CONSIDERATIONS REGARDING KITE TOWED SHIP'S MANOEUVERING

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Abstract

In the last 30 years air pollution has reached alarming levels. Marine pollution caused by ships scour the seas and oceans contribute to their continued degradation of air and marine environment. Fossil fuels for marine propulsion engines began to be challenged and the world have taken a number of restrictive measures with regard to fuel composition and especially the emission of NO_x, SO_x, CO.
In this context unconventional methods of propulsion have returned to date. Mixed solutions are sought for the propulsion generated by fossil fuels and high sail at a certain height or use electric motors for propulsion.
In this paper tried to show that it is possible to propel the ship and sail through high at a certain height (kite). Considering zero vessel speed, we watch the effect it has on the ship sail, traction and how they influence the stability of sail road towed vessel.
Considering the sail of a certain size, and constant wind speed of action and different wind angles, we calculated the force required to follow if elected to sail aerodynamic profile, can speed up a vessel and especially if lateral deviation force affects the accuracy of the stability of the road.

Key-Words: ocean pollution, unconventional energy, kite propulsion, aerodynamic force, ships manoeuvrability.

1 Introduction

Lately, seas and ocean's pollution has reached alarming levels. And despite all efforts made by owners, shipbuilders and all parties involved in maritime trading, the results are not those expected.

The 18^{th} century is to be considered the starting point for engineering research knowledge. With no defiance for contribution of earlier scientists like Galilei, Watt, Newcomen, Papin, the 19^{th} century was the beginning of world industrialization. It was the time when Fulton found the satisfactory solution of using steam as auxiliary power at "Clermont" ship (1807), and it was the time when Rudolf Diesel developed his version of engine based on Carnot principles.

Considering social and economic premises of that times, the new engineering discoveries, special those concerning ship's propulsion, were considered absolutely amazing ideas for maritime trading. Transition from sail's propulsion to steam and diesel engines lately was a gradual process in which the mixed propulsion had appeared as a preliminary solution of modern navigation.

At the beginning of 20^{th} century, there was no concern for high fuel consumption nor for air and seas pollution, nobody would thought that pollution will become such a serious problem affecting entire planet. It was naturally to be like that as soon as maritime trading was at a low level and only few nations owned ships at that times. Unfortunately with the booming science and technology the type and number of ships boomed as well in a rapid growing world market.

Marine environment is of crucial importance for earth climate and meteorolgical phenomenas as soon as it is the one to balance the carbon dioxide levels of global atmosphere.

Nowadays the total CO_2 quantity absorbed by planetary ocean has a significant decrease, comparing it with the one of 20 years ago. Changing in temperature and chemical seawater composition has led to increasing slowing down of CO_2 absorbtion.

The oceans represents about ¾ of global surface and also about 95 % of entire hydrosphere. It preserves the biggest variety of biological and mineral resources. All these, unfortunately are not inexhaustible, more than that, great part of it not studied or discovered yet.

Ship exhaust contains harmful air toxics that cause cancer, respiratory illness and premature death. The world's shipping fleet generates about four percent of the world's carbon dioxide emissions.

In these circumstances, in which oil price has risen leading to important modifications of the global economy, the solutions for unconventional energies have awaken the interest of those implicated in the maritime transport.

Unconventional propulsion systems, that use aeolian energy or electricity for propulsion, have came back in actuality, after a long period of time when their were simply ignored. In Figure 1 is represented the vessel "James Adger" , which used back in 1852 sail propulsion system combined with steam propulsion.[1]

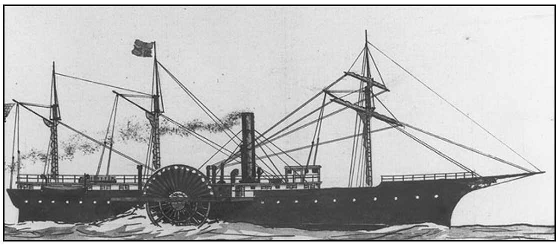

Fig. 1 "James Adger" in 1885 [1]

One of the methods that has been already tested, is utilizing aeolian energy, more precisely utilizing the tractive force of the wind in a kite rose to a certain height. The tests performed have presented us with a series of advantages compared with the classic sail cloths.

