Fluid Distribution Analysis of Kite Sail for Application on Ship

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***Abstract*—the increasing number of operating ships resulted in high air pollution from the combustion of the ship's engine. Efforts to utilize alternative energy to reduce ship engine work have been done, one of them is using unlimited alternative energy that is wind where one of its application of is the application of new ships sail, kite sail as auxiliary system of ship propulsion . In this final project purposed to find out the value of aerodynamic force of kite sail and power it can generated , with a CFD method that uses 3 kite sail design forms, rectangular, triangular, and elliptical, with an area of 160 m2 this models are simulated at wind speed variations from 13.4 m / s up 15.82 m / s and angel of attack variation of 15.20, and 25. From the variation obtained the total aerodynamic force generated can reach 28.73 kN in rectangular shape, 30.79 kN of Elipsical shape, and 27.55 kN of triangular shape, on variant Angel Of attack 25. From the value of the aerodynamic force, each kite sail capable of generating power, on a rectangular kite sail of up to 263.02 kW, an elipsical 276.75 kW, and a triangular 252.63 kW.**

Keywords— kite sail, aerodynamic forces, lift force, drag force, wind speed.

I. INTRODUCTION

Increased number of operating ship all around the world made sea and ocean's pollution getting worse, because the exhaust gas from engine combustion contain such a emissions like NOx, Sox, and CO that known cause green house effect [1-8]. To resolved this problem, people trying to find or use the unconventional energy, and one of them is wind. Using wind as propulsion system is a classic method from long time ago before engine was found, but recently a hybrid propulsion with combination of diesel engine and wind based auxiliary systems are applied on some ships [2]. Considering from social and economic premises at that times, using diesel engine or steam engine instead sail propulsion is a good transition for maritime trading. In early 20th century, there is no concern about sea and ocean's pollution from high fuel consumption, nobody could tought that pollution will become such a serious problem for humanity and environment,. As time passed by, with the development of since and technology, the type and number of ship are boomed as well as the rapid growing global market [9].

More ship operates, more exhaust are produced. Ship exhaust contains harmful air toxics that causes cancer, respiratory illness and premature death. In thi circumstances, while oil price has risen leading to important modification for ship systems, to start using unconventional energies that will reduce the pollution and oil use, and wind is one of it that already proved can used for ship propulsion.. There's a lot of wind propulsion system, like rigid sail, wing sail, turbine, flatner rotor, and the recent one is a kite sail. Kite sail is a kite that attached to the ship with steel rope as the towing rope with the purpose to make use of higher wind speed in high altitude and convert it into force that will pull the ship as addition thrust for ship. Kite sail forces appeared by effect of fluid flow that passed it surface, and generate an aerodynamic forces that divided into lift force and drag force. Lift force is a force with direction perpendicular with wind traction and drag force has same direction with wind traction. This forces are generated from pressure difference from upper surface and lower surface of kite sail [10].

Utilizing the kite traction does not mean to fully change the conventional fuel engine propulsion, the concern is making the engine not work at full capacity to get the required ship speed, by using combination propulsion system to covered speed deficit partially using kite's tractive force [1].

A. Force on Kite

Kite can considered as wing surface that can applied the three principle of forces acting on the kite, there are the weight, tension of towing cable, and aerodynamic force.. the weight is a force that affected by the density and volume of kite and gravity that will act from the center of gravity toward center of the earth. For the aerodynamic force, it has divide into two components, the lift force L, that has been act perpendicular to wind direction and drag force D, that has same direction with incoming wind.

One of the reason using the kite sail was to generate power from wind, where near the ground the wind may swirl , but as higher the altitude, the wind fairly become constant and nearly parallel to surface of the earth, and in thi case, lift force will go to directly opposed to the weight of the kite as shown at figure 1.

