CONSTANŢA MARITIME UNIVERSITY
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Ph. D. THESIS
ABSTRACT

Research on the design and operation of container vessels for improving energy efficiency

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I. Ph.D. Thesis content

II. Gratitude

I would like to express my full gratitude to the scientific leader, Prof.Ph.D. Eng. Dumitru DINU, who guided and advised me throughout the elaboration of this paper, showing a high degree of professionalism and understanding.

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And of course I would like to thank my family who showed a lot of understanding during this period when the free time spent with them was limited.

III. Introduction

This paper is part of a broader system of research on air pollution and methods of reducing pollutant emissions from marine engines.

Throughout the paper, a series of aspects regarding the classical propulsion are treated, with energy sources coming from the combustion of fossil fuels, naval engines with internal combustion and their contribution to the air pollution because of the exhaust gases.

After this presentation I have refered to unconventional electricity generating systems, those systems that use sources other than fossil fuels and I focused on electricity generation systems with the help of wind energy, more precisely the Flettner balloon but also some large vertical wind turbines.

In order to have an image as close as possible to reality, in the thesis I will study the following aspects:

- The current state of knowledge in the field of unconventional energy capture;
- The international strategic context regarding the community interest on unconventional energy capture;
- Research on unconventional energies that can be captured and used efficiently on board of cargo ships;
- Establishing the right energies to be captured on board of container ships;
- Elaboration of technical solutions and performance of experimental tests to highlight their effectiveness and the advantages of the electricity generating installation on container ships;
- Installation and coupling of the Flettner balloon and large wind turbines to the main power bar of the ship;
- Comparative study of filling the Flettner balloon with helium or hydrogen, advantages and disadvantages;
- Calculation of the forces that appear in the Flettner balloon, respectively in the large vertical wind turbines;
- The minimum calculation of the gas volume necessary to keep the balloon afloat;
- Calculating the anchoring lines of the Flettner balloon to the ship;
- Calculating the cable characteristics necessary for the transmission of the electric current generated by the Flettner balloon;
- The influence of the Flettner balloon and large vertical wind turbines on the maneuverability and stability of the ship;
- Reducing fuel consumption using the hybrid system;
- Reducing environmental pollution;
- Aeronautical meteorology;
- Hybrid system installation costs.

Throughout the thesis I focused mainly on capturing and using wind energy, which is much more suitable for modernizing existing ships, the equipment used is reliable, cheap and does not require the installation of new propulsion machines, but in the future, based on accessibility and as the price of new technologies decreases, we are convinced that it is possible to use efficiently other types of unconventional energies.

The solution for capturing wind energy treated and studied in the doctoral thesis opens the way for a hybrid combination of the propulsion system, as appropriate, depending on wind speed and direction, travel time on a predetermined route, safety of navigation, with the aim of promoting the use of wind energy, with a significant reduction in transport costs by saving fuel and lubricants.

Because the scope of wind energy is very wide, in this paper I have focused on the effect that the Flettner balloon raised to a certain height, related to the container ship and the large vertical wind turbines installed on the main deck, has on container ship maneuverability

and stability. We called the system hybrid because it can switch from a conventional power source to an unconventional, green power generator. In the paper the effect that the hybrid system has on the ship's maneuverability was studied, especially on the ship's ability to keep her course and also fuel economy and reduction of environmental pollution.

I believe that the paper is important because it addresses the issue of reducing environmental pollution, by using a hybrid electricity generating system, using conventional sources (fossil fuels) and unconventional (wind energy).

IV. Paper objectives

In this paper I set myself seven main objectives for study:

- Possibility of navigation with the help of unconventional energy sources. Establishing the appropriate energies needed to be captured on board of container vessels.
- Formation of the hybrid system achieved by connecting unconventional energy sources (Flettner balloon and large vertical wind turbines) and conventional energy sources, to the main power bar of the ship. Study of the choice of the ideal gas for filling the Flettner balloon.
- The calculation of the forces that appear in the Flettner balloon, respectively of the large vertical wind turbines and the minimum calculation of the gas volume necessary to keep the balloon afloat.
- Anchoring the ship's Flettner balloon and choosing the type of cables needed to transmit electricity from the balloon to the ship.
- The way in which the Flettner balloon and the large vertical wind turbines installed on the ship's deck, influence the stability and maneuverability of the ship, trim and banding. The influence of the ascending force, exerted by the Flettner balloon, on the ship and the influence of the new forces appeared on the ship's deck as a result of the location of the large vertical wind turbines.
- Calculation of the costs, related to the installation of the hybrid system, the attenuation time of the investment, the reduction of fuel consumption and the reduction of environmental pollution on an established route.
- Use of CFD software to determine the velocity and pressure distribution around the Flettner balloon and large vertical wind turbines.

