technologies contribute to fuel savings of between 5.6% and 8.9%. Therefore, it is necessary to select and operate the Flettner rotor according to the appropriate ship type, speed, cruise route, and weather conditions [5].

A wind turbine is a device used to convert wind energy into mechanical energy, which is then converted again into electrical energy. The rotation of the wind turbine shaft is connected to the generator to produce electrical

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energy. In the prototype of a catamaran ship that has a maximum total weight of 34 kg, the total energy obtained from PV and wind turbine generators is 774 Wh. This energy can be used to charge a battery with 35Ah battery specifications for 6 hours. Meanwhile, when the battery is full, it can supply a motor with a power of 474 Watt for 56.7 minutes at a speed of 1.81 m/s (3.5 Knots) when the load weight is 3 kg and when the load weight is 15 kg the ship speed is around 1.07 m/s (2.07 Knots) [6]. Alternative renewable energies such as wind energy, solar energy, and fuel cells can be used for ship propulsion, especially for medium or small vessels or to supplement power for lighting, navigation, and communication needs on large vessels, thereby reducing fuel consumption. This is because it reduces the greenhouse effect (GHG) and fuel costs. Wind energy technology can increase ship energy efficiency between 20%-30% compared to solar PV which is only 6.9% [7]. On tanker B573 with an overall length of 183 m and a width of 32.2 m a 15 m diameter turbine was installed. With a wind strength corresponding to 6-7 on the Beaufort scale (about 16 m/s), it provides a power output of 210 kW from one turbine [8].

Judging from some of the research that has been done before, this research will discuss the integration of vertical axis wind turbines and Flettner rotors as propulsion energy for model ships. The electrical energy generated from the vertical axis wind turbine is used to operate the Flettner rotor as the wind propulsion of the model ship. The design of the turbine-Flettner rotor can switch functions but remains a single unit that switches based on energy needs. The expected research results are to obtain the optimum performance of the combined vertical axis wind turbine-Fletner rotor to obtain effective energy management in supporting hybrid propulsion power on the model ship.

II. METHOD

The research begins with a literature study process that studies and understands the concept of equipment that will be used in this research including wind turbines, Flettner rotors, and model ships. The study of previous research becomes a reference in developing things that are still not perfect. After the material is collected, the research continues with the design of the vertical axis wind turbine-Flettner rotor using several appropriate design software. After the design is formed, then simulation calculations are carried out using Computational Fluid Dynamics (CFD) to determine the performance of equipment and energy moving in the fluid. From these calculations, outputs are obtained in the form of electricity input results derived from wind turbines and the results of the electricity output required for the Flettner Rotor. The most important step in this research is the simulation of energy management in hybrid propulsion power which is an integration of the vertical axis wind turbine-Flettner rotor. After obtaining effective energy management simulation results, the next stage is experimentation by designing and installing the equipment under study on a model ship of a certain scale.

The use of model ship in this study uses prototypes that are already available at the Laboratory of the Faculty of Engineering and Marine Science, Hang Tuah University Surabaya. This is done so that the research is more effective and efficient in utilizing campus facilities and getting optimal results because the technical specifications of this model ship have met the requirements and have been tested according to applicable regulations. The ship has been equipped with batteries, and power regulators that are ready to operate to support this research so that researchers only need to add some supporting equipment according to the problem under study. Designing a turbine-Flettner rotor model that can be integrated into a multifunctional design with complementary capabilities. Modelling can be done with software such as Autocad, Solidwork, and so on. Furthermore, the design is applied in a finished model with a certain scale according to the research needs. The model ship in this study has specification as Table 1. The initial design of the vertical axis wind turbine-Flettner rotor were installed on the front deck, as shown in Figure 1.

