Abstract

The constraints imposed by shipping require us to consider new energy sources. To that end, wind seems to be an interesting and effective alternative that can allows us to save up to 30% of the total ship's consumption through the towing-kite systems.

1. Introduction

Maritime transport generates more than 90% of global traffic of goods and is the most important way ahead of the airways, railways and roads. Providing transportation of various kinds such as energy sources (oil, coal) or minerals and raw materials, it can deliver record amounts over long distances making it possible to a large routing across the globe. The sea lanes are also borrowed through scientific research, and to lesser extent for travel and cruises.

The impact of marine transport on the global economy and environment is not trivial and steps must be taken to ensure security, organization of transport but also energy optimization of vehicles. Although less polluting than other modes of transport, trade by sea still generate more than 1.5 billion tons of CO2 per year!

The threat to marine biodiversity caused by the vessels (petrol , chemical waste , and other kind of pollution...) , the rise of the fuel costs are all reasons which justify why engineers and policies pay more attention to options able to minimize fuel consumption. Several studies aimed at harnessing the wind to propel vessels were performed. Currently the most successful one is the SkySails system who has developed an innovative concept similar to a kite surfing.

This report introduces the concept of pulling ships by kite and describes it through the SkySails system.

2. General considerations : ship propulsion

When a ship is moving, a force opposite to its trajectory called "resistance force" is applied. It consists of two resistances: aerodynamic, due to the viscosity of air and friction against the emerged party of the ship. The hydrodynamic also divided into two forces, called viscous resistance (due to water viscosity and friction against the hull) and a wave resistance (due to the formation of waves by the ship). We can see these forces on a boat , a main wave forms at the front and a wave train develops at the back, these waves are the manifestation of a significant part of the resistance as we can see on fig 1.

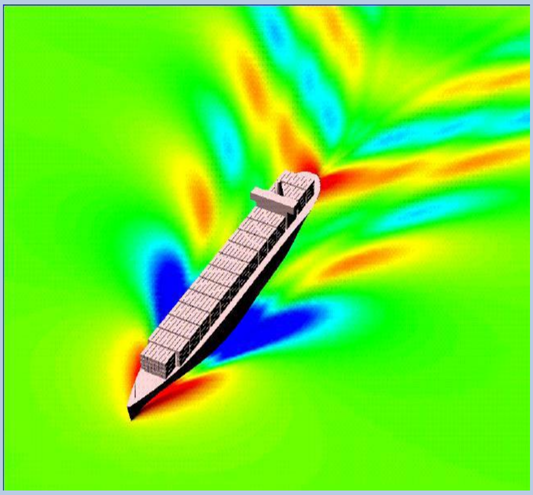

Fig 1 : Resistance forces applied to the ship

The waves created by the ship depend on:

- its speed
- its length

The wave resistance applied to a ship is quantified by a dimensionless coefficient, the number of Froude :

$$(1)\ \mathbf{F_n} = \frac{V}{\sqrt{(L.g)}}$$

The total resistance to the advancement is determined by several tests realized in pool on a model of the real ship having an equal Froude number.

(2) $\mathbf{R_t = R_f + R_r + R_w}$
$\mathbf{R_t = R_f + R_d}$

Rt : Total resistance (N)
Rf : The frictional resistance (N) is created by friction and turbulence in the disturbed area in the vicinity of the hull. Predominant at low speeds, it constitutes the main resistance to all boats
(3) $\mathbf{Rf = 0.5 * \rho * S_w * Cf * Vs^2}$ (N)

(4) $\mathbf{Cf} = \frac{0.075}{(\log Ry - 2)^2}$

with Ry (Reynolds number) = $\frac{V * Lm}{1.08} * 10E6$

Rr : this resistance is a consequence of higher friction, which is around the ship when its speed increases (N)
Rw : Waves resistance (N)
Rr + Rw = Rd : "residual resistance" (N)

(5) $\mathbf{Rd} = \frac{Rdmod * \nabla reel}{\nabla mod}$

The aerodynamic resistance includes all resistance "off water" but has little importance on the total resistance and can be neglected.

Nomenclature :

Sw : wet surface of the hull (m²)
Cf : Frictional coefficient
Vs : ship speed (m/s)
Lm : model's length (m)
Rd_{mod} : residual resistance in pool (N)
∇mod : testing advancement in pool (m^3)
$\nabla reel$: real advancement of the ship (m^3)

The calculations of the various resistance forces are necessary to determine the power of the ship propulsion motors.
According to data on the ITTC and the different equations (2), (3), (4) and (5), we can determine the total resistance force to the advancement and the engine effective power.

(6) $\mathbf{P = Rt * Vs}$ **(W)**

Sw : 1936 m²
Cf : 0.003606
Vs : 8 m/s
Rd_{mod} : 20 N
∇mod : 1.4037 m^3
$\nabla reel$: 14 896 m^3

The total resistance to the advancement for a ship (length = 132m) moving at **8 m / s** is **Rt = 23 173 N** (about **24 tons**) and the propulsive power needed is **P = 1873 kW**.