The Flettner balloon has an aerodynamic profile, with two stabilizers, with the role of maintaining its position in the air. It is positioned in a stream of air at a certain altitude, at which the wind direction and speed are approximately constant. The balloon remains in a fixed position to the ship to which it is attached, regardless the different angles from which the wind blows but also the direction of movement of the ship. During all this time it will generate electricity. The stronger the wind, the faster the balloon will rotate and generate more electricity. In the paper we studied how much current the Flettner balloon can generate at various wind speeds, at various altitudes.

Following the processing of the results obtained, we concluded that the seven proposed objectives have been achieved and this paper can be a starting point for further research on the use of wind energy for the propulsion of merchant ships.

V. Synthetic presentation of the chapters and annexes of the Ph.D. Thesis

The thesis was based on ten chapters, bibliography and annexes.

Chapter 1 is an explanatory introduction that includes the argumentation of the topic by explaining the importance of this paper, the opportunity and objectives of the thesis.

It also includes a subchapter, called *Gratitude*, in which I express my thanks to all the teachers from the Maritime University of Constanța, who helped me to complete this work and who were with me unconditionally throughout the research.

Chapter 2 raises the alarm about air pollution caused by shipping. This describes the categories of polluting gases and greenhouse gases produced by ships and their impact on the environment, in the world and in the European Union. At the same time, a study was conducted on the emissions of noxious substances caused by ships in ports.

Chapter 3 presents unconventional methods of generating electricity with possible applicability on ships.

In this chapter we can also find a subchapter on aeronautical meteorology. I consider that this subchapter has a special importance, given the fact that we use the Flettner balloon, which floats in the air above the ship, to produce electricity. In this subchapter we find details about the power of the wind, at various altitudes and locations.

I have made a comparison of different types of PV capture and focusing systems.

At the end of the chapter are highlighted some brief conclusions related to the use of unconventional methods of naval propulsion.

Chapter 4 presents the main components of the hybrid system proposed by me, used to generate energy from unconventional sources and its compatibility on a container ship.

The main specifications of the large vertical wind turbines, the Flettner balloon, the necessary supercapacitors and the secondary component of the hybrid propulsion system, diesel propulsion, are described, configured and underlined here.

In this chapter, an energy balance is made for each proposed unconventional energy source.

In the subchapter related to the Flettner balloon, a comparison is made between helium and hydrogen, in order to choose the most convenient gas to be filled with.

Chapter 5 presents the general energy balance of the hybrid system and the mooring scheme on a container ship.

The chapter also refers to the way of connecting conventional and unconventional energy sources to the main power bar of the ship, here are the exact electrical wiring diagrams of the hybrid system and their legend, which can be found in Annex I of the thesis.

At the end of the chapter I have presented and described the electrical charges of the ship 's consumers, broken down on each compartment (Annex II).

Chapter 6 describes the effect of using unconventional power generating systems on the safety of navigation. Here the maneuverability and stability of the ship with the Flettner balloon and the four large vertical wind turbines proposed for installation on board of the container ship are studied.

At the end of the chapter, some pertinent conclusions are stipulated regarding the effect of using unconventional power generation systems on the safety of navigation.

Chapter 7 Describes the use of the Ansys-Fluent program to determine the forces in the Flettner balloon and large vertical wind turbines at different angles.

Chapter 8 contains considerations regarding the implementation and use of an unconventional system on a route.

The chapter concludes with some conclusions related to the importance of the hybrid system, the reduction of environmental pollution and the reduction of expenses for shipowners or charterers in case of system implementation.

Chapter 9 represents the personal conclusions and contributions.

The thesis entitled: *Research on the design and operation of container vessels for improving energy efficiency* is a research on the installation of a hybrid system powered by energy from conventional and unconventional energy sources on container ships.

From the point of view of unconventional energy sources in the thesis, the most efficient devices have been selected, which are suitable for a container ship.

