Possibility of placing a retractable sail system for an oil tanker to optimize its efficiency

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Abstract. Nowadays, self-propelled maritime transport increasingly depends on the use of new technologies and energy from renewable sources.The Action Plan clearly shows that the vision of building a ship that does not release emissions is realistic. As far as manufacturing time is concerned, it is not only a question of technology development but also of the advancement of economy, infrastructure, laws, the freight market, etc. This paper aims to analyze a VLCC ship in terms of energy efficiency by introducing innovative systems on board and correlating with the classical systems of the ship. Also, the paper present theoretical and practical considerations for optimizing the operation of energy systems at a VLCC of 305000 dwt. The paper introduces an innovative VLCC concept where, through onboard innovative power systems, bring major improvements to this type of ship.

Keywords. VLCC, sail, wind resistance

1. Introduction

There are currently various emerging technologies that allow the use of renewable energy by small vessels or boats. These solutions may become applicable to larger ships in the future. Renewable energy sources have the potential to provide abundant energy supply with minimal environmental impact and relatively low costs. It should be stressed that it is quite possible to build a ship that operates without emissions today with existing technology, although it would not be economically convenient considering the today's maritime transport market.

Using sails can reduce fuel consumption and also reduce emissions, but it also has potential disadvantages such as:

- Vessels occupy a lot of space and therefore access is restricted during loading and unloading and therefore the cranes have to work around them
- Booms can generate unfavorable wind resistance. There is also a risk for crew with regard to changing wind conditions. Particularly on storms, masts and sails can cause dangerous ship shifts

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- In sailing, the ship tends to tilt. This may be impossible for container vessels and cargo ships, to operate under sailboat conditions. To avoid situations of this kind, an excessive ballast is needed, which is not economical

2. Sail system configuration

At the 305,000 dwt oil tank I will design five sail systems for better fuel economy. Of the five shipboard systems, we have four identical systems and one different system in the bow of the ship. Depending on the body of the ship we will place the five systems according to figure 1, as follows:

- the four same type systems placed in the curbs, two systems of the same type placed on the starboard and two systems of the same type on the port placed symmetrically as follows: two systems placed in the bow of the cargo tank no. 2 at a distance of 71.25 m from the bow of the ship and 261.75 m from the aft of the ship, and two systems placed in the aft of the cargo tank no. 5 at a distance of 109.25 m from the aft of the ship and at a distance of 223.75 m from the ship's bow
- one system located on the bow of the ship at a distance of 12 m

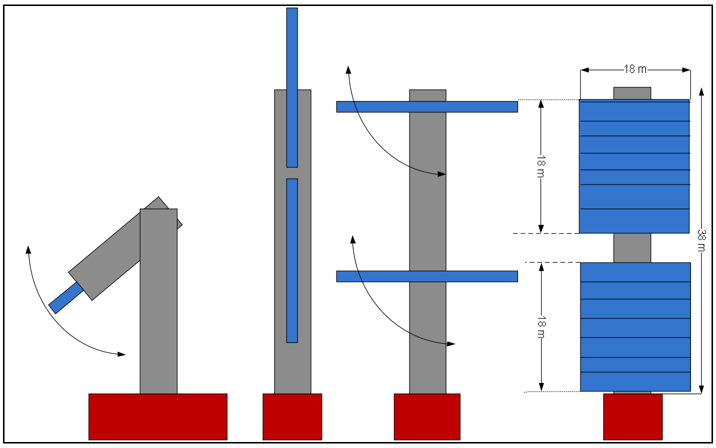

Figure 1. Sail system configuration

As can be seen in Figure 1, the systems are tiltable depending on the navigation and cargo requirements as follows:

- The four identical systems are tiltable at 90º from the vertical position in the horizontal position
- The ship's flap system at 180º from the middle of the mast