TABLE 1.
THE MODEL SHIP SPECIFICATION

Dimension	Notation	Value (m)
Length Overall	L_{OA}	2,26
Length Between Perpendicular	L_{BP}	2,14
Overall Wide	W	0,40
Height	H	0,22
Depth	D	0,18

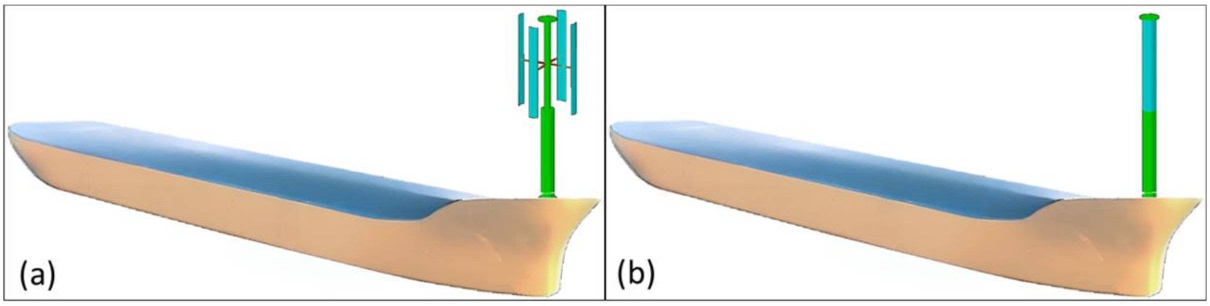

Figure 1. Preliminary design of floating vehicle with integrated turbine-Flettner rotor when open condition becomes turbine (a) and closed condition becomes Flettner rotor (b)

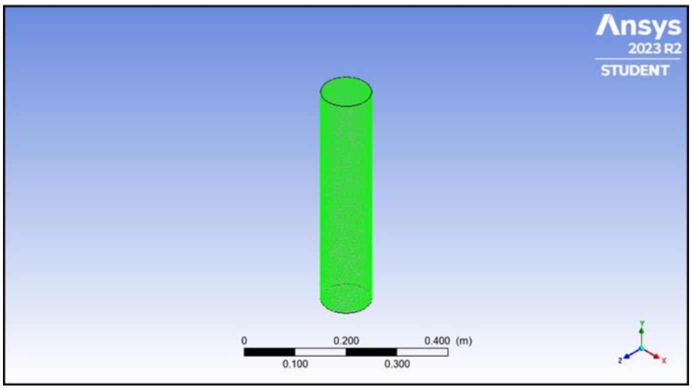

Figure 2. Flettner rotor model

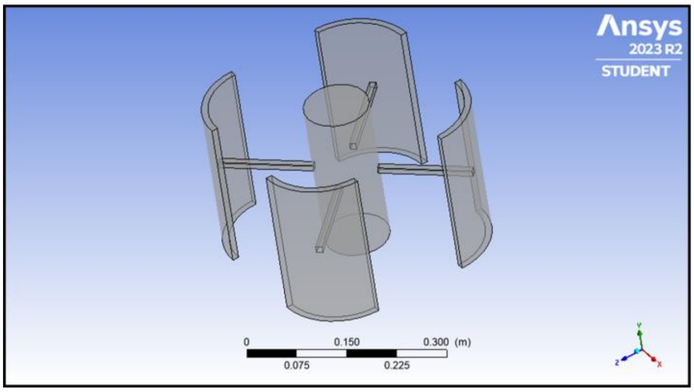

Figure 3. Turbine model

When the condition is open, the wind turbine absorbs wind energy to convert it into electrical energy. Electrical energy from wind turbines is stored in batteries as a backup of electrical energy. When the condition is closed, supported by the reserve electrical energy from the wind turbine stored in the battery to drive the rotor, the Flettner rotor functions to provide thrust energy from the blowing wind to move the ship. Simulation can be done with one vertical axis wind turbine model that can switch shape and function into a Flettner rotor, this model change adjusts the needs of the ship when sailing. At certain times the vertical axis wind turbine model is operated to generate electrical energy that can be stored in batteries. At other times, the vertical axis wind turbine model can close tightly so that it is in the form of a solid cylinder and switches its function to a Flettner rotor which functions as a propulsion model ship by utilizing wind movement through the rotation of the rotor. Computational Fluid Dynamics (CFD) is the art of replacing integral and partial differential equations with discrete algebraic equations that can be solved by numerical flow values at discrete points in space and time [9]. CFD is concerned with the numerical solution of differential equations governing the transport of mass, momentum, and energy moving in a fluid [10]. The stages of the Ansys-CFX CFD simulation [11] are as follows:

(1) Pre-processing: geometry, mesh, setup

At the Geometry stage, the Flettner rotor has height 50 cm and diameter 10 cm with variable speed of angular velocity, as shown in Figure 2. The turbine has height 25 cm and diameter 35 with variable speed of angular velocity, as shown in Figure 3.