The purpose of this thesis is:

- To raise the alarm on environmental pollution caused by ships equipped with conventional propulsion systems;
- To present viable solutions to reduce environmental pollution by container vessels;
- To reduce fossil fuel costs for shipowners or charterers using a hybrid energy system;
- To extend the lifespan of conventional propulsion systems by using unconventional energy sources together with conventional ones.

The use of green wind energy from unconventional energy sources has several benefits:

- Reduction of flue gases, especially nitrogen oxides NO_x, carbon dioxide CO_2 and sulfur dioxide SO_2, thus achieving a cleaner environment.
- Reducing the quantities of fossil fuels used to produce propulsion energy by main internal combustion engines (fuel oil, diesel oil);
- Reducing the costs for shipowners or charterers, with the amount of fossil fuels consumed by the ship;
- Extending the life of diesel generators, as the period between periodic overhauls or current repairs increases.

The three natural sources: wind, sun and waves have proven to be sustainable energy sources, to be used in ship propulsion. The study shows that the most efficient unconventional source of energy is the wind.

In areas where the winds do not have the same speed, are weak, in ports or in areas where the weather conditions are not favorable, the classic propulsion, part of the hybrid system, will be used.

The hybrid system proposed in the thesis for installation on a container ship includes:

- Unconventional energy devices that capture wind energy (four large vertical wind turbines and a Flettner balloon);
- Conventional propulsion devices (one diesel and one electric);

Switching from one system to another is done automatically. The use of conventional electricity generating devices will be used only in case of absolute necessity to supplement the electricity demand and in case of entry / exit of the ship from the port.

We used the fluid flow modeling (CFD) program, Ansys Fluent for the study of the installation of two types of unconventional energy devices adapted for a container ship and the AutoCAD program for the design of the electrical wire diagram of energy sources, to the ship main power bar.

This Ph.D. thesis tries to highlight the fact that a qualitative contribution can be made in the development of naval research by using numerical calculation programs (Ansys Fluent).

Although the numerical method has grown in recent years, it does not replace existing research methods.

It improves and optimizes classical research methods through the advantages it brings:

- Low cost for a wide range of similar experiments;
- Obtaining results in a relatively short time;
- If the analytical method is not yet completed, results can be obtained by computer simulation (using the Ansys Fluent program);
- Visualization of all parameters by entering the structure of the studied physical phenomenon.

Numerical computer programs have appeared due to the need of solving engineering problems. At the beginning, computational algorithms solved only certain physical properties, over time, through the development of programs, their increased diversity, the problems solved being more and more complex.

In the first stage, there were several programming languages, which required the user to have a thorough knowledge of mathematical analysis, simultaneously with a thorough knowledge of programming.

The Ansys Fluent program allows the user to access the source code. This allows you to change the configuration of the program in all its routines and subroutines.
Ansys Fluent offers a friendly interface, being easy to use compared to previous experimental methods.

The advantage of using the Ansys Fluent program is that only specific knowledge to the researched field is required, no programming knowledge is needed.

The disadvantage of the program is the limitation of the modification of the numerical program, the user having at his disposal only the solutions proposed by the company that developed the program.

Most physical phenomena can be described by mathematical equations. Based on them, numerical algorithms have been built. They calculate the parameters that describe the physical phenomena.

This thesis is a first step towards the combined use of wind energy together with the classical one, thus forming a hybrid energy system.

Personal contributions

As it results from those presented in the paper, some of the main personal contributions with a pronounced character of originality can be highlighted, as follows:

1. Carrying out a detailed study in order to determine and analyze the main polluting gases and greenhouse gases produced by maritime transport. Identification of the main polluting gases and greenhouse gases but also their impact on the environment, allow us to discover various methods of combating pollution.

By conducting a relevant analysis on emissions due to maritime transport in ports, in the coastal area of the European Union but also in the world, we can suggest various methods

or means to reduce environmental pollution. The paper proposes various possible methods to reduce environmental pollution, caused by the maritime industry.

Compared to other methods of transport, pollutant emissions from maritime transport are substantial. Emissions from fuel combustion depend on its grade and composition. Because the combustion characteristics of fuel oil and diesel are different, their combustion can produce significantly different emissions.

