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THE EFFECT OF USE OF UNCONVENTIONAL POWER GENERATION SYSTEMS ON THE SAFETY OF NAVIGATION

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Abstract. By using a hybrid system formed from two unconventional energy devices large vertical wind turbines and FLETTNER Balloon and a conventional source of energy, ship owners can save a great deal of fuel, thus making substantial savings and not least, reducing pollution, making environmentally friendly ships. Unfortunately, the legislation in force does not allow ships to enter ports with unconventional energy sources. For this reason, unconventional energy sources will be used only during transoceanic crossings or during longer journeys. In this article major points are: 1) the influence of the FLETTNER helium Balloon on the manoeuvrability and road stability of the ship; 2) the influence of large Vertical wind turbines installed on the deck of the container ship on the manoeuvrability and road stability of the ship; 3) the calculation of the stability of the ship with the FLETTNER Balloon with helium coupled and with the 4 Vertical wind turbines installed on the ship's deck; 4) modelling the phenomena regarding the comparative analysis of the forces in the FLETTNER Balloon and in the large Vertical wind turbines. As results were obtained: 1) velocity and pressure distributions, forces and kinetic energies for the FLETTNER Balloon in various weather conditions, with winds of 10 and 20 m / s respectively from different directions: 0^0, 30^0, 60^0, 90^0 in various planes; 2) the distributions of speeds and pressures, forces and kinetic energies studied individually for each of the four large vertical wind turbines at winds of 10 m/s and 20 m/s respectively in various planes, segregated according to the position of port bow, starboard and stern port, starboard. This development was due to the growing demands to solve various problems at the industrial level, coming to the aid of many engineers who wanted an improvement in the equipment used, but did not have the financial support to perform experiments.
Key words**:** FLETTNER helium balloon, vertical wind turbines, manoeuvrability, road stability.

1. INTRODUCTION

Ships have become the main source of pollution in the European Union. More than 77% of goods are brought to the EU by ship. More than 30% of the world's NO_x is produced by shipping [1].
Due to cu NO_x and SO_x pollution in the European Union, more than 50,000 premature deaths are caused each year. Due to NO_x and SO_x medical costs are over € 61 billion annually in the EU. The EU land Industry, thanks to the legislation in force, aims to reduce the amount of SO_x between 2000-2030. Unfortunately, the maritime industry is expected to emit more and more gas SO_x by 2030.
In order to reduce greenhouse gas emissions, urgent measures are needed, such as:

- ➢ Alternative fuel sources;
- ➢ Alternative, unconventional, non-polluting energy sources:
- • Use of wind energy;
- • Use of solar energy;
- ➢ Operational measures:
- • Ship maintenance done on time, according to the builder;
- • Planning, executing and monitoring the trip, done correctly, on the shortest road, avoiding areas with unfavourable weather conditions;
- • Optimizing the draft and trim of the ship.
- ➢ Technical measures:
- • Maintenance of the main engine and generators;
- ➢ Structural changes:
- • Reducing the speed of ships;
- • Increasing port efficiency.

Unconventional propulsion methods any other method that differs from the classical propulsion of merchant ships, which do not use internal combustion engines to produce the mechanical work necessary to rotate the propeller shaft and thus move the ship. Compared to internal combustion engines, these processes can be considered as clean for seawater and atmospheric air. Research has shown that small vessels can successfully use unconventional energy sources, and solutions have been sought to extend them to large ships capable of carrying cargo. Wind energy is a renewable energy source, generated by wind power. Wind power is the use of airflow through wind turbines to provide mechanical power, which has the role of rotating some generators and creating electricity [1]. Vertical wind turbine performance depends on ship speed, wind speed, actual wind angle and other aerodynamic parameters [2]. The FLETTNER balloon is a generator of electricity, filled with a gas lighter than air - initially helium that rotates around a horizontal axis and sends electricity using a cable. The electricity generated can be used immediately or stored in a battery. The FLETTNER balloon is a device that generates electricity at high altitude. It rotates around a horizontal axis in response to wind, efficiently generating clean, renewable electricity at a lower cost than all competing systems [3]. Due to the high altitudes at which the FLETTNER rotor rises, the power generated by it is at least double the power generated by a classic wind turbine. The energy generated by the system at height is sent to the ship by cables. The electricity generated flows through the cables to a transformer located on the ship, then is redirected to the grid [4].

2. MATERIALS AND METHODS

In this paper is presented a hybrid system. By using a hybrid system formed from two unconventional energy devices large vertical wind turbines and FLETTNER Balloon and a conventional source of energy, ship owners can save a great deal of fuel, thus making substantial savings and not least, reducing pollution, making environmentally friendly ships [2]. Unfortunately, the legislation in force does not allow ships to enter ports with unconventional energy sources. For this reason, unconventional energy sources will be used only during transoceanic crossings or during longer journeys.
The main aspects of study are: 1) the influence of the FLETTNER helium Balloon on the manoeuvrability and road stability of the ship; 2) the influence of large-vertical wind turbines installed on the deck of the container ship on the manoeuvrability and road-stability of the ship; 3) the calculation of the stability of the ship with the FLETTNER Balloon with helium coupled and with the four vertical wind turbines installed on the ship's deck; 4) modelling the phenomena regarding the comparative analysis of the forces in the FLETTNER Balloon and in the large vertical wind turbines.
Following the research, helium was chosen as the filler gas. The balloon remains suspended in an upright position. The helium supports the FLETTNER balloon, which rises to an operator-selected altitude of up to 300 meters, for the best performance. Although hydrogen has a lower density than helium and requires a smaller volume of gas than helium to fill and keep the FLETTNER balloon afloat, it is much more dangerous because it mixes hydrogen with air. creates an explosive gas, which would endanger the balloon and even the ship.
That's why it chose the FLETTNER balloon to be filled with helium. The latter being lighter than air, giving the balloon buoyancy in the air and due to its inert gas properties, it cannot explode if the gas in the balloon mixes with the air, if gas from the balloon is lost [3].
In order to present the hybrid propulsion system of the ship, calculations must be made for the forces appearing on the propulsion elements, respectively on the FLETTNER balloon and on the wind turbine, the traction forces of the ship, as well as calculations of the influence of the system on the manoeuvrability and stability of the ship. It is necessary to verify that exist differences between the ship initial manoeuvrability and the ship manoeuvrability with the hybrid system installed.