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Fot the cable tension, it will act through the bridle point or the controlling pod where the lne will attached to the kite. The cable tension divided into two pulling direction, there are vertical pull Vp ad horizontal pull Hp

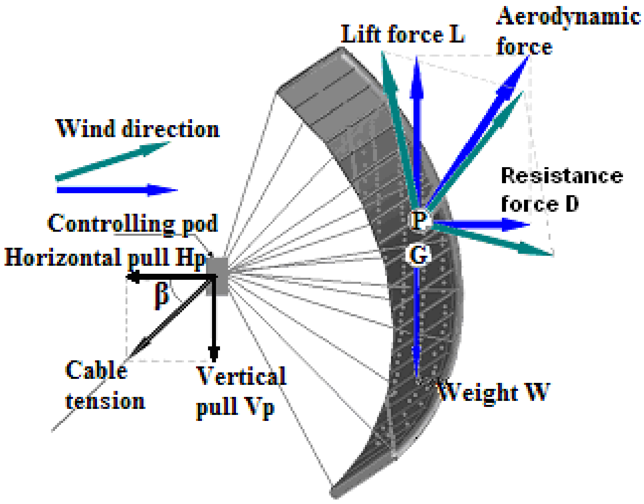

Figure. 1. Aerodynamic Force of Kite

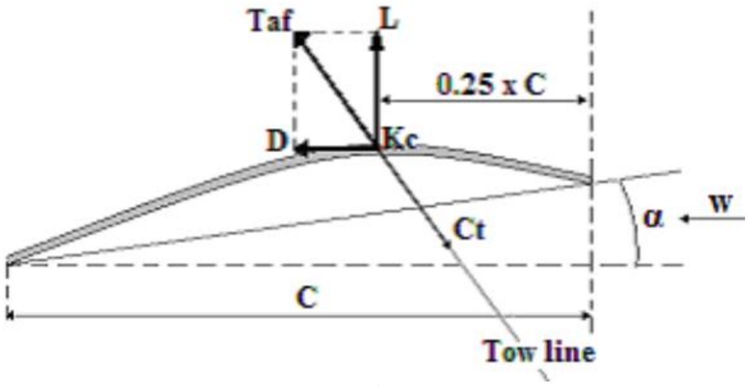

Figure. 2. Formula of Aerodynamic Force

B. Aerodynamic Force on Kite

As explained before, aerodynamic force divided into lift force and drag force . this forces are affected by various factor that will determine the value of the force, there are :

- Area of the kite
- Shape of the kite
- Wind velocity
- Angle of Attack
- Density of the fluid that passed the kite, in this case the air.

The formula to calculate the force based on the the aspect are

$$L = \frac{1}{2}\rho C_L W^2 A_k \quad (3)$$

$$D = \frac{1}{2}\rho C_D W^2 A_k \quad (4)$$

$$T_{af} = \sqrt{L^2 + D^2} \quad (5)$$

With the following note based on figure 2. Where :

D	= resistance force
L	= lift force
Taf	= total aerodynamic force
C	= chord
Ct	= towing cable tension (equal value with Taf)
α	= incidence angle of wind
w	= wind velocity
Kc	= application center of forces

C. Kite sail's force into power for ship propulsion

the main target of using kite sail for propulsion system is to reduce work of engine , by using thhe kite traction trough the towing rope. When applying a kite for the propulsion of an object on the horizontal plane, e.g. a ship at sea or a trolley moving along a track, the trajectory of the fixation point itself becomes an important factor [2]. Show in figure 3 where the elevation angle represents the position in the wind window, the fixation point of the tethermoves along the ship's or trolley's course parallel to the true wind while the kite follows its designated flight pattern at its own speed above