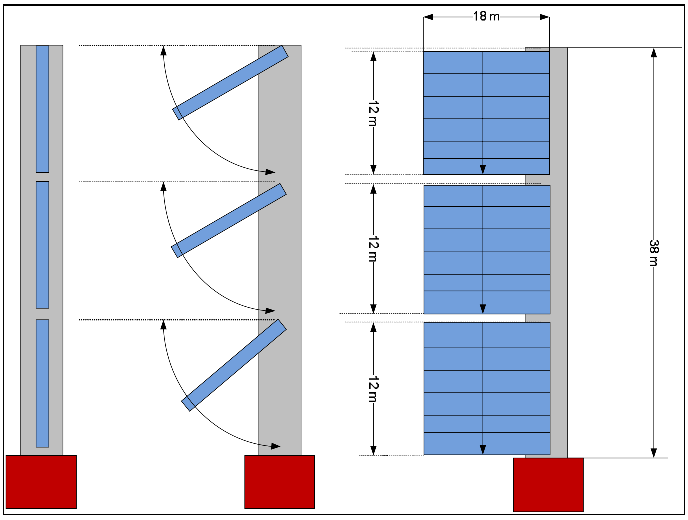

Figure 2. Sail system configuration

As can be seen in Figure 2, the system consists of the main mast and three side arms that can be opened at an angle of 90 ° to the main mast. On the three arms are placed the floats that are in the same three identicals. The veels open from top to bottom as needed depending on the navigation conditions.

At the same time, they can be folded into the fan system as can be seen in Figure 3 rotation can be done at a 360° angle only for identical masts because it is possible to increase the large surface working in the wind. For identical masts, each mast has a height of 38 m and consists of three identical sails having a length of 18 m and a height of 12 m each. For the forward mast, it has a height of 38 m and consists of two identical sails having a length of 18 m and a height of 18 m each. The forward mast is formed of only two arms rotating at 90° to the mast and symmetrical to it. The sail system also works on the fan opening system.

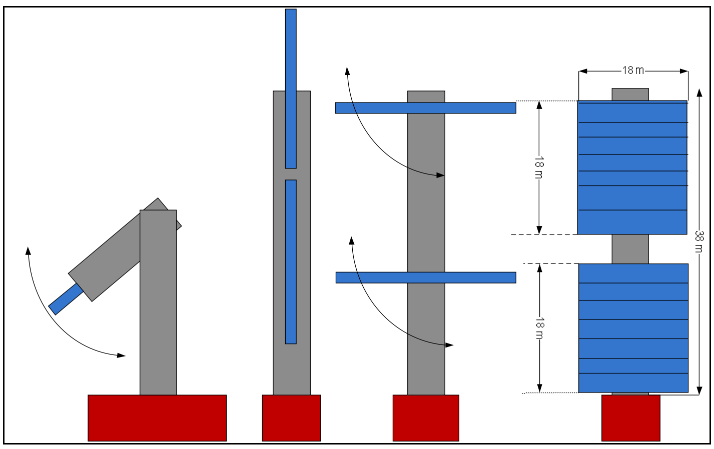

Figure 3. Sail system configuration

3. Calculation of sail system

At For the sail system described in the previous section, I will calculate the sail drag at different wind speeds.

$$T_V = \frac{1}{2} \cdot \rho \cdot V_A^2 \cdot C_T \cdot S_V \quad \text{[kN]} \tag{1}$$

T_V - sail force

ρ - air density (at 20ºC)

$\rho = 1.2 \frac{Kg}{m^3}$

C_T - the coefficient of sail force

$C_T = 1.165$

S_V - sail area

$$S_V = 36 \cdot 18 \cdot 4 + 36 \cdot 18 = 3240 m^2 \tag{2}$$

$\cdot V_A \cdot$ - the speed of apparent wind

I have to calculate the apparent wind speed. For this I take into account the following: $R(V_E) = T(V_R^E)$

$V_R^E = V_A^V - V_A^N$

$V_R = 5 - 50$ Nd

$V_R = 1 - 18$ Nd

$V_R^2 = V_A^2 + V_N^2 + 2V_A V_N \cos 45°$

$V_A^2 + V_N^2 + 2V_A V_N \cos 45° - V_R^2 = 0$

$$V_{A1,2} = \frac{-2V_N \cos 45° \pm \sqrt{(2V_N \cos 45°)^2 - 4(V_N^2 - V_R^2)}}{2} \tag{3}$$

$$V_{A1} = \frac{-2V_N \frac{\sqrt{2}}{2} + \sqrt{4V_N \frac{2}{4} - 4(V_N^2 - V_R^2)}}{2} = \frac{-2V_N \sqrt{2} + \sqrt{2V_N - 4V_N^2 - 4V_R^2}}{2} \tag{4}$$

$$V_{A1} = -V_N \frac{\sqrt{2}}{2} + \frac{\sqrt{4V_R^2 - 2V_N^2}}{2} = \frac{\sqrt{2}}{2}\left(-V_N + \sqrt{2V_R^2 - V_N^2}\right) \tag{5}$$

V_{A2} - has negative value, so it has no practical significance.