2.1. The influence of the FLETTNER helium Balloon on the manoeuvrability and road stability of the ship

The FLETTNER Balloon with helium was two wind stabilizers, at each end of the balloon, with the role of maintaining it in a controlled area (figure 1)[2].

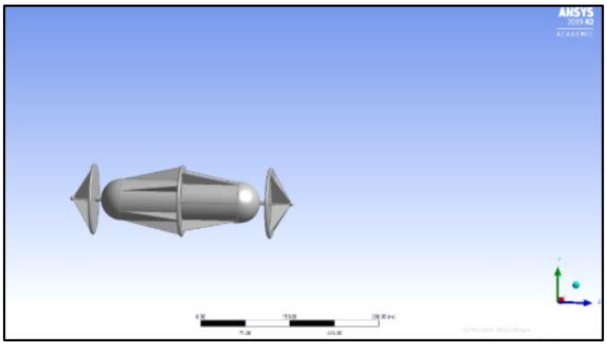

Fig. 1. Projection of FLETTNER Balloon design in ANSYS FLUENT [2].

Forces which appear in FLETTNER Balloon (figure 1) with helium:
On vertical axis is the lifting force F_a and the weight force$G$.
On horizontal axis is wind force/ friction force with air and traction force F_T (figure 2).

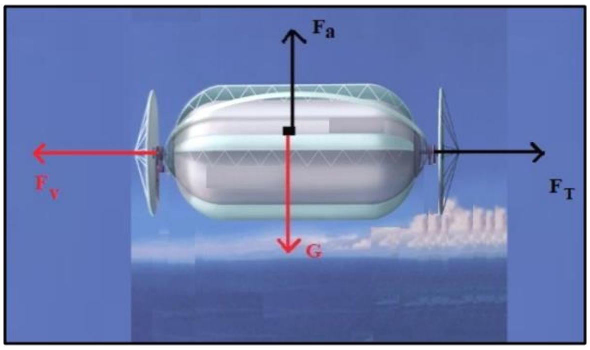

Fig. 2. The forces which appear in the FLETTNER Balloon with helium [1].

The balloon position is maintained in the air because of helium gas which is lighter than air and because of Magnus effect created by the rotor.

2.1.1 Horizontal force calculation which can influence the ship manoeuvrability because of the connection of the FLETTNER Balloon with helium to the ship

At an altitude around 300 m, the wind can have a speed up to v= $30\ m/s$.

2.1.2 The wind blows from abeam of the ship

Calculation of wind force F_V [N] or of friction force with air, when the wind blows from abeam is done with equation (1):

$$F_V = \frac{1}{2}\rho C_D v^2 A \quad [kN] \qquad (1)$$

where:

ρ = air density; $\rho = 1.299\ [kg/m^3]$

C_D = friction coefficient with air; v = speed vector; v = $30\ m/s$; A = lateral area of the balloon [m^2];

Calculation of lateral area of the balloon is done with equation (2):

$$A = \frac{\pi D^2}{4} = 490.625\ [m^2] \qquad (2)$$

where: D = diameter of the balloon [m^2]; D $= 25\ [m]$; also $F_V = 13.5\ [kN]$.

Calculation of the traction force of the ship:

d $= 6$ m; d = diameter of the engine propeller; P = 69535 kW; P-engine power [kW].

$$\text{Propeller pitch} = 75\%\ \text{x d} = 4.5\ \text{m} \qquad (3)$$

RPM = 90; where RPM-rotations per minutes;

$F_T = 10448.2$ kN ; F_T the traction force of the ship [kN]; the traction force is bigger than wind force

$F_T > F_V$; $\quad 10448.2\ \text{kN} > 13.5\ \text{kN}$.

If the FLETTNER helium balloon is installed on the ship and the wind blows across the ship, port or starboard, it will slow the ship by 0.12% of the ship's towing power. Being such a small value it can be considered negligible, in relation to the traction force of the ship.

The wind speed and implicitly the force of friction of the air with the FLETTNER balloon with helium coupled, do not influence the manoeuvre of the ship.

Calculation forces report is done with equation (4):

$$\frac{F_V}{F_t} \text{x}\ 100 \cong 0.12\ \% \qquad (4)$$

If on the ship we have installed the FLETTNER Balloon which helium and the wind blows from abeam, port or starboard of the ship, it will slow the ship with 0.12% of the traction force. Because is a very small value comparing with the traction force we can consider it inessential.

Wind speed and the friction force of air with the FLETTNER Balloon connected to the ship are not influencing the ship manoeuvrability.