Utilizing the kite for traction does not mean a total reduction of the conventional fuel propulsion, the first being used in combination with the main engine, in the way in which the main engine does not work at full capacity, and the speed deficit is covered partially by the tractive force of the sail. Figure 2 presents the ship and the fore kite attached. [2]

Another method is the "ladermill" system, a system which uses kites attached "in ladder", having a double effect: traction and generating electric current.

Starting from the usage of kites in nautical sports, such as kite surfing and kite sailing, and basing on the tractive force developed by the sail under the action of the wind, we propose to analyse the way in which the kite influences the manoeuvering characteristics of the ship, more precisely the ship's roadability in different conditions of altitude wind.

Fig.2 Ships propelled by kite [2]

2. Course ship's stability and kite traction

2.1 General considerations

Ship's course holding or course ship's stability on the fixed way is one of the main characteristic of the vessel.

Under influence of the propulsion system, the vessel had a yawing from initial course because of the propeller effect. The yawing effect is minor or nearly zero for the vessels with two propellers, with different direction of rotation, where the yawing forces are reciprocal annihilated. The effect of the single right hand propeller for ship's movement ahead and astern is showing in Figure 3.

Any other external forces which act on the ship, as wind, waves or current, aspire to take out the vessel from his fixed way. The influence of the external factors and the yawing effect due to propulsion system, are balanced by steering system, which act on the rudder such as to bring the vessel on the ordered course.

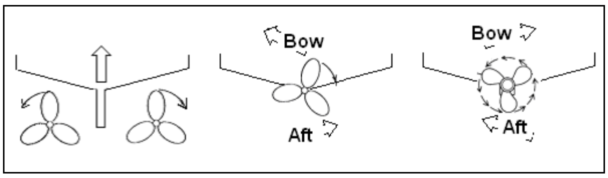

Fig.3, Direction of yaw of right hand propeller ship going ahead and astern

The kite is attached to the ship by towing line. It is very important the position of attachment point; as much as the position is more foreword, to the ship's bow, the require rudder angle is minimized.

The drag force of the kite under wind effect, acts as well as the external force, which, dependent on the direction of drag force, may increase the ship's speed or take out the vessel from initial way.

In contrast with classic sails, which use the wind surface energy, the kite can use the powerful wind at high altitudes, where the direction and speed of wind are usually uniform, without any influence of the obstacles from the environment.

There are some facilities involved with kite propulsion :

- the ship's deck is clean, without masts for sails
- the ship's heeling moment is smaller
- the cost of all kite's system is covered in short time considering the fuel reduction quantity
- the system is same for different kite's size, having possibilities to change the kite without to replace the telescopic mast, the storage winch rope or the controller computers
- wind is cheaper than oil and the most economic and environmentally sound source of energy on the high seas
- a ship's average annual fuel costs can be reduced by 10 to 35% by using the kite
- under optimal wind conditions, fuel consumption can temporarily be cut by up to 50%.
- virtually all existing cargo vessels and new builds can be retro-or outfitted with the kite auxiliary wind propulsion system.

Of course, there are some deficiencies when using kites:

- navigation only in some areas where the altitude winds are stable,
- near the coast, where the traffic is heavy, is possible to create some confusion from the vicinity ships,
- blocking of the fly track, specially for the small airplane which flying at low altitude.

2.2 Forces on a kite

A kite can be considered as a wing surface which enables the application of three principle forces acting on the kite: the weight, the tension in the towing cable, and the aerodynamic force. [3]

The weight W always acts from the center of gravity toward the center of the earth.

The aerodynamic force is usually broken into two components: the lift force L, which acts perpendicular to the wind, and the resistance force D, which acts in the direction of the wind.

The aerodynamic force acts through the center of pressure. Near the ground, the wind may swirl and gust because of turbulence in the earth's boundary layer.

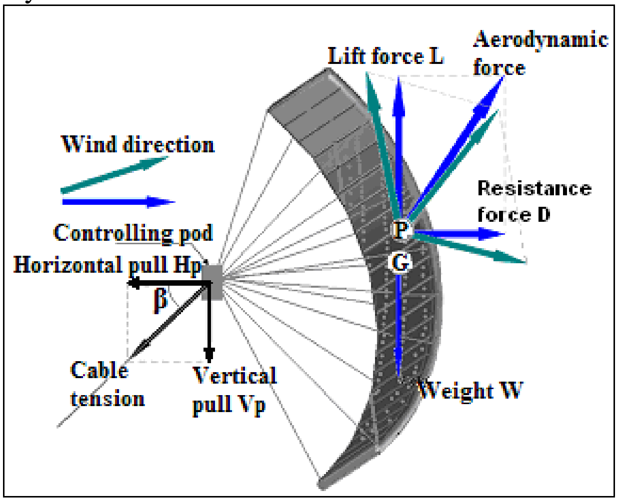

Fig. 4, Forces on a kite [3]

But away from the ground, the wind is fairly constant and nearly parallel to the surface of the earth. In this case, the lift is directly opposed to the weight of the kite, as shown in the figure 4.