3.1. Calculation of apparent wind speed

Table 1. Calculation of apparent wind speed (V_R = 30 Nd)

V_N	$\sqrt{2V_R^2 - V_N^2}$	$V_A = \frac{\sqrt{2}}{2}\left(\sqrt{2V_R^2 - V_N^2} - V_N\right)$
1	42.42641	30
2	42.37924	28.55243
3	42.23742	27.03794
4	42	25.45584
5	41.66533	23.80499
6	41.46082	22.95327
7	41.23106	22.08369
8	40.69398	20.28971
9	40.38564	19.36457
10	40.04997	18.42011
11	39.68627	17.45583
12	40.69398	20.28971
13	40.38564	19.36457

3.2. Calculation of sail drag

Table 2. Sail drag calculation (V_R = 30 knots)

V_N	$V_A[m/s]$	$T_V = \frac{1}{2}\cdot\rho\cdot V_A^2\cdot C_T\cdot S_V$ [kN]	$T_V(total) = 5$ [kN]
1	30	2038.284	10191.42
2	28.55243	1846.326	9231.632
3	27.03794	1655.653	8278.267
4	25.45584	1467.564	7337.822
5	23.80499	1283.388	6416.941
6	22.95327	1193.195	5965.973
7	22.08369	1104.5	5522.498
8	20.28971	932.3388	4661.694
9	19.36457	849.2548	4246.274
10	18.42011	768.4341	3842.17
11	17.45583	690.0859	3450.429
12	20.28971	932.3388	4661.694
13	19.36457	849.2548	4246.274
14	18.42011	768.4341	3842.17
15	17.45583	690.0859	3450.429

4. The technical and economic efficiency of the sailing system

I will calculate for wind speed values of 30 knots and the maximum sails surface area of 3240 m². The results obtained by the wind speed and the ship can be tracked below.

Table 3. Calculation of apparent wind speed

Ship speed [knots]	Engine power-P [Kw]	Effective consumption –C [t/h]	Drag sails force-Fd [kN]	Sails power-Ps[Kw]	Ship required power-Preq [Kw]	Total fuel consumption [t/h]-Ct	Fuel saving-ΔC [t/h]
0	0	0	10191	0	0	0	0

2	85.81	0.01493	9231.6	18463	-18377	-3.1976	3.2126
4	581	0.10126	827.26	33113	-32531	-5.6604	5.7616
6	1660	0.28832	7337.8	44026	-42366	-7.37175	7.6606
8	3300	0.57437	6416.9	51335	-48034	-8.3580	8.9323
9	4295	0.74753	5965.9	53693	-49398	-8.5953	9.3427
10	5388	0.93556	5522.4	55224	-49836	-8.6715	9.6091
12	9903	1.72322	4661.6	55940	-46036	-8.010	9.7336
13	13350	2.3231	4246.2	55201	-41850	-7.2820	9.6050
14	17864	3.10889	3842.1	53790	-35925	-6.2510	9.3595
15	23777	4.13769	3450.	5156	-27979	-4.8683	9.0056
16	31518	5.48467	3072.1	49154	-17636	-3.0686	8.5528

We note that at the wind speed of 30 knots and a surface area of 3240 m² sails the ship no longer requires the force of the engines to reach the speed of 16 knots. So we have 100% fuel savings. Since the total sail area is no longer efficient above the wind speed of 30 knots, we will analyze the economic efficiency by reducing the very large area by using a limited number of sails.