2.1.3 The wind blows from astern or from ahead of the ship

If the wind blows perpendicular to the length of the FLETTNER balloon with helium, i.e. from the stern or bow of the ship, it does not affect the manoeuvrability of the ship, because the rotor will rotate faster, will generate more electricity, but will not move the balloon. The stabilizers will help the balloon maintain its position.

2.2. The influence of large vertical wind turbines installed on the deck of the container ship on the maneuverability and road stability of the ship

The force and direction of the wind experienced by the ship as it moves forward will be the result of induced wind (airflow felt due to the ship's forward motion) and true wind (wind direction when the ship is stationary) to create apparent wind (figure 3)[3].

Apparent wind is used to calculate the speed ratio. Apparent wind varies depending on power, direction, ship speed, direction and true wind speed.

Apparent wind is variable because of the: power, direction, ship speed, direction and speed of true wind.

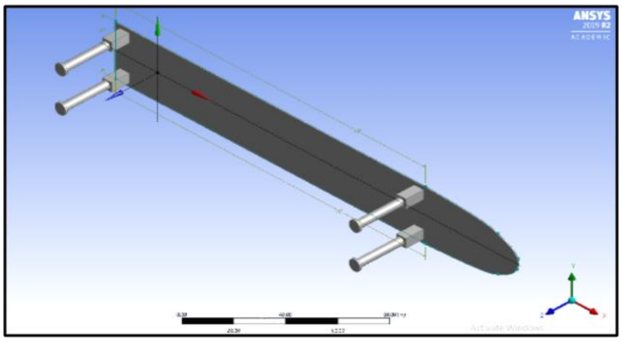

Fig. 3. Projection of vertical wind turbines installed on a container ship main deck design in ANSYS FLUENT

- Lift force formula:

$$F_a = \frac{\rho_{air}\ A\ V_{apparent}^2\ C_L}{2} .[kN] \qquad (5)$$

- Traction force formula:

$$F_t = \frac{\rho_{air}\ A\ V_{apparent}^2\ C_T}{2} [kN], \qquad (6)$$

where: ρ_{air}= air density, [kg/m^3]; $v_{apparent}$= apparent wind speed, [m/s]; C_T= traction coefficient; C_L= lift coefficient.

The power of the vertical wind turbines is easier to calculate by considering separate each component:

$$P_{Disk} = C\ m_{disk} \rho_{air} N^3 R_{Disk}^5\ [kW] \qquad (7)$$

$$P_{cylinder} = \frac{1}{2} Cm_{cylinder} \pi \rho_{air} N^3 R_{cylinder}^4 L_{cylinder} [kW] \qquad (8)$$

$$P_{relev} = \frac{k_{relev} F_{relev} D_{relev} N}{2}\ [kW] \qquad (9)$$

The factors that can affect the safety of the ship, when the vertical wind turbines are installed are:

- ➢ higher bending moment because of the forces which are abeam. Increasing the heel moment due to lateral forces. Higher rolling period;
- ➢ strong vibration;
- ➢ when the angle of the apparent wind (β) is very small or behind, the abeam forces (oscillate forces) are very big. When this abeam force is combined with a vertical lever, it appears a big moment of bent and the ship static angle is increased (figure 4).

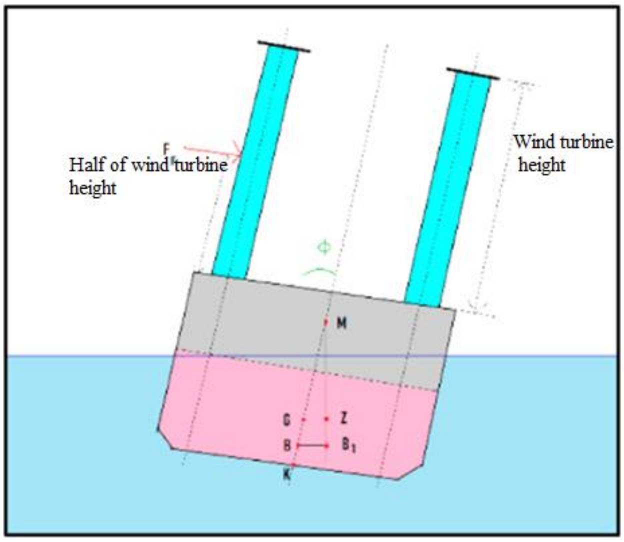

Fig. 4. Static angle of inclination.

The maximum static inclination angle of the ship with the wind turbines installed on the main deck, is not bigger than the normal angle of roll and can be considered negligible being smaller than 1%.
The installation of the wind turbines on the main deck of the ship will not influence the ship manoeuvrability.

2.3. The calculation of the stability of the ship with the FLETTNER Balloon with helium coupled and with the four vertical wind turbines installed on the ship's deck

For this must represent the forces which influence the lift of the balloon (figure 5, figure 6) [1]:

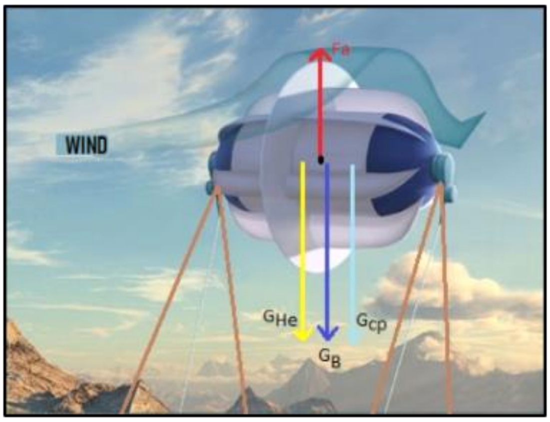

Fig. 5. The forces which influence the lift of the balloon, [1]