The tension in the line acts through the bridle point (controlling pod) where the line is attached to the kite.

The cable tension is divided in two components: the vertical pull Vp, and the horizontal pull Hp.

When the kite is in stable flight the forces remain constant and there is no net external force acting on the kite, from Newton's first law of motion.

In the vertical direction, the sum of the forces is zero.

$$Vp + W = L \quad (1)$$

So, the vertical pull plus the weight minus the lift is equal to zero.

$$Vp + W - L = 0 \quad (2)$$

In the horizontal direction, the sum of the horizontal pull and the resistance must also equal zero.

$$Hp - D = 0 \quad (3)$$

Near the bridle point, the line is inclined at an angle called the bridle angle β. The magnitude of this angle is related to the relative magnitude of the components of the tension.

$$\tan \beta = Vp / Hp \quad (4)$$

Knowing the bridle angle, the length of line, and the weight of line, can predict the height at which the kite flies.

The relative strength of the forces determines the motion of the kite as described by Newton's laws of motion. If a gust of wind strikes the kite, the lift and drag increase. The kite then moves vertically because the lift now exceeds the weight and the vertical pull, and the tension force increases because of increased drag.

Eventually a new balance point is established and the kite achieves a different stable condition. Because of the change in relative strength of the aerodynamic and weight forces, the kite also rotates about the bridle point to balance the torques.[4]

2.3 Calculation of total aerodynamic force

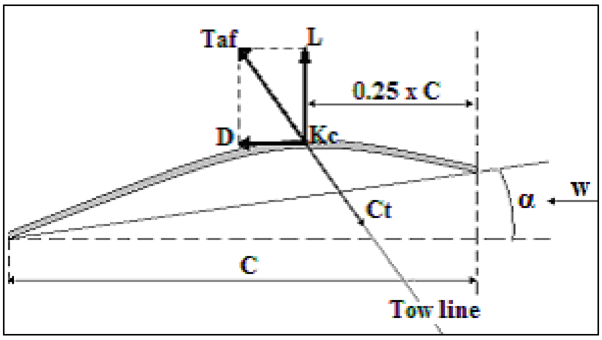

Fig.5, Traction aerodynamic force and cable tension

In Figure 5 the following notes were included:

D = resistance force

L = lift force

T_{af} = total aerodynamic force

C = chord

C_t = towing cable tension (the value is equal with value of T_{af})

α = incidence angle of wind

w = wind velocity

K_c = application center of forces

Considering the incidence angle of wind 15º and the total area of kite 200 square meters, we have possibility to calculate the values of the lift, drag and total aerodynamic forces.

$$L = \frac{1}{2}\rho C_L w^2 A_K \quad (5)$$

$$D = \frac{1}{2}\rho C_D w^2 A_K \quad (6)$$

$$T_{af} = \sqrt{L^2 + D^2} \quad (7)$$

and the following values were considered:

$C_L = 0.9250$ (lift coefficient),

$C_D = 0.2421$ (drag coefficient),

Both coefficients are on the basis the incidence angle of 15º on the aerodynamic profile G 417-a which was selected.

ρ = 1.2047 Kg/sqm (air density),

w = 15 m/s (wind velocity),

A_k = 200 sqm (kite's total area).

The wind direction and force are considered constant.

As a result of (5), (6) and (7), the total value of aerodynamic force T_{af}, for the kite's profile described above is 22029.116 N and the value of resistance force D = 6562.302 N.

The projection of aerodynamic force T_{af} on the water plan WP it is shown in Figure 6. The value of F_z (lift force) is negligible because the ship is too heavy for it to lift her and the value of the F_y (resistance force) sheers the ship off course.

