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Flettner Rotor Implication on Ship Ferry The Kalianget-Kagean Route Using Computational Fluid Dynamics

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ABSTRACT

Ship's Ferries are a sea crossing that continues to operate around the time. The consequence related to shipping activities is an increase in ship exhaust emissions. One alternative for ship propulsion that is environmentally friendly is the flettner rotor. The working principle of the tool follows the theory of the Magnus effect, where the force arises due to the difference in pressure between the two sides of the Flettner rotor. This study implicates the flettner rotor on the Kalianget-Kangean ferry route with variations in wind speeds of 10, 15 and 20 knots and variations in dimensions of 3x1, 5x1 and 7x1 meters with a rotational speed of 500 rpm. Optimal results through computational fluid dynamics (CFD) simulations show a coefficient of thrust from flettner rotor (C_T) of 3.647 and a thrust of flettner rotor (T_{FR}) of 2,980.5 kN with dimensions of 5x1 meters and a wind speed of 15 knots. While the implicit percentage of flettner rotors in KMP. DBS I of 18.11%, KMP. DBS III of 11.27%, and KMP. NS 92 of 5.45%.

Keywords: Flettner Rotor, CFD, Coefficient of Lift, Lift Force, Ship Ferry

Introduction

Ships as a means of sea transportation are very effective for travelling through waterways or the open sea. A ferry boat, or what was known as a ferry boat, was a means of sea transportation with short distance routes between islands, while the primary function of a ferry boat was a means of crossing vehicles or land transportation equipment, such as cars, trucks, etc [1] . In 2018, the Deputy Regent of Sumenep inaugurated a sea transportation facility called KMP Dharma Bahari Sumekar III to support the people of the Kangean Islands in carrying out crossing activities to Sumenep and vice versa. The existence of this ship is a form of strengthening transportation connectivity between islands in the Sumenep Archipelago region [2] .

The consequence of shipping activities is the emergence of ship exhaust emissions, resulting in NOx, SOx, CO2 and greenhouse gases. In 2007, we estimated that ship transportation contributed to 3.3% of the world's pollution. The International Maritime Organization

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(IMO) was making efforts to control and reduce CO2 emissions over five years in stages, starting in 2013 with a decrease of 10% until 2025 of 30% with the emergence of several regulations, such as the Energy Efficiency Design Index, Ship Energy Efficiency Management Plan [3] [4] . Apart from that, ferries that operate daily experience an increase in fuel consumption, directly influencing the increase in exhaust emissions [5] .

This tool was first used on the Buckau Ship in 1925, which crossed the Atlantic with one or more flettner rotors installed vertically on the ship's deck and rotating using a motor, which, when turning, could act as a sail to propel the ship under wind power. The benefits of Flettner rotors on ships can save fuel from 10 to 30% depending on the shipping route [6] . Compared with propulsion driven by conventional wind or sails, the advantage of the Flettner rotor was that it weighs only a quarter of the mast, sails and rigging. In addition, the Flettner rotor does not need to move the sail to accommodate the wind angle so that the ship can travel faster in various wind speeds and directions [7] . The use of a flettner rotor on a 4,000 DWT container ship with a ship speed of up to 10 knots shows that the rotation speed of the flettner rotor at 500 rpm and a wind speed of up to 5 knots produces 17.438% of the force that it must be exerted to move the ship [8] . The potential of flettner rotors as a ship propulsion system shows that drag and lift can positively contribute to thrust for various wind angles and reduce ship drag by up to 25% [9] .

Based on previous research, this research aims to propose an energy-efficient and environmentally friendly ship energy technology for ferries on the Kaliaget-Kagean route. One technology that can be applied on ships is the flettner rotor. This tool is cylindrical and rotates along the y-axis in a fluid flow of air to produce a fluid dynamic force due to the Magnus effect, discovered by Anton Flettner in 1920.

Methods

Flettner rotor

The aerodynamic force generated by a rotating cylinder, namely the flettner rotor, was mainly dependent on the spin ratio (or velocity ratio, also namely α), which accounts for the angular speed Ω, the flettner rotor diameter d, and the free stream velocity U as shown in Figure 1.

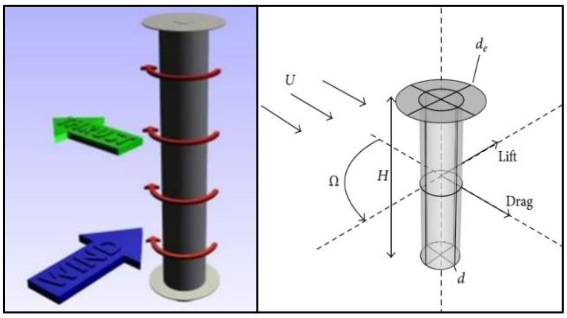

Figure 1. Flettner rotor parameters [10]

The power consumed by the motor, and the lift and drag forces acting on the cylinder determine the amount of main engine power the rotor is able to replace. The thrust gained from the rotor was calculated as the projection of the sum of the lift and drag force, respectively onto the course of the ship [11] .