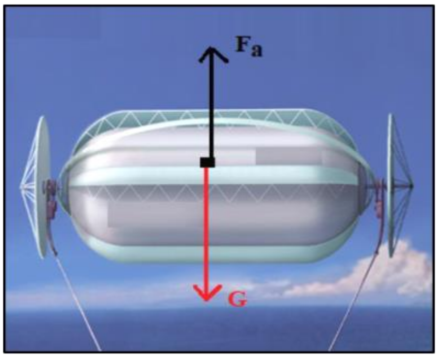

Fig. 6. The forces which influence the lift of the balloon merged. [1]

$F_a = 2528.4$ kN $= 2528400$ [N] ;

$G = G_{He} + G_B + G_{cp} = mg;$ (10)

where: G- the total weights [kN]; G_{He} –the Helium weight [kN]; G_B – the balloon weight [kN]; G_{Cp}- the weight of cables and ropes;

If $m = 12.626$ t, then G= mg = 123.7348 [kN] = 123734.8 [N];

The final lift force will be:

$F_a^{``} = F_a - G = 2404665.2$ N $= 2404.6652$ kN $\cong$ 245 mt ; (11)

where: $F_a^{``}$= the final lift force, with the extended value of the weights; D – Displacement = 39449 [mt].

From the above calculations it can be observed that the minimum required ascending force F_a ' is much lower than the ascending force F_a that the balloon can lift.

2.3.1 Calculation of the new displacement D`

If consider the green installation with wind turbine, the new displacement will be

$D^{`} = D - F_a^{``} + 4\,m = 39364$ mt (12)

where: m = the mass of one vertical wind turbine ; m = 40 t.

2.3.2 Draft calculation for the new displacement D`

Using the value for new displacement $D^{`}$ = 39364 [mt] and using the hydrostatic tables with $D^{`}$ an interpolation can be made to obtain the immersion value TPC = 45.42 [mt] and new draft :

$D^{`} - D_{9.53} = 38.58\ mt$ (13)

New Draft – $T_p^{`}$; $T_p^{`} = 9.53 + \frac{D^{`} - D_{9.53}}{TPC}$ x 0.01 = 9.5384 m (14)

Table 1. GZ calculated for different angles of heel θ from 0^0 to 90^0 before installation of green generators.[3]

θ	sin θ	KG	KN	KG x sin θ	GZ
0	0.000	8.0000	0.000	0.000	0.000
10	0.174	8.0000	2.113	1.392	0.721
20	0.342	8.0000	4.260	2.736	1.524
30	0.500	8.0000	6.310	4.000	2.310
40	0.640	8.0000	7.830	5.120	2.710
45	0.707	8.0000	8.406	5.656	2.750
50	0.766	8.0000	8.828	6.128	2.700
60	0.866	8.0000	9.330	6.928	2.402
70	0.939	8.0000	9.332	7.512	1.820
80	0.984	8.0000	8.892	7.872	1.020
90	1.000	8.0000	8.010	8.000	0.010

With the value of new draft $T_P^{`} = 9.5384$ [m] and using the hydrostatic tables, can be made an interpolation to deduct the value of the statically transverse stability.

2.3.3 Calculation of $\mathbf{GZ_{initial}}$ for the drawing of transversal stability graph

It is denoted by

GZ - righting lever [2] ; GM- the metro centric height; GM= 4.32 [m] [3].

The statically transverse stability is a term used to describe the capacity of a ship to return in the vertical position (initial stability) after being heeled by an external force like wind or wave (figure 7) [2].

GZ - *Righting Lever*, is the horizontal distance measured in meters between the centre of gravity G and the vertical line where the floatability force action in B point when the ship is heeled by the external force, formed the righting couple or the GZ righting lever (before installation the green generators).

$G'Z'$ - *Righting Lever*, after instalation of green generators (figure 8) [3].

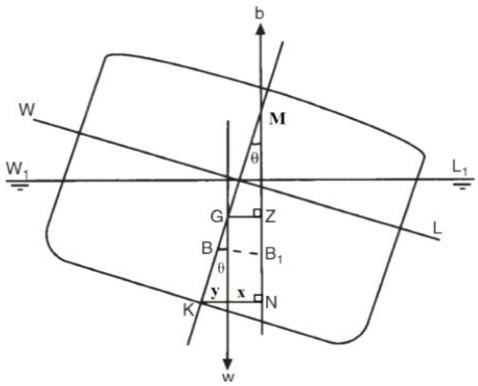

Fig. 7. Initial condition of ship statically stability [2].

where: $$\mathrm{KN} = \mathrm{x} + \mathrm{y} \quad (15)$$

$$\mathrm{x} = \mathrm{GZ} \quad (16)$$

$$\mathrm{y} = \mathrm{KG\,x\,\sin\theta} \quad (17)$$

$$\mathrm{KN} = \mathrm{GZ} + \mathrm{KG\,x\,\sin\theta} \quad (18)$$

$$\mathrm{GZ} = \mathrm{KN} - \mathrm{KG^{`}x\,\sin\theta} \quad (19)$$

$\mathrm{GM} = 4.32$ [m] ; $\mathrm{D} = 39449$ [mt] ; θ - angle of heel [^{0}]; GZ − righting lever; B − centre of buoyancy; KG −the high centre of gravity; represents the distance from centre of gravity G to metacentre M. WL − water line; W − mass; KM- distance from keel K to metacentre M.