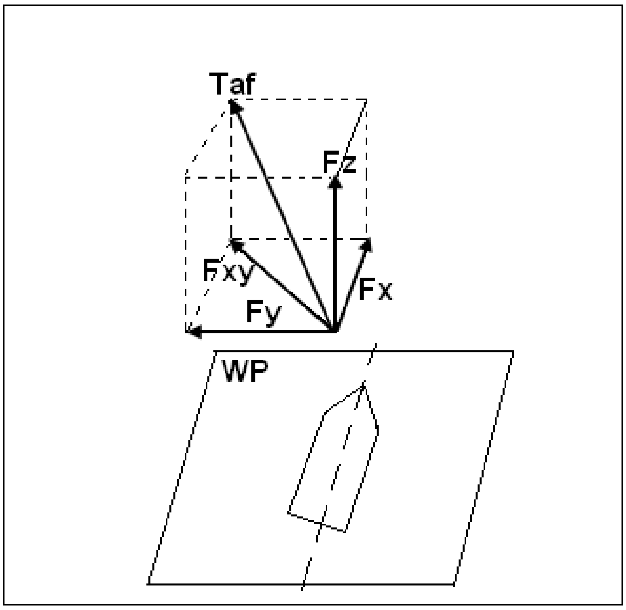

Fig.6, The projection of the forces on the water plan

3. Simulation of the total aerodynamic force and influence on the ship's course stability

Having calculated all the force values we have introduced them in the simulation for different scenarios with different wind direction while keeping constant the wind force and angle of incidence.

The results are the following: the aerodynamic force of a specific value has the possibility of moving the ship with a slow speed while sheering her off course. The effect of the rudder when the speed is slow is negligible and because of this it is required the use the main engine. The sheer itself is not of great value on short distances but on long distances is considerable.

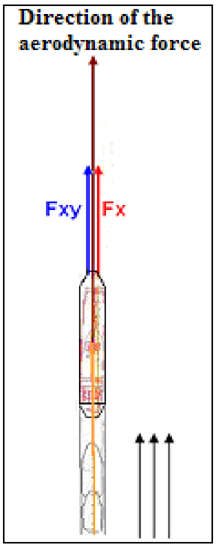

Fig.7 The forces T_{af} and D for wind direction from180º

In the Figure 7 the wind direction is considered just from the stern of the vessel and the projection of the kite forces on the water plan are represented by $F_x = F_{xy}$. The value of the force F_y that led the vessel out off normal course is zero or nearly zero. The vessel remains on the initial course and the speed is between 0.5 and 0.9 knots.

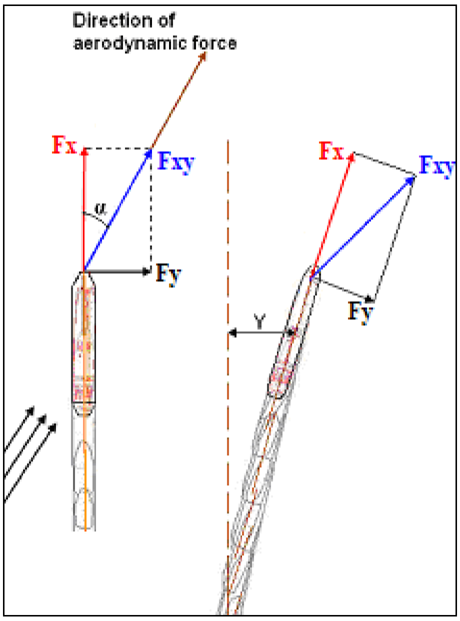

Fig.8 The forces T_{af} and D for wind direction from 210˚

In the Figure 8, the wind direction is considered 30˚ from ship's axis, from 210˚. The traction force F_x is greater than F_y. The value of F_y is not so great but the vessel is taken out from initial course, the speed of the ship is between 0.6-0.7 knots and the value of yawing (Y) is about 1 cable (185 meters).