The field used as a fluid medium or the place where the fluid flows is in the form of a beam and the barrier between the Flettner rotor and the fluid flow is shown in Figure 4. The Rotor domain is created with the rotation option and the stator domain of the fluid field is created with the stationary option. Other parameters that can be entered include the rotational speed of the Flettner rotor which varies every 500 rev/min and the type of fluid to be used in the simulation is air float in speed value is 4 knots.

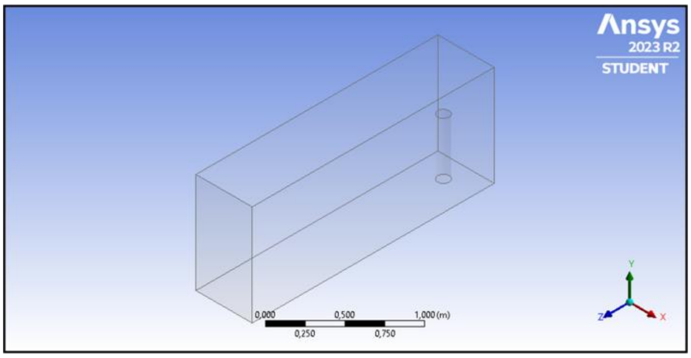

Figure 4. Modelling of Flettner rotor field and barrier

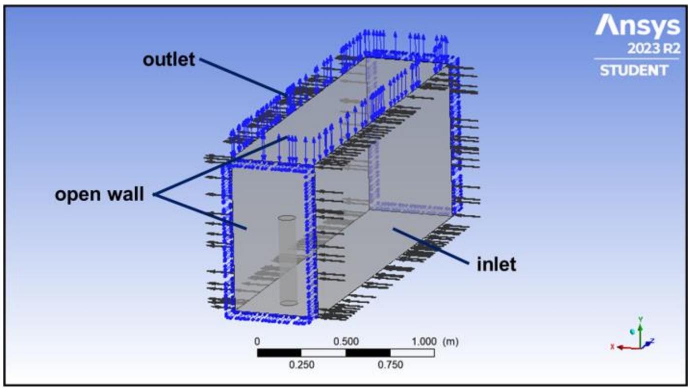

Figure 5. Boundary of Flettner rotor

The influences of parameter that taking simulation results in the form of animation shown in Figure 5.

The field used as a fluid medium or the place where the fluid flows is in the form of a beam and the barrier between the turbine and the fluid flow is shown in Figure 6. Other parameters that can be entered include the rotational speed of the turbine which varies every 10 rev/min and the type of fluid to be used in the simulation is air float in speed value is 10 knots. The influences of parameter that taking simulation results in the form of animation shown in Figure 7.