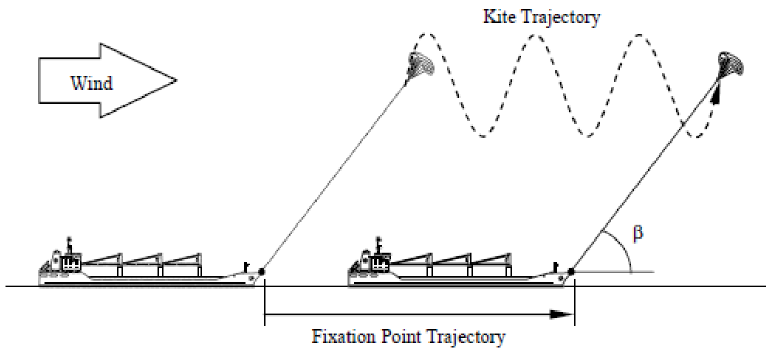

Figure. 3. Trajectory of Aerodynamic Force

To calculate the power generated by kite traction, are determined by fixation or ground pont speed and the equal aligned component of lether force (cable tension) with the following formula [6] :

$$P = Vg \times Ct \times \cos\beta \quad (6)$$

Dimana

Vg = ground point velocity (ship velocity) (m/s)

Ct = cable tension (kN)

B = angle between kite sail and ground (°)

III. METHOD

1. Data Gathering

With the purposed to find how much force will generated from kite sail, spesification of the kite are needed for design stage. There are 3 shape of kite are used , rectangular, elipsical and triangular. This designs use same airfoil profile, using NACA 6409 and have flat area 160 m^2 with span/chord ration 2.5.

Using the surfplan software, the result of span x chord of each form is rectangular (20 x 8) m , elipsical (23.7 x 8.6) m , and triangular (19.5 x 11.8) m shown in figure 4. For wind speed data, because the kite has operating condition between 100 – 300 m altitude, the wind speed will more higher than wind speed at sea surface. A surface wind data need to determined wind speed at higher altitude using this calculation :

$$Vwz = Vg \times z^{0.14}$$

Vwz = Wind speed at Height z (m/s)

Vg = wind speed at surface (m/s)

Z = altitude (m)

To determine wind direction and wind speed at surface , it is necessary to specify the shipping route to be used, in this case, the domestic shipping route using BATAM - SURABAYA route. On the voyage of this route, based on general wind conditions in the area (maret period) with averange wind speed 14 knot , then the direction of wind speed mapping as shown in figure 5, that direction are :

point 1 : 21 from portside (201 derajat)
point 2 : 57 from portside (237 derajat)
point 3 : same direction with ship (90 derajat)
point 4 : 62 from arahstarboard (298 derajat)

with data of wind speed on the surface of the water, the wind speed can be found at the specific height that will be used for kite sail operation. At this time using variations of altitude 100 M, 150 M, 200 M, 250 M, and 300 M.

To find out the substantial power generated by kite sail, use the following formula (Falko Fritz, 2013):

$$P = Vg \times Taf \times \cos\beta$$

Where

Vg = speed of ground point (in this case the speed of Ship) (m / s)

Taf = total aerodynamic force (kN)

B = angle kite sail against ship (°)

this kite angle is created from the position of the kite sail against the ship connected to the kite rope, which is influenced from the far kite sail of the ship and the height of the kite sail. The result are shown in tabl;e 2.