The stability of the ship is calculated before the location of the power generators (table 1, figure 8, figure 9-black colour) and after (figure 8, figure 9-blue colour, table 2) [3].

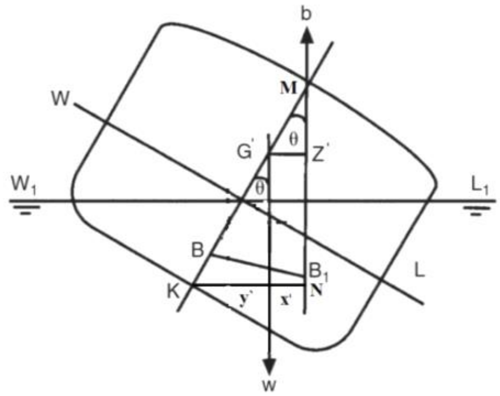

Fig. 8. Ship transverse stability before and after the installation of the green energy generators [2]

Table 2. $G^{`}Z^{`}$ calculated for different angles of heel θ from 0^0 to 90^0 after installation of green generators [3].

θ	$\sin\theta$	$KG^{`}$	$KN^{`}$	$KG^{`}\,x\,\sin\theta$	$G^{`}Z^{`}$
0	0.000	8.0016	0.0000	0.000	0.000
10	0.174	8.0016	2.1102	1.3922	0.718
20	0.342	8.0016	4.2525	2.7365	1.516
30	0.500	8.0016	6.3008	4.0008	2.300
40	0.640	8.0016	7.8260	5.1210	2.705
45	0.707	8.0016	8.3971	5.6571	2.740
50	0.766	8.0016	8.8192	6.1292	2.690
60	0.866	8.0016	9.3223	6.9293	2.393
70	0.939	8.0016	9.3235	7.5135	1.810
80	0.984	8.0016	8.8835	7.8735	1.010
90	1.000	8.0016	8.0066	8.0016	0.005

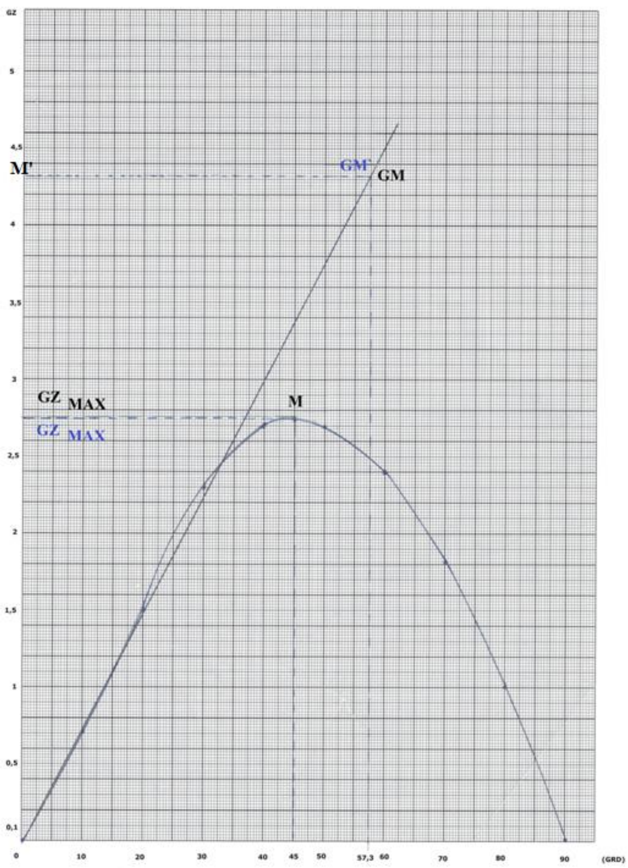

Fig. 9. Transversal stability graph [2].

The graph contents the ship static stability curve and the variation of right lever, which depended of the influence of the variation angle of heel, where: O - origin of the curve; M, M` - maximum of the curve, critical angle of rolling or maximum angle of heel (the point where the right lever has the maximum value); V-point of decrease; ascendant branch - between O and M ; O and M`; descendent branch- between M and V ; M` and V`; ϕ_v- maximum angle of heel, at which the ship comes back to the initial position; ϕ_m- the angle of heel at which the openings from the ship body, superstructure, cannot be close tight and are drowning.
The area delimited by the static stability curve and abscissa represents the total mechanical work of the recovery moment, i.e. the mechanical work with which the ship is able to oppose the dynamically applied external moments. This area represents the dynamic stability reserve of the ship.
The flowing angle of the deck or modulation point of the curve is the point where the curve changes its form from ascendant in descendent on the ascendant branch. For $GM^{`} < GM$ $4.3184 < 4.3200$ ship static stability decrees slightly after the installation of green energy generators, comparing with the initial stability [3].

2.3.4. Calculation of the ship longitudinal stability and its effect on the ship trim

In the same way, the longitudinal stability of the ship is calculated, within and without the installation of the "green " generators system and the conclusion is reached:

$$GM_L < GM_L^{`} \quad 227.281 < 227.518 \qquad (20)$$

It means that the ship longitudinal stability, after the installation of green energy generators was improved. This reduced the effect of stresses on the longitudinal axis of the ship [3].