3. The wind as restitution force to power ships

3.1 : System presentation

The SkySails system can compensate a part of the ship's engine power with a traction kite. Directly inspired by the traditional kite-surfing, this system differs from the others by its technology which allows it to control the sail with an advanced electronic command system.

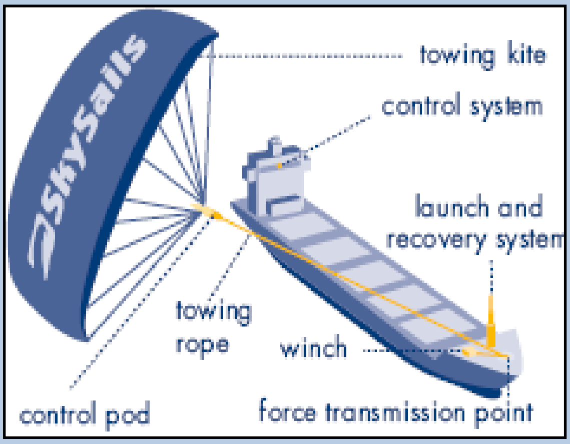

Fig 2 : Skysails system components

Fig 2 describe the main components of the whole system necessary for its functioning.

Sailing is directly controlled by the central control unit located on board. The data transmission is ensured by the control pod situated under the sail which allows to establish the communication with the control system unit. This connection is important because of the main data which are transmitted like speed and direction of wind , sail position and altitude. (fig 3)

Fig 3 : Control pod and control unit system

The different phases of sail's launch and recovery are supported by a mast at the forward of the ship. The mast will rise gradually to its maximum height (or demean according to the phase) in order to let the sail rise up without inconvenient. The winch allows the sail to gain altitude until the height set by the system control is achieved. (fig 4)

Fig 4 : Launch & recovery system

The force generated by the sail is restored to the transmission force point at the extremity of the ship. (fig 5)

System performances :

In order to offers the best performance , the system must be used under certain conditions:

It can operate only for an angle of attack superior to 50°. The fig 6 shows the different direction of the ship and sail regarding the wind direction. Practical experience shows that the higher propulsion power are included between 90° and 270°

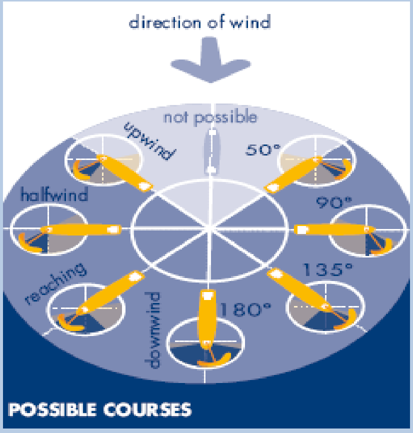

Fig 6 : possible courses according to the wind direction

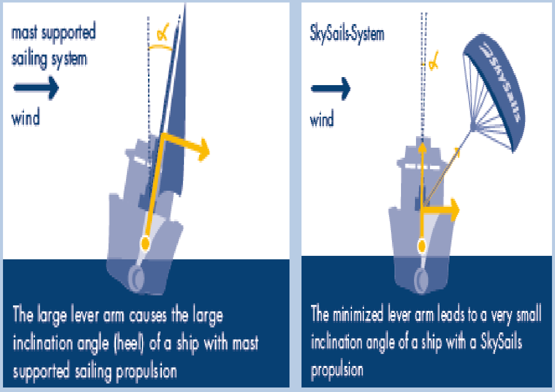

Fig 7 : comparison with the classical sailboats and ships equipped with the Skysail systems

In case of strong winds the sail can be positioned in the neutral zenith position directly above the ship. Thus the kite doesn't exert any force and the sail can be safely recovered. That's how the Skysails system allows to minimize the inclination angle when the kite is used.

3.2 : Forces on the kite and calculation of the tractive force

The kite can be modelised as a flat rectangular surface on which exerted three different forces: The weight, the aerodynamic force and the traction on the cable. Each of these forces is made up of several components (The lift force and resistance to the aerodynamic force, also horizontal and vertical components for traction)

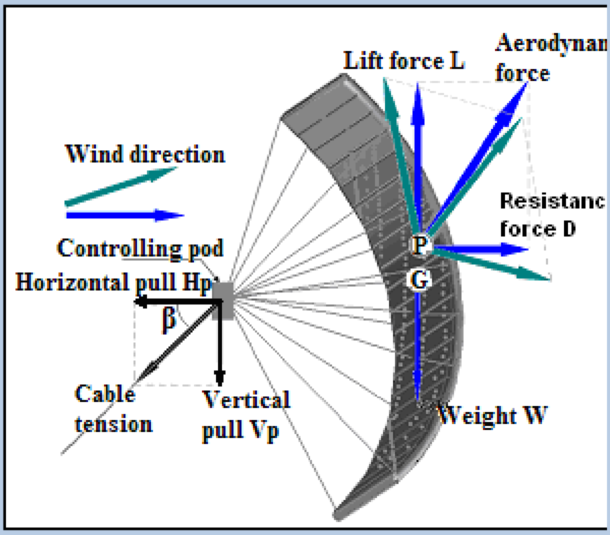

Fig 6 : Forces on the towing kite

When the wind rushes the sail's area , lift and drag force increase until the weight becomes negligible and the sail rises in the sky. As a result, tension in the cable will also increase because the tensile forces and drag resistance are linked as demonstrated by Newton's equations of motion:

(7) **Vp + W – L = 0** → **VP + W = L**

(8) **Hp – D = 0** → **Hp = D**

The aerodynamic principle defines wind force exerted on a surface as:

(9) $$F = 0.5.\ \rho.\ C.\ S.\ Vv^2$$

More the wind will be strong and more the force generated will be important. Wind velocity is not a controllable parameter, so the traction kites are generally used at a minimum altitude (between 100 and 300 meters) to take advantage of wind speed more significant and unidirectional.

Optimize the angle of attack proves to be an important factor to maximize the force exerted on the sail. The lift and drag coefficients Cl, Cd represents the different pressures on the sail under the effect of air (viscosity, sail position according to the wind direction) and also have an influence on the system tractive force. To maximise it , it's important to optimize the angle of attack for a higher pull force. Hence the need to accompany the towing kite by an electronic system which can continuously determine the wind direction and orient the sail accordingly (how detailed on the precedent part 3.1).

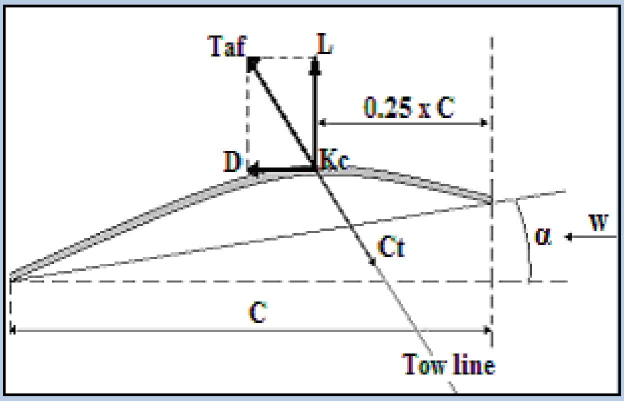

Fig 7 : Aerodynamic forces on the sail.

Nomenclature :

D = drag force (N)
L_f = lift force (N)
T_{af} = total aerodynamic force (N)
C_t = towing cable tension (equal with the value of T_{af})
C = chord
α = incidence angle of wind (radians)
w = wind velocity (m/s)
A_k = Kite Area (m²)

Lift & drag coefficients by the methods of calculation from NASA:

$$(10)\ C_l = \frac{Clo}{1+(\frac{Clo}{AR*\pi})} \qquad C_{lo} = 2\pi\alpha$$

$$(11)\ C_d = C_{do} + C_{di}$$

$$C_{di} = \frac{Cl}{e\pi AR} \qquad C_{do} = C_{drp} \cdot \sin\alpha$$

Taking into account the different relationships (7), (8) and (9) it is easy to give an expression for the total force exerted in the cable.

$$\mathbf{(12)}\ L_f = 0.5 \cdot \rho \cdot Cl \cdot A_k \cdot V_v^2$$

$$\mathbf{(13)}\ D_f = 0.5 \cdot \rho \cdot Cd \cdot A_k \cdot V_v^2$$

$$\mathbf{(14)} = \sqrt{\ } L_f\, T_{af}^2 + D^2 = C_t$$

w = 12.8 m / s
Kite Area = 160m ²
Cl = 4.2453
Cd = 0.6656
α = 70 ° = 1.2217 rad

Considering the results obtained for (12), (13) and (14) The total aerodynamic force is equal to **69 238 N** (Approximately **7 tons**). The traction generated represents the third of the total advancement resistance of the vessel and therefore the power required to supply the engines as has been detailed in the second part of this report (part 2).

4. Conclusion

The results obtained following the first tests on the vessels equipped with a towing kite proved satisfactory. We can probably expect to see the concept grow in the coming years and why not improve it. Indeed, the current system offers some interesting innovative elements like the reduction of the inclination angle of the ship during the use of the sail , the kite control by an advanced electronic command system which allows to research the best physical parameters (altitude ; wind direction , sail trajectory) in order to benefit of the best conditions to maximize the tractive force.

References :

Fig 1. Ministère de l'agriculture et de la pêche « *Plan de sauvetage et de restructuration : dans le cadre de la phase de restructuration, mise en place des audits financiers et techniques des entreprises de pêche maritime* » http://agriculture.gouv.fr/IMG/pdf/DPMAC20109640Z.pdf

fig 2 , 3 , 4 , 5 : Skysails website « system component » http://www.skysails.info/english/products/the-skysails-technology/

fig 6 , 7 : Proceedings of the 3rd International Conference on Maritime and Naval Science and Engineering "*considerations regarding kite towed ship's*" http://www.wseas.us/e-library/conferences/2010/Constantza/MN/MN-04.pdf

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