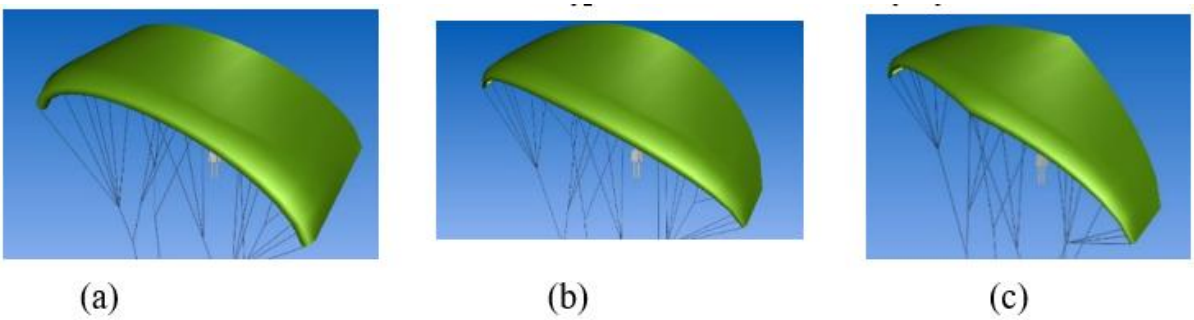

Figure. 4. Three types of kite form , (a) Rectangular , (b) elipsical, (c) triangular

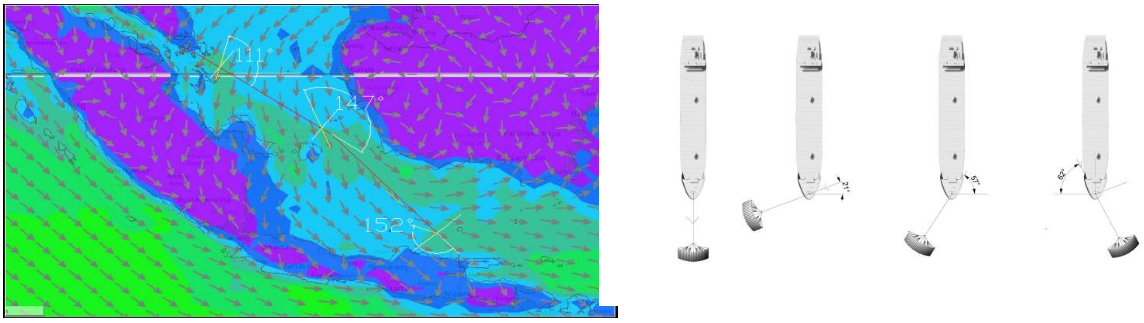

Figure. 5. Ship route Batam –Surabaya with wind direction

TABLE. 1.
WIND SPEED DEPEND ON HEIGHT

Height	wind speed (knot)	wind speed (m/s)
100	27.04755644	13.52377822
150	28.6621712	14.3310856
200	29.86588064	14.93294032
250	30.8342548	15.4171274
300	31.6487364	15.8243682

TABLE. 2.
ANGLE BETWEEN SHIP AND KITE SAIL AT SPECIFIC HEIGHT

Height (m)	β (º)
100	27
150	37
200	45
250	51
300	56

2. Model Design

Design process using rhino 3D software, using airfoil profile sourced from airfoiltools website, then made using the size of each form. After the design process is completed, the 3d model is positioned with 3 position variations based on the angle of attack

3. Simulation

The next step is Modeling kite sail on CFD and doing Simulation to get the value of lift and drag force from each kite sail's Form. Analyze the amount of force acting on the kite sail Can be done by modeling the kite sail and inserting Boundary conditions[5].
The output of this CFD modeling Is the value of Lift and Drag force of kite sail. In Modeling this CFD, the process is divided in three stages, ie Stage pre-processor, flow solver, and post-processor[4].

IV. RESULT AND DISCUSSION

A. CFD Simulation Result

The simulation of cfd is done using Ansys Fluent software where from the model which has boundary condition in meshing then done simulation process with variation of velocity determined by wind direction equal to vector determination where y vector is monitored as lift force and vector x / z as monitor style Drag depending on where the position of the sail facing, where the results obtained as shown in table 3