3. RESULTS AND DISCUSSION

Using the software ANSYS FLUENT and CFD (Computational Fluid Dynamics) flow modelling method, the following results were obtained: velocity curl and pressure distributions, forces and kinetic energies for the FLETTNER Balloon in various weather conditions; the velocity curl distributions, pressures, forces and kinetic energies studied individually for each of the four large vertical wind turbines at winds of $10\ \mathrm{m/s}$ and $20\ \mathrm{m/s}$, respectively in various planes, segregated according to the position of port/ starboard bow or at port/starboard aft part.

3.1. Modeling the phenomena regarding the comparative analysis of the forces in the FLETTNER Balloon and in the large vertical wind turbines

3.1.1 Velocity curl and pressure distributions, forces and kinetic energies for the FLETTNER Balloon in various weather conditions, with winds of 10 and 20 m / s respectively from different directions: $0^{\circ}, 30^{\circ}, 60^{\circ}, 90^{\circ}$ in various planes

They were simulated for the FLETTNER balloon: the distribution of the density on the balloon (figure 10), [5], the velocity (figure 11), the pressure on the balloon (figure 12), the force on the balloon (figure 13), the turbulence kinetic energy (figure 14), all in the XOY plane, then XOZ, at a wind speed of 10 m / s, 20 m / s and a direction of wind of 30°, 60°, 90°.

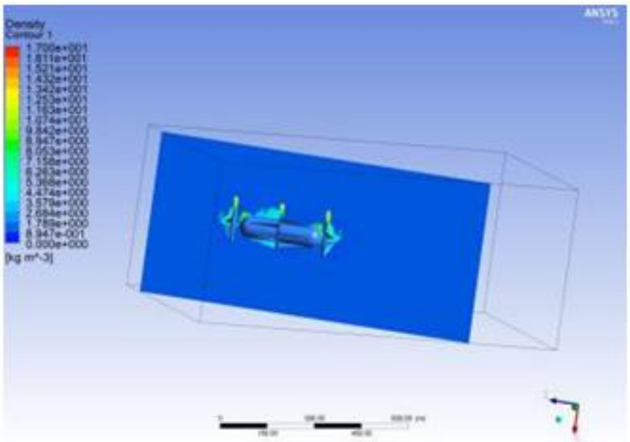

Fig. 10. Density distribution on the plane, in the XOZ plane - at a wind speed of 20 m / s and a wind direction of 60°. [5]

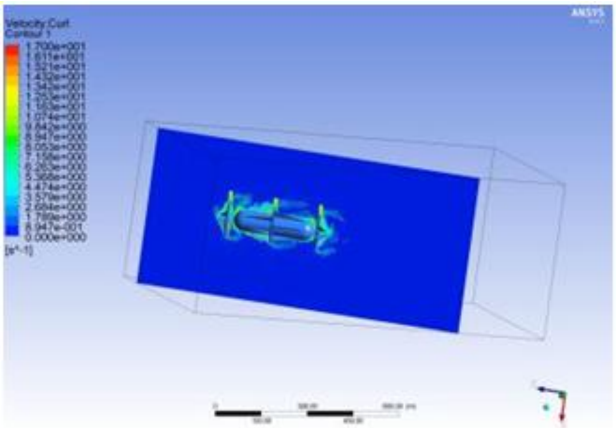

Fig. 11. Velocity distribution on the plane, in the XOZ plane - at a wind speed of 20 m / s and a wind direction of 60°.[5]

From the figure 11 can see the velocity curl distribution on the plan where is situated the FLETTNER Balloon, in XOZ plane at a wind speed of $20\ m/s$ and a wind direction of 60°. In the area near the balloon the velocity curl distribution is bigger. It drops while getting far away.

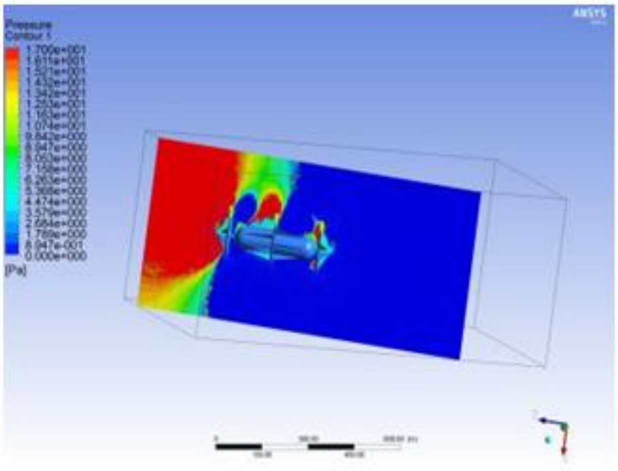

Fig. 12. Pressure distribution on the plane, in the XOZ plane - at a wind speed of 20 m / s and a wind direction of 60°, [5]

In the figure 12 it can see the pressure distribution on the plan where is situated the FLETTNER Balloon, in XOZ plane at a wind speed of $20\,m/s$ and a wind direction of 60°. The pressure is bigger on the left side of the balloon. On the area near the balloon the pressure drops while getting far away.