5. Calculation of sail efficiency at different degrees of sea

In the initial design phase, drag resistance generated by sea waves can be determined by:

$$R_{VM} = C_{VM} \frac{\rho \cdot v}{2} S [\mathrm{kN}] \tag{6}$$

The value of the C_{VM} is selected from the tables according to the degree of the sea and is:

Table 4. The value of the C_{VM}

Beaufort value	C_{VM}
1 … 2	$(0,1 \ldots 0,2) \cdot 10^{-3}$
3 … 4	$(0,3 \ldots 0,4) \cdot 10^{-3}$
5 … 6	$(0,5 \ldots 0,6) \cdot 10^{-3}$

The ship's overall propulsion resistance is determined on the basis that:

$$R_T = R + R_S \quad [\mathrm{kN}] \tag{7}$$

where: R is the main forward resistance and R_S is the additional forward resistance. The vessel's displacement by water at a certain constant speed is achieved by means of the propulsion system which, by its developing force, has to overcome the total resistance. Towing power is produced by the propeller and has the definition relation:

$$P_r = R_T \cdot v \quad [\mathrm{kW}] \tag{8}$$

$$P_r = 1.36 \cdot R_T \cdot v \quad [CP] \qquad (9)$$

where: R_T is the total drag resistance in kN and v the speed of the ship in m / s.

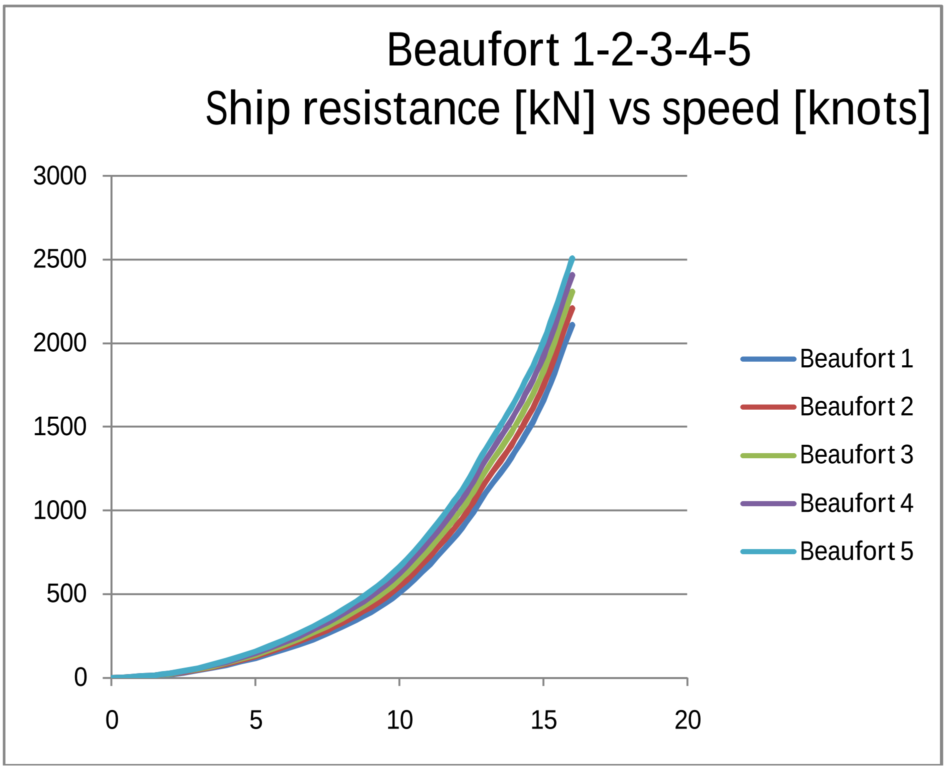

Figure 4. Calculation of ship resistance according to sea level

6. Calculation of sail efficiency at different degrees of sea

It is estimated that using sails the cost of fuel can fall between 10-35% depending on the wind conditions. It is concluded that the benefits of both the environment and the financial can be convincing. Sail vendors indicate that using this system, ship operation will become more profitable, secure and independent of the decline in fuel reserves.The idea of using a combined sail-engine system is not a new generation idea, but because of constructive and conservative inconveniences, this system has not been implemented on a large scale. Nowadays, five elements are considered to be major sources of pollution of the marine environment: industrial activity on land, underwater, waste discharged into the marine environment, ships and the atmosphere. Unfortunately, as I have shown earlier, the measures were taken and which are still being considered are not a true reflection of the workload effort.

Good results have indeed been achieved in certain areas of the world, such as the limitation of SOx production in northern Europe and the North American coast, but are still areas in the world where no precautionary measures have been taken into account.

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