TABLE. 3.
LIFT FORCE AND DRAG FORCE OF KITE SAIL

Kite sail form	Angle of attack	Wind speed (m/s)	Lift force(kN)	drag force (kN)
Rectangular	15	13.52377822	16.9	3.01
		14.3310856	18.97	3.38
		14.93294032	20.61	3.67
		15.4171274	22.01	3.92
		15.8243682	23.76	4.23
	20	13.52377822	16.62	4.98
		14.3310856	18.61	5.59
		14.93294032	20.13	6.01
		15.4171274	21.57	6.55
		15.8243682	23.25	7.07
	25	13.52377822	16.93	7.9
		14.3310856	18.99	8.86
		14.93294032	23.01	9.55
		15.4171274	24.56	10.2
		15.8243682	26.54	11.02
Elipsical	15	13.52377822	17.82	2.67
		14.3310856	20.12	2.99
		14.93294032	21.93	3.25
		15.4171274	23.42	3.47
		15.8243682	25.28	3.75
	20	13.52377822	19.34	5.67
		14.3310856	21.52	6.33
		14.93294032	23.54	6.87
		15.4171274	25.14	7.34
		15.8243682	27.13	7.92
	25	13.52377822	19.68	6.76
		14.3310856	22.43	7.69
		14.93294032	24.66	8.89
		15.4171274	26.07	9.87
		15.8243682	28.78	10.97
Triangular	15	13.52377822	16.07	3.02
		14.3310856	18.04	3.388
		14.93294032	19.59	3.679
		15.4171274	20.92	3.93
		15.8243682	22.58	4.28
	20	13.52377822	16.82	5.02
		14.3310856	18.86	5.635
		14.93294032	20.47	6.12
		15.4171274	21.86	6.537
		15.8243682	23.59	7.06
	25	13.52377822	18.17	7.38
		14.3310856	20.68	8.43
		14.93294032	22.18	8.98
		15.4171274	23.63	9.56

From the table can be seen where the lift force and drag force generated by each form the larger the kite sail when the wind speed faster and also when the angle of the enlarged attack will increase the lift and drag force generated where from the simulation performed the largest results obtained at the speed Wind 15.82 m / s at angle of attack 25 ..

seeing from the result of the greatest force generated, the ellipsical form is capable of producing the greatest lift style and the rectangular produces the greatest drag force, wherein the result is influenced by the shape of the kite sail, although it has the same area in which (3) 4), the shape of the kite sail will affect the lift and drag coefficient. Where By entering the value of elevator and drag into equation (3) and (4), it will get the value of elevator and drag coefficient. The value of lift and drag coefficients can be seen in table 5.

TABLE. 4.
LIFT COEFFICIENT OF KITE SAIL

Wind speed	Rectangular			Elipsical			Triangular		
	15	20	25	15	20	25	15	20	25
13.52	0.94	0.93	0.94	0.99	1.08	1.10	0.90	0.94	1.01
14.33	0.94	0.92	0.94	1.00	1.07	1.11	0.90	0.94	1.03
14.93	0.94	0.92	1.05	1.00	1.08	1.13	0.90	0.94	1.01
15.42	0.94	0.93	1.05	1.01	1.08	1.12	0.90	0.94	1.01
15.82	0.97	0.95	1.08	1.03	1.11	1.17	0.92	0.96	1.04

TABLE. 5.
DRAG COEFFICIENT OF KITE SAIL

Wind speed	Rectangular			Elipsical			Triangular		
	15	20	25	15	20	25	15	20	25
13.52	0.17	0.28	0.44	0.15	0.32	0.38	0.17	0.28	0.41
14.33	0.17	0.28	0.44	0.15	0.31	0.38	0.17	0.28	0.42
14.93	0.17	0.28	0.44	0.15	0.31	0.41	0.17	0.28	0.41
15.42	0.17	0.28	0.44	0.15	0.32	0.42	0.17	0.28	0.41
15.82	0.17	0.29	0.45	0.15	0.32	0.45	0.17	0.29	0.42

As can be seen in the table above where the magnitude of both lift and drag coefficients of each different shape, which is influenced by various factors, such as wind velocity that attack the surface of the kite sail, the magnitude of the attack angle of the kite sail, and also the shape of the kite Sail itself, which in general elipsical shape has a small drag force (1)

In searching the total value of aerodynamic force by finding the resultant of the lift and drag using equation (5) with the results that can be seen in the table. With the total aerodynamic force ratio produced can be seen in graph 1.