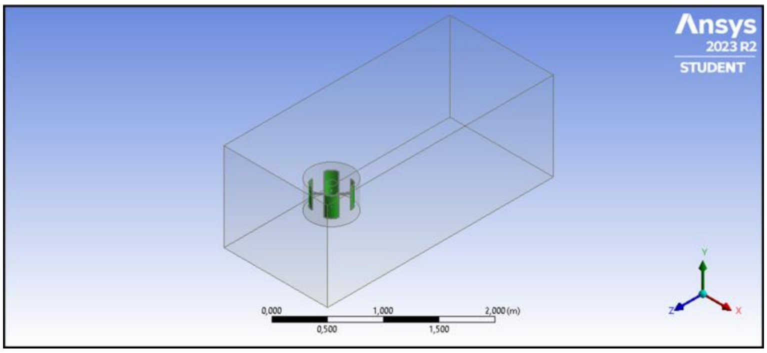

Figure 6. Modelling of turbine field and barrier

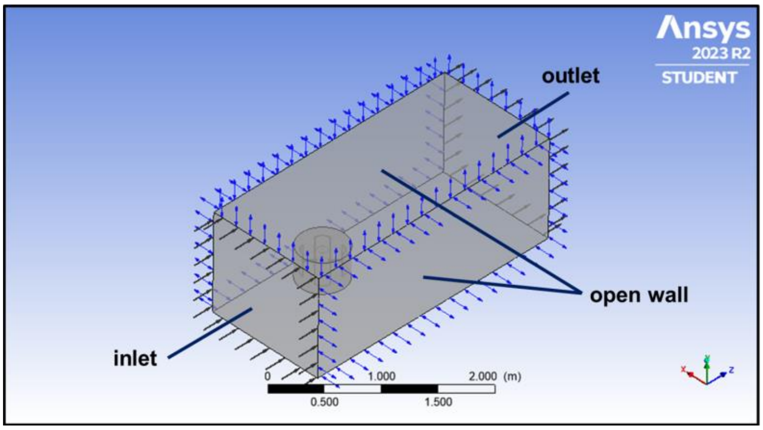

Figure 7. Boundary of turbine

(2) Solver-processing: solution

The number of iterations used in the running process affects the time when the simulation process is carried out, the stop of the iteration process has several factors, namely reaching the specified limit and the number of iterations that reach the convergence value. The running process of Flettner rotor was carried out 10 times with variations in rotor angular velocity every 500 rev/min from 500 rev/min to 5,000 rev/min. The running process of turbine was carried out 10 times with variations in turbine angular velocity every 10 rev/min from 10 rev/min to 100 rev/min.

(3) Post-processing: Results

The processing results obtained are images, graphs and animations with certain patterns that have pressure model values and three-dimensional flow visualization. The calculation of the thrust coefficient (C_T) [12] followed by the Flettner thrust (F_T) and Flettner rotor area (A) is shown in equations (1), (2), and (3).

$$C_T = \frac{F_T}{0,5\ .\ \rho\ .\ A\ .\ AWS^2} \qquad (1)$$

where
F_T = thrust on the Flettner rotor
F_T = P. A (2)
A = vertical cross-sectional area of the Flettner rotor
A = 0.5 x 3.14 x D x H (3)
ρ = air density
AWS = real wind speed
D = Flettner rotor diameter
H = Flettner rotor height

The calculation of power measurement from the force of Flettner rotor and turbine with linear velocity is shown in equation (4) and (5).

$$P = F\ x\ v \qquad (4)$$

where
P = Power
F = Force
v = Linear velocity

$$v = \frac{\text{RPM}}{60}\ x\ \pi\ x\ D \qquad (5)$$

where
RPM = Angular velocity
D = diameter

The Flettner rotor contribution was carried out in two calculation stages: ship resistance through the Ship Power Prediction - Holtrop and Mennen application and the percentage contribution of lift force to the ship's height, as shown in equation (6).

$$F{\sim}R = \frac{Thrust\ of\ FR}{Ship\ Resistance}\ x\ 100\% \qquad (6)$$

This research will discuss the energy management that must be done to some of the equipment installed on the model ship. Equipment that functions as a producer of electrical energy, namely wind turbines, will be placed in the most optimal position of the ship to get wind energy. The absorbed wind energy will be regulated by the wind controller and then converted into electrical energy stored in batteries with a certain capacity. The electrical energy becomes the source of electricity used to power the ship's propulsion equipment, namely the Flettner rotor. The management of the amount of electrical energy received and used on the model ship is calculated according to the capacity of each equipment. The amount of electrical energy stored in the battery must be kept greater than the electrical energy absorbed by the model ship's propulsion equipment. The electrical scheme shown in Figure 8.

The strategy of using hybrid energy is set according to the natural conditions crossed by the model ship. Data on the intensity of the wind blowing in the water area was obtained from reports published by competent agencies, followed by measurements of field conditions during the experiment. When the wind is at its maximum, the device functions as a turbine that captures gusts of wind. When the wind is stable, the device functions as a Flettner rotor to move the model ship by utilizing the direction of the wind. The storage of electrical energy in the battery is always monitored so that it can continue to supply the electricity needed to drive the model ship. In emergency conditions when the electrical energy in the battery is indicated to be running low, the ship is directed to be prepared to use a backup battery to get additional electricity supply until the main battery is re-energized from wind energy.