Cruise route

Three Ferry Ship data were obtaining from the Indonesian Classification Bureau (BKI Ship Register) with the Kalianget-Kangean shipping route, including KMP. Dharma Bahari Sumekar (DBS) I, KMP. DBS III, and KMP. Sabuk Nusantara (SN) 92.

Table 1. Ship ferries dimensions

Dimensions	DBS I	DBS III	SN 92
L_{PP} (m)	37.62	42.50	57.36
B_{MLD} (m)	8.00	12.00	12.00
H_{MLD} (m)	3.00	3.60	4.00
T (m)	2.00	2.42	3.00
Engine (HP)	800	2x1,032	2x1,138

Source: BKI – Ship Register [12] [13] [14]

Table 2. Wind and wave risk

Level	Wind	Wave
Very safe	< 11 knots	< 1.25 m
Safe	11-15 knots	1.25-2.0 m
Less Dangerous	15-21 knots	2.0-2.5 m
Dangerous	> 21 knots	> 2.5 m

Source: BMKG [15]

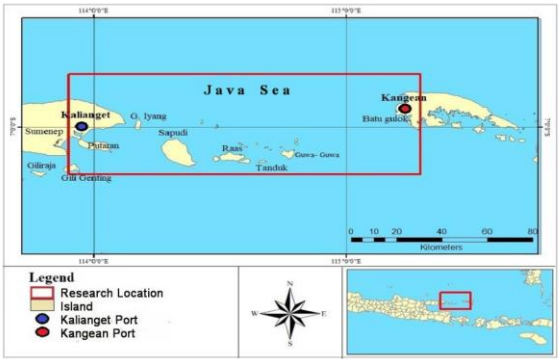

Figure 2. Kalianget-Kangean route [16]

Based on Figure 2, the Kalianget-Kangean shipping route was very safe, except for bad weather in December, January, and February, with wind speeds of more than 21 knots and wave heights of more than 2.5 m.

Simulation of CFD

Computational fluid dynamics (CFD) is an art that can replace integral and partial differential equations into discrete algebraic equations from which solutions can be obtained in the form of flow values at discrete points in space and time [17] . Meanwhile, CFD was related to the numerical solution of differential equations that regulate the transport of mass, momentum and energy in fluids [18] .

The stages of the Ansys-CFX CFD simulation [19] are as follows:

a. Pre-processor: geometry, mesh, setup

At the Geometry stage, two main fields are made. First, the flettner rotor has as many as three models with variable sizes 3x1 m, 5x1 m, and 7x1 m, as shown in Figure 3.

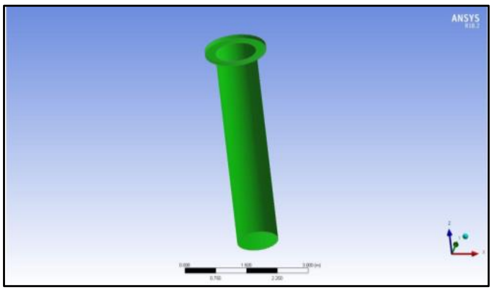

Figure 3. Flettner rotor model

The beam plane was useful as fluid media or fluid flowing place and interface as a barrier between the flettner rotors with fluid flow as shown in Figure 4.

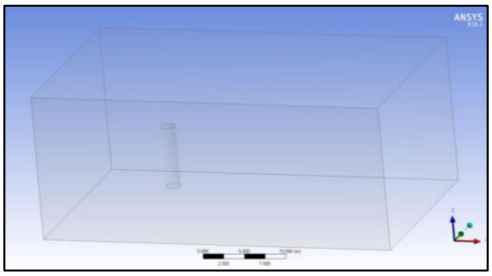

Figure 4. Domain and interface modeling

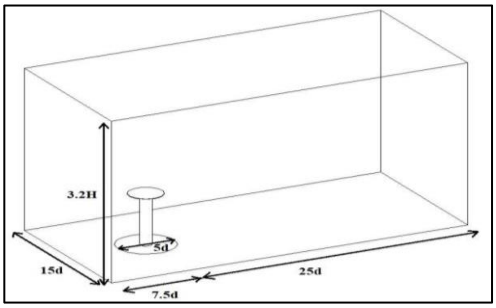

Figure 5. Computational domain dimensions [20]

Meshing itself is a process of uniting each image segment so that all parts of the image can be simulated CFD. This is because when the CFD simulation takes place, the software performs calculations on each of the elements as shown in Figure 6.