$$F_{xy} = D \; ; \; F_y = D \sin \alpha \tag{8}$$

$$F_y = 6562 \text{ x } 0.5 = 3281 \text{ N}$$

$$F_x = D \cos \alpha \tag{9}$$

$$F_x = 6562 \text{ x } 0.5\sqrt{3} = 5709 \text{ N}$$

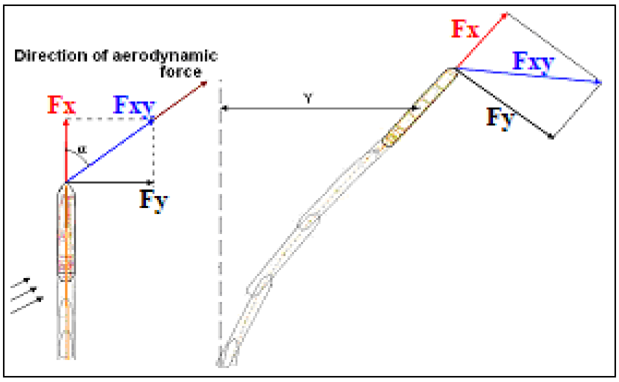

Fig.9 The forces T_{af} and D for wind direction from 240˚

In the Figure 9, the wind is considered 60˚ from the ship's axis, from 240˚. The value of traction force F_x is smaller than in previous case but the value of F_y is greater. The ship's speed is about 0.7 knots and the yawing (Y) is between 2 and 3 cables.

In all presented cases, the initial ship's speed is considered zero. One of the effects of kite traction is the yawing of the ship, which is reduced by using of the rudder. But at slow speed, as our results obtained regarding traction force, the rudder's effect is ineffective and is necessary to use the main engine to bring the ship at ordered course.

Depending on the apparent wind direction and wind speed, this kite force will cause a drift angle of the ship, resulting in additional resistance. This effect is taken into account by simultaneously solving the force balance in longitudinal and lateral direction and the yaw balance.[5]

Ideal condition for the kite operation are steady winds with constant direction and strength. However, wind is a complex phenomena and has unpredictable tendencies. Turbulence and gusts are therefore the main threat to the operating kite.[6]

4. Conclusion

From the foregoing it's clear that kite propulsion has good results and its use together with the main engine propulsion means a new opportunity, until now considered unconventional.

This method has been tested and the results were considered satisfactory. In this paper we did not refer to the handling of the kite's, which focused in one direction and positive angles of attack of wind, can reduce power lateral deviation and create traction of higher values.

A dynamically flown kite can generate up to 25 times the force of a static aerofoil or kite of the same plan form area. A kite attached to a relatively low mast also generates a much smaller heeling moment than a conventional sailing rig and occupies much less deck area – making it suitable as a retro-fit also. The uplifting forces of the towing kite also mean that the hull slices more smoothly into the waves, thereby increasing safety.[7]

There are three major advantages to kite rigs as compared to conventional sailing rigs. First, since a kite flies some 150 – 200 meters above the water, it works above the turbulent boundary layer of wind over water that conventional rigs must deal with. As power derived from the wind varies with the square of the wind speed, 25-70% more energy is available to the kite.[8]

Kites can power a boat without the dangerous overturning moments inherent in masts and sails. Kites can fly high up in the sky, far from the effects of the waves and of the boat hull, in steadier and stronger wind conditions. Current kites can achieve a lift-to-drag ratio of about 6 to 1, which can sometimes give a boat more versatility and more power than is possible with masts and sails.[9]

Wind technologies are used on ship as assistance to the main engine because the power produced by the wind alone is not enough to move the ship at the contract speed.[10]

Figure 10 shows the power extracted by various sail types at various course angles. This was originally published by Loyd Bergessen in support of the design of Mini Lace in 1981, then adapted for kites by Schmidt in 1985, and finally by Roeseler in 1996 for more efficient kites. The advantage of efficient kites over conventional sails in assisting slow moving cargo ships will approach 10:1.[11]

If they made a vessel speed of 2-3 knots by the kite traction, combined with the engine propelling force of the ship working at lower capacity, saving fuel is proportional to the amount needed to achieve speed and therefore created by kite, to reduce atmospheric pollution hazards from marine engines.

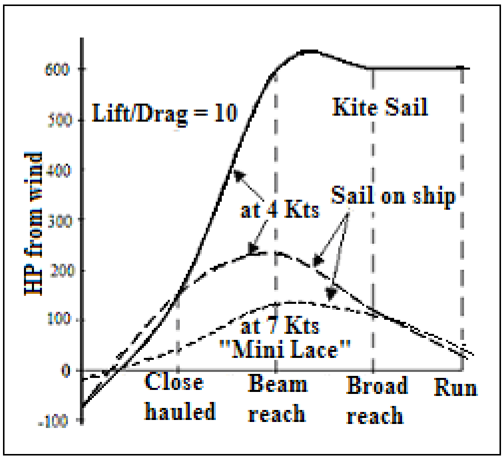

Fig. 10 Power from the wind [11]

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