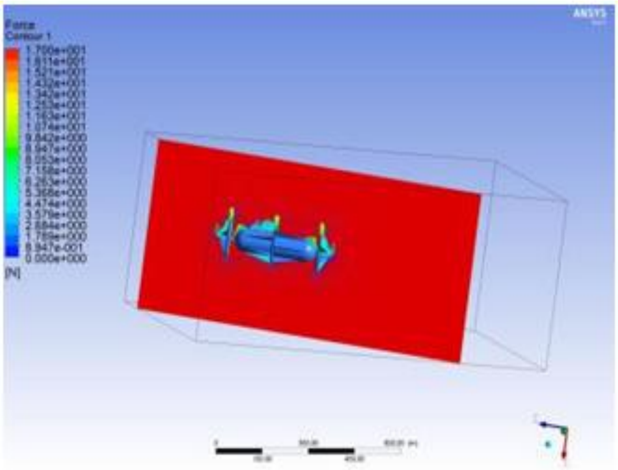

Fig. 13. Distribution of force on the plane, in the XOZ plane - at a wind speed of 20 m / s and a wind direction of 60 °.[5]

In the figure 13 it can see the force distribution on the plan where is situated the FLETTNER Balloon, in XOZ plane at a wind speed of $10\,m/s$ and a wind direction of 0°. The force is bigger near the balloon. The arrows are showing the rotation way of the balloon.

In the upper figure 14 it can see the variation of the turbulence kinetic energy on the plan, in the direction of the flow, for a vertical plane XOZ at a wind speed of $20\,m/s$ and a wind direction of 60°. Turbulence kinetic energy which is represented on the plan is bigger near the extremities of the balloon and it drops while getting far away.

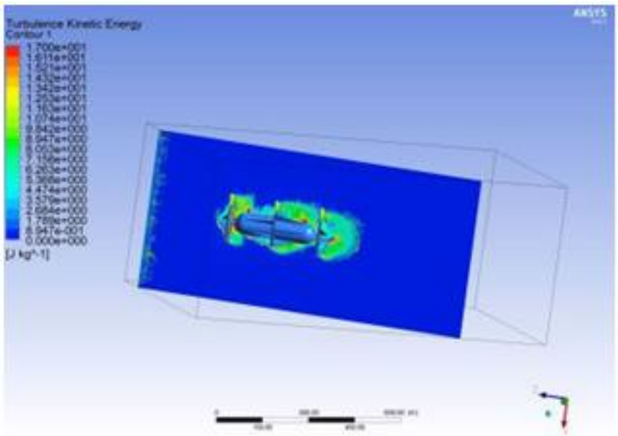

Fig. 14. Distribution of vortex kinetic energy on the plane, in the XOZ plane - at a wind speed of 20 m / s and a wind direction of 60°.[5]

3.1.2 The velocity curl distributions, pressures, forces and kinetic energies studied individually for each of the four large Vertical wind turbines at winds of $10\,\mathrm{m/s}$ and $20\,\mathrm{m/s}$ respectively in various planes, segregated according to the position of port/ starboard bow or at port/starboard aft part.

For the large vertical wind turbine were simulated: density distribution (figure 15), force distribution (figure 16), pressure distribution (figure 17), vortex kinetic energy distribution (figure 18), in the XOY and XOZ plane, respectively, on vertical wind turbine located aft to port, at a wind speed of 20 m / s.

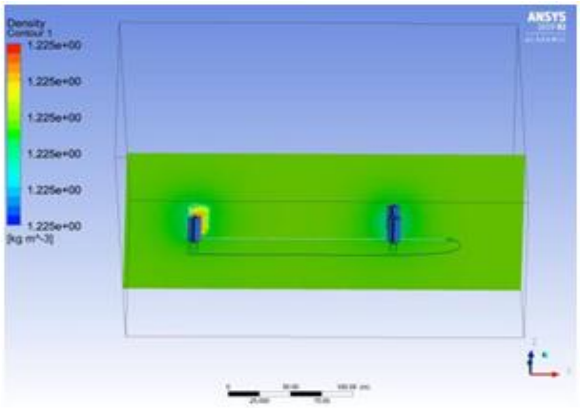

Fig. 15. Density distribution on the vertical wind turbine located in the stern port, in the XOZ plane - at a wind speed of 20 m / s. [5]

In the figure 16 is presented the force distribution variation on the Vertical wind turbine which is situated in starboard side aft, in XOZ plane at a wind speed of $10\,m/s$. The force is drawn in the direction of the flow.

In the figure 17 it can see the pressure distribution on the vertical wind turbine, which is situated in starboard side aft, in XOZ plane- at a wind speed of $10\,m/s$, in the direction of the flow.

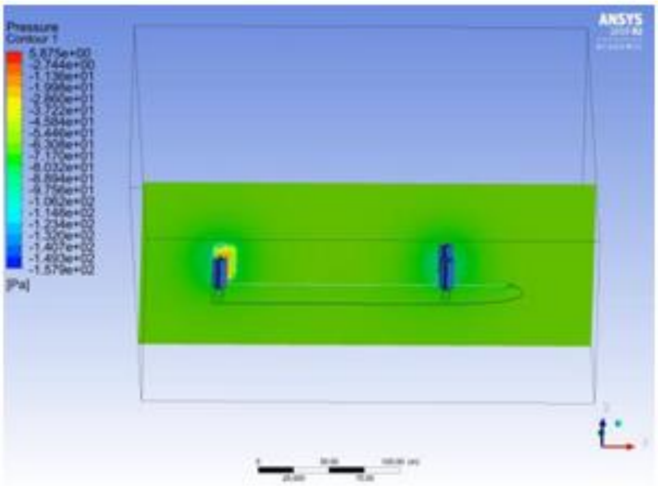

Fig. 17. Pressure distribution on the vertical wind turbine located in the stern port, in the XOZ plane - at a wind speed of 20 m / s. [5]