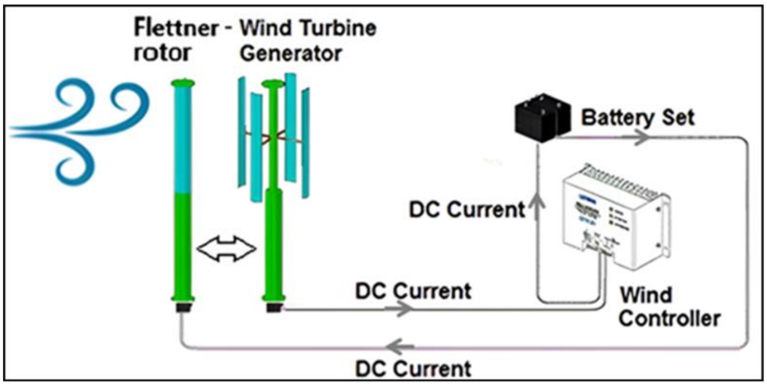

Figure 8. Electrical scheme of model ship with integrated turbine-Flettner rotor

TABLE 2.
FORCE AND PRESSURE VALUE OF FLETTNER ROTOR

Angular velocity (rev/min)	Force on Flettner (N)	Pressure on Flettner (Pa)
500	0,20	0,62
1000	0,43	0,42
1500	0,57	0,73
2000	0,67	1,52
2500	0,58	4,25
3000	0,58	5,40
3500	0,60	7,94
4000	0,58	10,59
4500	0,56	13,51
5000	0,51	16,77