TABLE. 6.
TOTAL AERODYNAMIC FORCE OF KITE SAIL

Wind speed	Rectangular			Elipsical			Triangular		
	15	20	25	15	20	25	15	20	25
13.52	17.17	17.35	18.68	18.02	20.15	20.81	16.35	17.55	19.61
14.33	19.27	19.43	20.96	20.34	22.43	23.71	18.36	19.68	22.33
14.93	20.93	21.01	24.91	22.17	24.52	26.21	19.93	21.37	23.93
15.42	22.36	22.54	26.59	23.68	26.19	27.88	21.29	22.82	25.49
15.82	24.13	24.30	28.74	25.56	28.26	30.80	22.98	24.62	27.56

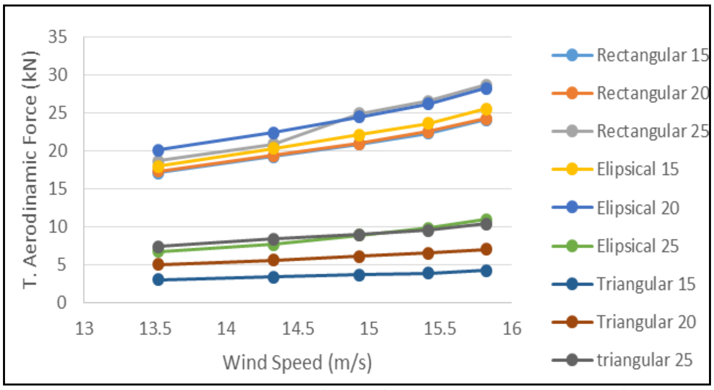

Figure. 6. Total Aerodynamic force of Kite Sails depend on their form

B. Power Generated by Kite Sail

The value of the cable tension generated by the kite sail will cause traction on the ship, which can cause the ship to move in the direction of the kite, in other words there will be power to drive the ship. To determine the amount of power generated, using equation (6), where the magnitude of the angle of the beta is the angle between kite sail with the direction of the ship, where it can be seen the force acting on the vessel as in figure 6. where angle b is the angle between the Taf vectors And Fxy, which indicates that there is a horizontal and vertical force acting on the ship, the vertical force is negligible because it is insufficient to lift the vessel.

In this simulation it is assumed that the kite sail is 200 meters in front of the ship, with a variation of altitude corresponding to that used to find the wind speed, which can be seen in figure 7. The power generated by kite to propulse the ship are shown in table 7