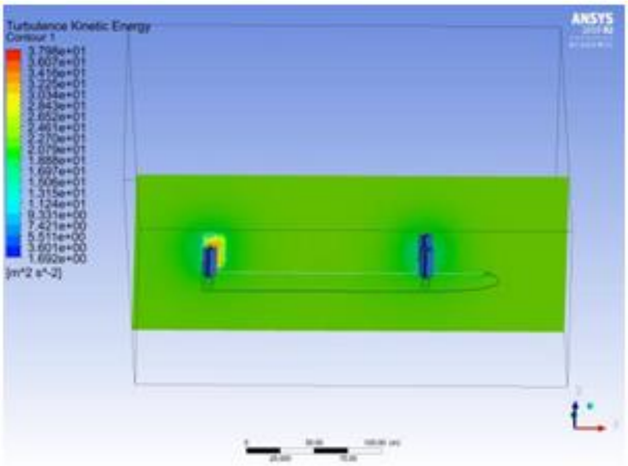

Fig. 18. Turbulence kinetic energy distribution on the vertical wind turbine located in the stern port, in the XOZ plane - at a wind speed of 20 m / s [5]

In the figure 18 is represented the turbulence kinetic energy on the vertical wind turbine, which is situated in starboard side aft, in XOZ plane at a wind speed of $10\ m/s$, in the direction of the flow.
By using the ANSYS FLUENT program can studied the FLETTNER Balloon at different weather forecast conditions, with a wind of $10\ \mathrm{m/s}$, $20\ \mathrm{m/s}$, from different directions: $0^{\circ}, 30^{\circ}, 60^{\circ}, 90^{\circ}$ in different plans.
We used ANSYS FLUENT program to study each of the four vertical wind turbines, individually, at a wind speed of $10\ \mathrm{m/s}$ and $20\ \mathrm{m/s}$ in different plans, segregated by the position port side aft port side forward, starboard side aft and starboard side forward. The numerical program ANSYS FLUENT gives a very good representation of the turbulent air flow. The software uses an unstructured discretization network.
By using the ANSYS software we can determine also other important elements for the flow like density, force, pressure, turbulence kinetic energy, velocity curl.

4. CONCLUSIONS

After the installation of the green energy [4] sources (a FLETTNER Balloon [5] with helium and four vertical wind turbines) part of the hybrid system, on a container ship, ship stability and maneuverability are not fundamentally changing. There are not big differences between the ship initial manoeuvrability and the ship manoeuvrability with the hybrid system installed.
Transversal ship stability was decreased: $\mathrm{GM}^{`} < \mathrm{GM}$ $(4.3184 < 4.3200)$ but the value is insignificant.
Longitudinal ship stability was increased, due to the installation of green energy sources: $\mathrm{GM_L} < \mathrm{GM_L}^{`}$ $(227.281 < 227.518)$.
Frequency of the rolling period was increased, after the installation of the green energy sources: $\mathrm{T} < \mathrm{T}^{`}$ $(10.4956 < 10.4975)$.
The installation of this hybrid system on a container ship is efficient by the decreased of the amount of fuel used, of reduction of greenhouse effect – pollution and is safe for navigation.
After comparing the various types of gases suitable for the FLETTNER balloon, it was concluded that helium is the ideal gas with which the balloon should be filled.
Following the calculations, the optimal dimensions of the FLETTNER helium balloon were obtained, which can capture winds from 183 to 305 meters above the ground.
Large vertical wind turbines are made of carbon fiber and steel reinforced polymer components. Their data sheet has been modified according to the technical requirements for a container ship, showing that they will have: 24 m height and a weight of 40 t each.
The FLETTNEr balloon was positioned above the ship, anchored with ropes. In order to calculate the number and type of ropes, the minimum strength required for the ropes connecting the ship was determined. Following the calculation, it was concluded that at least three ropes are needed, the balloon with four ropes was anchored for safety.
Vertical wind turbines were installed on the main deck of the ship, in its bow and stern.
Following the calculation of the energy balance of the two types of wind energy capture systems, it was concluded that, depending on the speed of the ship, in ideal wind conditions and depending on the number of vertical wind turbines running, which use wind energy, the system balloon turbine can generate between 500 kWh and 9000 kWh. Of course, it will never be necessary to turn on all wind power equipment at full capacity.
It has been shown that the static angle of inclination of the container vessel with the vertical wind turbines installed on its deck does not exceed the normal roll angle of the ship and may be considered negligible being less than 1%. This means that the installation of

large vertical wind turbines on the deck of a container ship will not affect the manoeuvrability of the ship.
If the wind blows perpendicular to the length of the FLETTNER balloon with helium, ie from the stern or bow of the ship, it does not affect the manoeuvrability of the ship. The higher the rotational speed, the more electricity it will generate, but it will not move the balloon. The balloon has two stabilizers that help it maintain its position.
In order to perform the stability calculation, we determined the ascending force, the mass of the FLETTNER balloon, the mass of the ropes necessary to anchor the ship's balloon, the mass of the cables necessary to transmit the electric current from the balloon to the ship and the mass of the gas.
As a conclusion, after all the calculations made after the installation of the elements of the hybrid energy system, both the manoeuvrability and the stability of the ship do not change fundamentally.
There are no major differences in the manoeuvrability of the ship compared to the ship without the hybrid power system installed.

5. ACKNOWLEDGMENTS

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