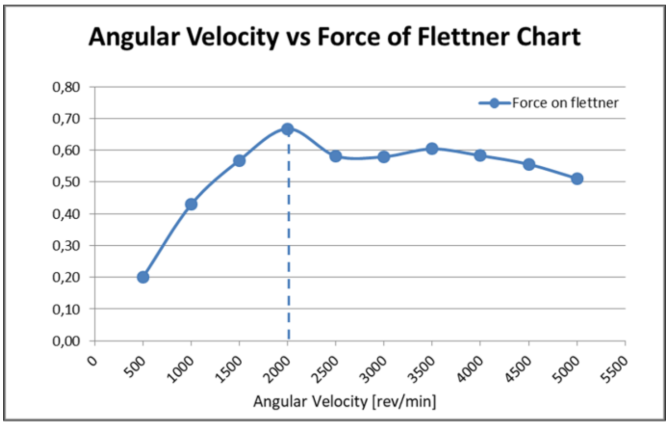

Figure 9. Angular Velocity vs Force of Flettner Chart

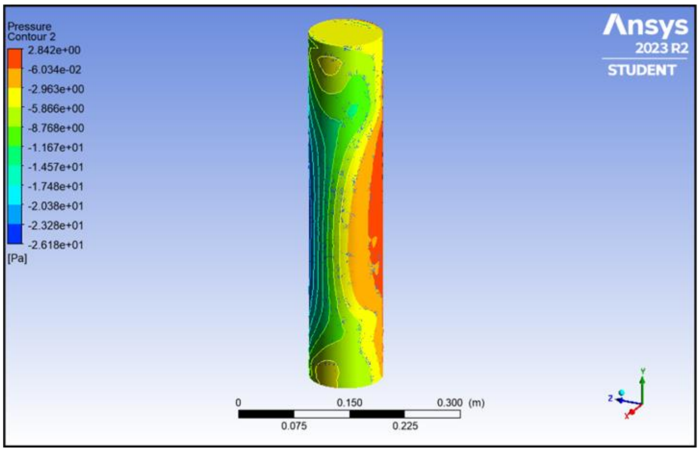

Figure 10. Visualization of Flettner rotor pressure

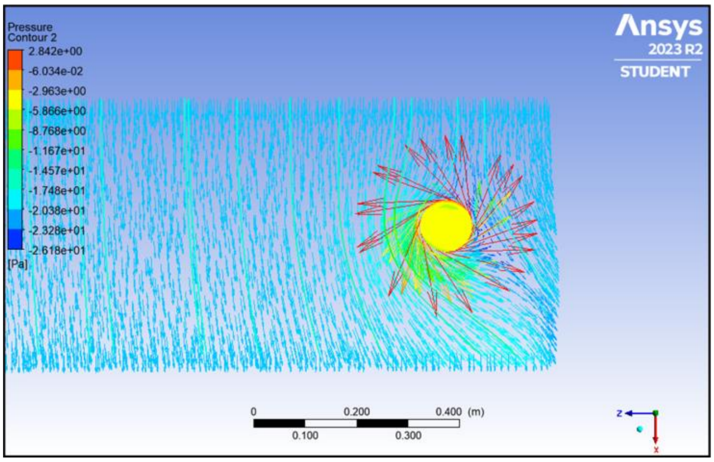

Figure 11. Visualization of Flettner flow speed

III. RESULTS AND DISCUSSION

The Ansys-CFX CFD simulation results show the force and pressure values with air float in 4 knots speed shown in Table 2.

The optimal force on the Flettner rotor starts at the moment of angular velocity in 2,000 rev/min based on chart as shown in Figure 9, with pressure value 1.52 Pa as shown in Figure 10.

From the simulations performed, the flow distribution in the Flettner rotor starts to experience a change in flow direction when it reaches 2,000 rev/min. Wind flow from the side of the ship is channeled towards the front of the ship so as to produce a forward thrust that helps the movement of the ship. The Visualization of the flow passing through the Flettner rotor cylinder in the form of laminar flow is shown in Figure 11.

After the simulation process of pressure and flow distribution in the Flettner rotor, the F_T and C_T values are calculated according to equations (1) and (2) with the result coefficient of thrust from Flettner rotor C_T of 0.15 and a thrust of Flettner rotor F_T of 0.26 kN at a wind speed of 4 knots.

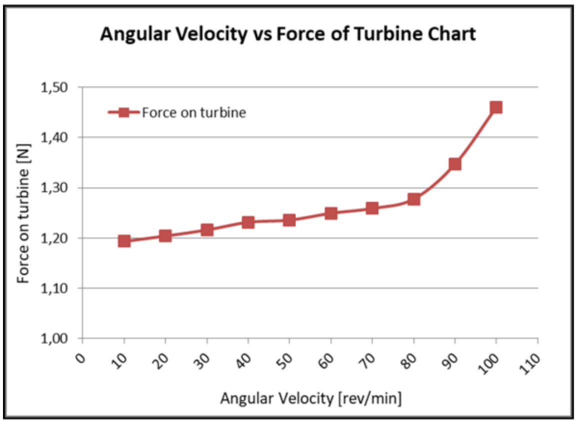

Figure 12. Angular velocity vs force of turbine chart

The calculation of the power required by the Flettner rotor at an angular velocity of 2,000 rev/min is calculated according to equations (5) so that a value of 10.472 m/s is obtained. Then the linear velocity of Flettner is calculated with the Force of 0.67 N according to equations (4), so that the power required by Flettner is 0.695 Watt.

To support these power requirements, the Flettner is transformed into a Vertical Axis Wind Turbine that takes wind energy and turns it into turbine force. The Ansys-CFX CFD simulation results show the force values of turbine with air float in 10 knots speed shown in Figure 12. To obtain power data from the turbine force, it is calculated according to equations (4) and (5), angular velocity is converted to linear velocity so that the power data generated by the turbine is obtained according to Table 3.

Based on this table, to meet Flettner's power requirement of 0.695 Watt, the turbine must rotate at a minimum angular velocity of 40 rpm so that a power of 0.903 Watt is generated to be stored in the battery as a reserve of electrical energy to rotate the rotor. The Visualization of the velocity passing through the turbine in the form of laminar flow is shown in Figure 13.