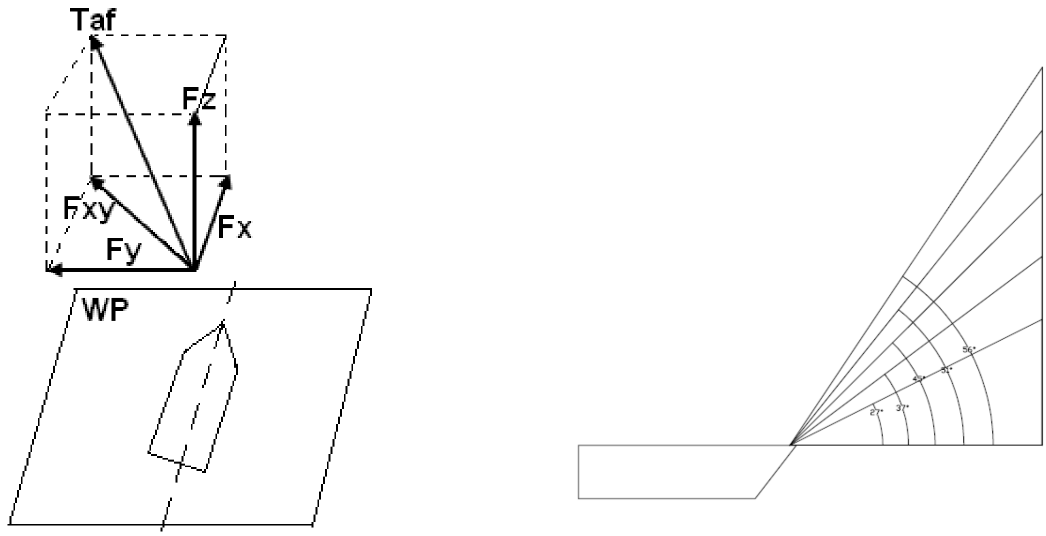

Figure. 7. Direction of forces works on ship at waterplan and angle of kite sail and ship direction

TABLE. 7.
TOTAL AERODYNAMIC FORCE OF KITE SAIL (RECTANGULAR)

Kite form	AoA	Vs (m/s)	Cable Tension (kN)	β	Cos β	Power (kW)
Rectangular	15	13.52	17.17	27	0.891	206.84
		14.33	19.27	37	0.798	220.36
		14.93	20.93	45	0.707	221.01
		15.42	22.36	51	0.629	216.80
		15.82	24.13	56	0.559	213.48
	20	13.52	17.35	27	0.891	209.06
		14.33	19.43	37	0.798	222.22
		14.93	21.01	45	0.707	221.79
		15.42	22.54	51	0.629	218.60
		15.82	24.30	56	0.559	214.96
	25	13.52	18.68	27	0.891	225.12
		14.33	20.96	37	0.798	239.65
		14.93	24.91	45	0.707	263.02
		15.42	26.59	51	0.629	257.89
		15.82	28.74	56	0.559	254.20

TABLE. 8.
TOTAL AERODYNAMIC FORCE OF KITE SAIL (ELIPSICAL)

Kite form	AoA	Vs (m/s)	Cable Tension (kN)	β	Cos β	Power (kW)
Elipsical	15	13.52	18.02	27	0.891	217.12
		14.33	20.34	37	0.798	232.62
		14.93	22.17	45	0.707	234.06
		15.42	23.68	51	0.629	229.59
		15.82	25.56	56	0.559	226.07
	20	13.52	20.15	27	0.891	242.85
		14.33	22.43	37	0.798	256.53
		14.93	24.52	45	0.707	258.89
		15.42	26.19	51	0.629	253.97
		15.82	28.26	56	0.559	250.00
	25	13.52	20.81	27	0.891	250.74
		14.33	23.71	37	0.798	271.17
		14.93	26.21	45	0.707	276.75
		15.42	27.88	51	0.629	270.32
		15.82	30.80	56	0.559	272.45

TABLE. 9.
TOTAL AERODYNAMIC FORCE OF KITE SAIL (TRIANGULAR)

Kite form	AoA	Vs (m/s)	Cable Tension (kN)	β	Cos β	Power (kW)
Triangular	15	13.52	16.35	27	0.891	197.03
		14.33	18.36	37	0.798	209.92
		14.93	19.93	45	0.707	210.44
		15.42	21.29	51	0.629	206.42
		15.82	22.98	56	0.559	203.30
	20	13.52	17.55	27	0.891	211.51
		14.33	19.68	37	0.798	225.11
		14.93	21.37	45	0.707	225.57
		15.42	22.82	51	0.629	221.26
		15.82	24.62	56	0.559	217.82
	25	13.52	19.61	27	0.891	236.31
		14.33	22.33	37	0.798	255.40
		14.93	23.93	45	0.707	252.63
		15.42	25.49	51	0.629	247.19
		15.82	27.56	56	0.559	243.79