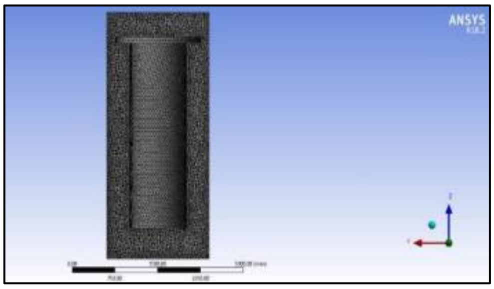

Figure 6. Meshing of flettner rotor

Set up the stage first, we create the Rotor domain with the rotating option and the stator domain of the fluid field with the stationary option. Other parameters that can be entered include the rotational speed of the flettner rotor which is 500 rpm and type of fluid that will be used in the simulation. The fluid speed of each model has three variables in simulation, namely the wind speed of 10.15, and 20 knots, the temperature of the fluid, and the parameters that have an influence on taking simulation results in the form of animation as shown in Figure 7.

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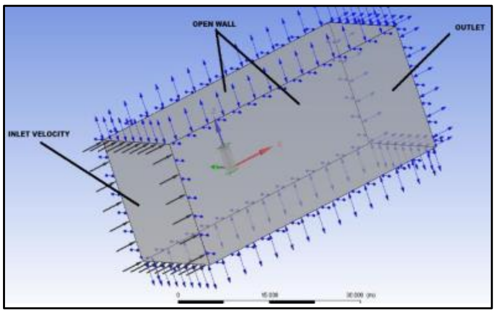

Figure 7. Boundary of flettner rotor

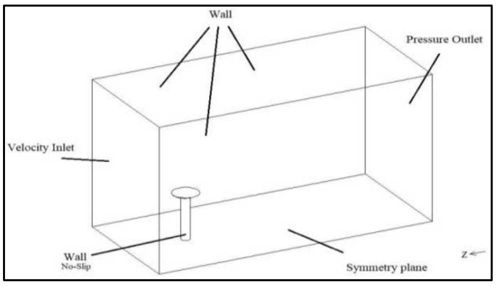

Figure 8. Defined boundary condition [20]

b. Solver-processor: solution
The amount of iteration used affects the time in the running process so the more iteration was used, the more the simulation process, and the cessation of the iteration process have several factors, namely reaching the specified limit and the amount of iteration reaching convergence. The running process was performed nine times on sizes flettner rotor models 3x1m, 5x1m, and 7x1m, where each with variations in wind speed of 10 knots, 15 knots, and 20 knots.
c. Post-processor: result.
Visualization takes the form of graphs, pictures and animations with specific patterns in the form of pressure model values and three-dimensional flow visualization.

Coefficient of Thrust (C_T)

The coefficient of thrust from flettner rotor (C_T) [21] followed by the thrust of flettner rotor (T_{FR}) and the flettner rotor area (A) as shown in equations (1), (2), and (3).

$$C_T = \frac{T_{FR}}{0{,}5\ \rho\ A\ U^2} \quad (1)$$

where

T_{FR} = thrust of flettner rotor = $P\ x\ A$ (2)

A = surface area of flettner rotor

$A = 0{,}5\ x\ 3{,}14\ x\ d\ x\ H$ (3)

ρ = air density

U = air velocity

d = diameter of flettner rotor

H = height of flettner rotor

Implication of flettner rotor

The Flettner rotor contribution was carried out in two calculation stages: ship resistance through the Maxsurf resistance application and the percentage contribution of lift force to the ship's height, as shown in equation (4).

$$F{\sim}R = \frac{Thrust\ of\ FR}{Ship\ Resistance}\ x\ 100\% \quad (4)$$

Results and Discussions

Ansys-CFX CFD simulation results showing pressure values are shown in Tables 3 and 4, while three-dimensional flow visualization as shown in Figures 2 and 3.

Table 3. Average of pressure value

Wind	Dimensions	Pressure (Pa)
	3x1 m	101,314
10 knots	5x1 m	121,312
	7x1 m	151,065
	3x1 m	111,300
15 knots	5x1 m	151,296
	7x1 m	171,127
	3x1 m	121,283
20 knots	5x1 m	161,310
	7x1 m	181,108

Table 4. Deviation average of pressure value

Dimensions	Wind	Pressure (Pa)
	10 knots	101,314
3x1 m	15 knots	111,300
	20 knots	121,283
	10 knots	121,312
5X1 m	15 knots	151,296
	20 knots	161,310
	10 knots	151,065
7x1 m	15 knots	171,127
	20 knots	181,108

Tables 2, 3, and 4 relate to risks at wind speeds of 10 – 20 knots and quite large pressure deviations, so the optimal Flettner rotor dimensions are 5x1 m in size.