Ship resistance calculation simulation was carried out using the Holtrop method through the Maxsurf resistance application at a speed of 1-4 knots. The results as shown in Figure 14. Based on equation (6) and Figure 14, the Flettner rotor contribution on the Ship model was calculated, and the results as shown in Table 4. The highest contribution of the Flettner rotor with thrust of Flettner F_T of 0.26 kN at ship service speed 1 knot and ship total resistance of 0.01 kN reached 26,20%.

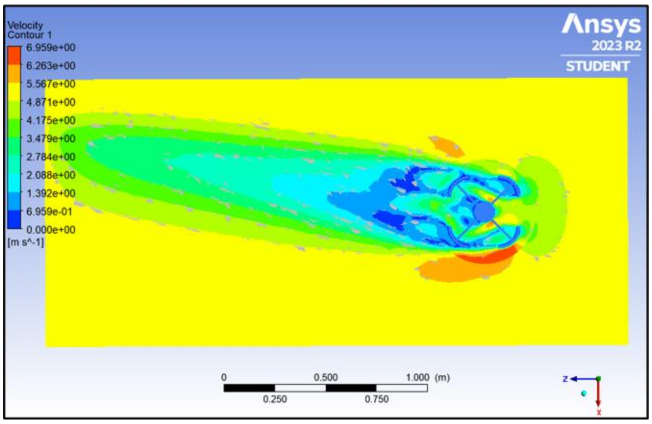

Figure 13. Visualization of turbine angular velocity

TABLE 3.
FORCE, LINEAR VELOCITY AND POWER VALUE OF TURBINE

Angular velocity (rev/min)	Force on Turbine (N)	Linear Velocity (m/s)	Power (Watt)
10	1,193	0,183	0,219
20	1,204	0,367	0,441
30	1,216	0,550	0,669
40	1,232	0,733	0,903
50	1,236	0,916	1,132
60	1,249	1,100	1,374
70	1,259	1,283	1,615
80	1,278	1,466	1,873
90	1,347	1,649	2,222
100	1,461	1,833	2,677

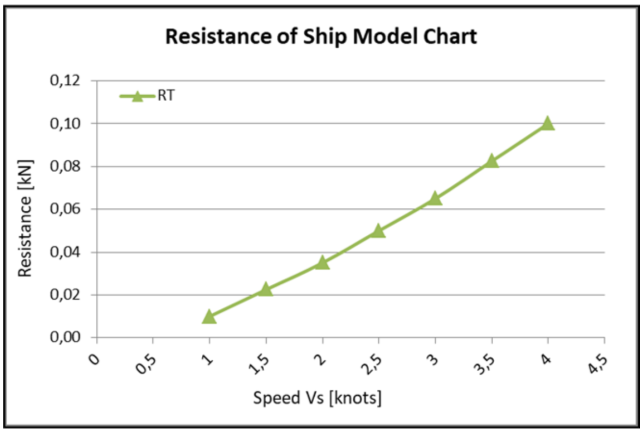

Figure 14. Resistance of Ship Model Chart

TABLE 4.
CONTRIBUTION PERCENTAGE OF FLETTNER ROTOR

Service Speed (knots)	Flettner Thrust (kN)	Total Resistance (kN)	Flettner Contribution (%)
1	0,26	0,010	26,20
1.5	0,26	0,023	11,64
2	0,26	0,035	7,49
2.5	0,26	0,050	5,24
3	0,26	0,065	4,03
3.5	0,26	0,083	3,18
4	0,26	0,100	2,62

IV. Conclusion

The use of this alternative energy in the hybrid power function on the model ship is the integration of vertical axis wind turbines and Flettner rotor. The Computational Fluid Dynamics (CFD) has calculated the optimal force on the Flettner rotor at the moment of angular velocity in 2,000 rev/min with pressure value 1.52 Pa. In this condition, the thrust coefficient (C_T) is 0.15 and the Flettner thrust (F_T) of 0.26 kN at a wind speed of 4 knots. The power required by Flettner is 0.695 Watt and the turbine must rotate at a minimum angular velocity of 40 rpm so that a power of 0.903 Watt. The highest contribution of the Flettner rotor at ship service speed 1 knot and ship total resistance of 0.01 kN reached 26,20%.

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