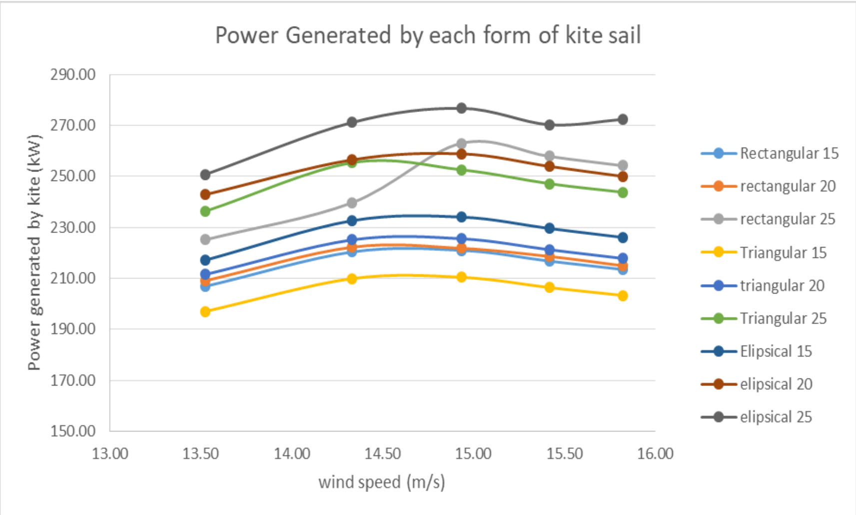

Figure. 8. Power Generated by each form of kite sail

From the graph and table above, the position of the kite sail will affect the power generated to move the ship. The style that exists between the sleek style of the ship which will bring up the horizontal force acting on the ship whose total force works is a tension cable on a rope crane connecting the kite with the ship. At some point, the power generated will increase. But due to the higher position the resulting horizontal force decreases. From these results can be seen that there are some conditions where kite sail is able to produce optimal power. For the case where the kite sail is attacked from various directions of the wind, on a stationary vessel, there is a distorted movement due to the Fx and Fy forces acting on the ship as shown in figure 6. for example, if a ship uses a kite sail rectangular with a wind velocity of 15.82 m / S with AoA 25, then the amount of deviation generated based on the wind direction used in the simulation can be seen in table 8, where sought Fx and Fy values, with calcuation like below :

$$Fx = Fxy \sin\alpha \quad (7)$$

$$Fy = Fxy \cos\alpha \quad (8)$$

even though Fx is smaller but on the ship without any style of rudder it will be deviation .

TABLE. 10.
SHIP DIRECTION AFTER KITE SAIL ATTACKED FROM DIFFERENT WIND DIRECTION

Direction of wind came from (º)		α (º)	Fxy (kN)	Fx	Fy	Ship's heading
90	Stern	90	16.06827	16.06827	0	Ahead
21	Portside	69	16.06827	15.001	5.758	SB
57	Portside	33	16.06827	8.751	13.476	SB
62	Starbooard	28	16.06827	7.543	14.187	PS

V. CONCLUSION

The use of kite sail as auxiliary system for ship propulsion purposes can be a consideration in selecting solutions to reduce pollution from combustion engine results and can be used to save fuel because by using it is able to lower the engine work to not work at full capacity. Where there are some points to note are:

- the operation of the kite sail is focused on utilizing stable and high wind speeds at certain altitudes.
- the shape and extent of the kite sail will affect the magnitude of the force generated by the kite sail. Where the force will pull the ship through the towing rope that connects the kite sail
- the position of the kite sail will affect the magnitude of the force acting on the vessel, therefore from the whole kite sail system there is a sub-system control to adjust the position of the kite sail against the wind that crashed to produce optimal power.
- looking at the speed and altitude of kite sail work in general, then kite suitable for use on ocean loose like ocean and can not be used continuously where in coastal waters will be very risk if operate kite sail because besides wind not as strong in the middle of sea also disturb Flight path especially for domestic aircraft.
- Kite sail follows the direction of the wind that attacked him, so that if none of the rudder the ship will experience the deviation direction from the previous direction follow the direction of kite sail.

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