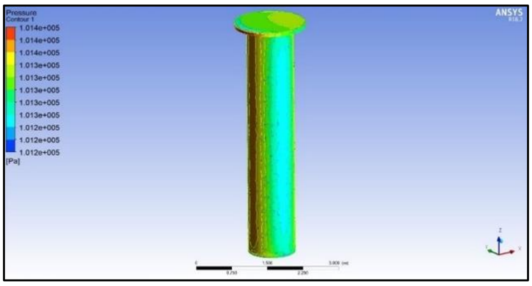

Figure 9. Pressure visualization of flettner rotor 5x1 m with wind speed 15 knots

Figure 9 shows a visualization of pressure at a wind speed of 15 knots and a rotation of 500 rpm, resulting in an even pressure distribution with an average pressure value of 151,296 Pa.

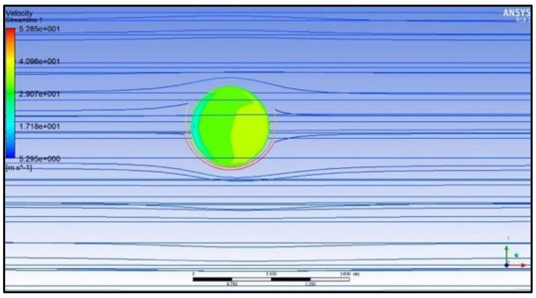

Figure 10. Flow speed visualization of flettner rotor 5x1 m with wind speed 15 knots

Figure 10 shows a visualization of the flow passing through the Flettner rotor cylinder in the form of laminar flow.

After the simulation process regarding the pressure and flow distribution in the Flettner rotor, the T_{FR} and C_T values were calculated according to equations (1) and (2) with the results shown in Table 5.

Table 5. T_{FR} dan C_T value

Dimensions	Wind (knots)	T_{FR} (kN)	C_T
5x1 m	10	2,389.8	2.924
	15	2,980.5	3.647
	20	3,177.8	3.889

Table 5 shows that a 5x1 meter Flettner rotor with a wind speed of 10 – 20 knots has a C_T value in the range of 3 to 4.

Before the implication of the Flettner rotor on the three Ferry Ships, a ship resistance calculation simulation was carried out using the Holtrop method through the Maxsurf resistance application at a speed of 15 knots. The results as shown in Table 6.

Table 6. Resistance value on Ship Ferries

Ship Ferries	Resist. (kN)	Power (kW)
DBS I	164.5	1,823.872
DBS III	264.3	2,914.114
SN 92	546.1	6,019.948

Based on equation (4) and Table 6, the Flettner rotor contribution on the three Ferry Ships was calculated, and the results as shown in Table 7.

Table 7. Percentage of flettner rotor

Ship Ferries	Wind	%
DBS I	10 knots	14.52
	15 knots	18.11
	20 knots	19.31
DBS III	10 knots	9.04
	15 knots	11.27
	20 knots	12.02
SN 92	10 knots	4.37
	15 knots	5.45
	20 knots	5.81

Table 7 shows the contribution of the Flettner rotor regarding the implications on the Ferry at a wind speed of 15 knots, indicating KMP. DBS I was 18.11%, KMP. DBS III at 11.27%, and KMP. SN 92 is 5.45%.

Based on the most significant contribution, the implications of the Flettner rotor on KMP are proposed. DBS I is presented in Figure 11.

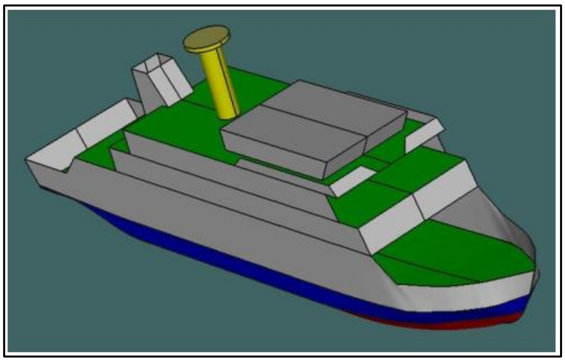

Figure 11. Model of Flettner rotor 5x1 m

Conclusions

Implications of the flettner rotor on a ship ferry have dimensions of 5x1 meter with a coefficient of thrust from flettner rotor (C_T) of 3.647 and a thrust of flettner rotor (T_{FR}) of 2,980.5 kN. At a wind speed of 15 knots, the flettner rotor contribution is given to the KMP. DBS I at 18.11%, KMP. DBS III at 11.27%, and KMP. SN 92 is 5.45%.

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Author Contributions
Akmal Firdausyah: conceptualization, collecting data, prepare model, Ansys running, draft writing; **Ali Munazid**: final model, Ansys running-supervision and editing: **Prasetyono Eko Pambudi**: collecting data, writing – review and editing; **Ahmad Fitriadhy**: supervision, writing – review and editing **Bagiyo Suwasono**: conceptualization, methodology, supervision, writing – review and editing.

Conflicts of Interest
The authors declare no conflict of interest.

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