In the study it had been described and calculated the values of the main pollutant emissions have been described and calculated:

- Emissions of particulate matters PM;
- Emissions of sulfur oxides SO_X;
- Nitrogen oxide emissions NO_x;

but also greenhouse gases:

- Carbon monoxide emissions CO_2;
- Methane emissions CH_4;
- Nitrogen oxide emissions N_2O;

and their impact on the environment.

Most of these emissions take place at sea, but the most visible part of them is concentrated around port areas and port cities.
Over 85% of the emissions from the shipbuilding industry come from container vessels and oil tanks.

Emissions from maritime transport contribute significantly to environmental and health risks, mainly in coastal regions.

They affect human and animal health because they contain particles and gases, acidifying and eutrophicating substances, as well as greenhouse gases.

The maritime industry is considered one of the most polluting industries on Earth, due to the large number of ships and the use of fossil fuels.
Many countries have already taken severe measures against pollution due to maritime transport, by establishing various protected areas ECA, DECA, NECA, where ships can only sail using fuel with low sulfur content.

2. Identify, in the current technological context, the main unconventional energy sources and their possibilities to be used efficiently on vessels

By unconventional, renewable energies are meant those energy sources that can be considered inexhaustible. Renewable energy sources are widespread and non-polluting. Installations which are built to capture energy have a long service life in normal operation. Wind energy is a free, abundant source of energy with a high potential at sea. For these reasons, they are of great strategic importance in the maritime industry, in the context of compliance with the international legal framework for the prevention of pollution of marine environment.

By performing a relevant analysis we identified the main equipment for capturing wind and solar energy and how to convert them into electricity, their main characteristics and energy balance. The study analyzed several types of PV capture and focusing systems.

Following this analysis, we identified wind energy as the most important source of unconventional energy, suitable for use in a hybrid energy generating system, as an element of modernization of classical propulsion, on fossil fuels, for container vessels.

I believe that the capture and use of wind energy is the best choice for the modernization of existing ships. The necessary equipment used is reliable and cheap compared to the price of fossil fuels.

In the paper I have proposed the adaptation, implementation and modernization of new devices, which are used in capturing and converting wind energy into electricity. They are called the Flettener balloon and the large vertical wind turbines. The unconvetional sources of energy, together with conventional fossil fuels energy sources form a hybrid system of electricity generators, which are used in naval propulsion.

3. Description of the main components of the hybrid system. Original method of design and sizing the system. Balloon anchoring calculations, energy balance calculation, the necessary cable calculation for electricity transmission, design the electrical wiring diagrams of the Flettner balloon and of the four large vertical wind turbines located on the main deck to the container ship.

The Flettner balloon is part of a complex system, containing turbines, generators, stabilizers, anchoring lines and power transmission cables.

After comparing the various types of gases suitable for the Flettner balloon, I came to the conclusion that helium is the ideal gas with which the balloon should be filled. The arguments are:

- Safety in use compared to hydrogen (helium is an inert gas, hydrogen is an explosive gas mixed with air);
- Lower density of helium in relation to air.

To perform the buoyancy calculations of the Flettner balloon, I have compared it with an airship. I have calculated the minimum lift force F_a required for the balloon to stay in the air, when it is full with helium and its minimum volume.

I have also calculated the minimum lift force F_a required for the balloon to stay in the air, when it is full of hydrogen. Although the use of hydrogen leads to a smaller volume, for safety reasons, I preferred to use helium as the gas with will fill the Flettner balloon. After the calculations I performed, I reached its optimal dimensions:

L_B=245 m
V_b= 200 000 m^3
m_b=5000 kg =5 t

Where:

L_B = Balloon length;
V_b = Balloon volume;
m_b = Balloon mass;

The Flettner balloon with helium can capture winds from 183 to 305 meters above the ground. Winds at these high altitudes are significantly faster than winds at lower altitudes.

The 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.

In this paper I have designed the electrical wiring connection diagram, of the Flettner balloon and of the four large vertical wind turbines to the electrical installation of the ship. The wiring diagram was designed in AutoCAD.

The Flettner balloon will be positioned above the ship, anchored with lines. To calculate the number and type of lines, I have determined the minimum strength required for the lines that anchor the ship. Following the calculation, I concluded that at least three lines are needed, for safety I anchored the balloon with four lines.

The large vertical wind turbines will be installed on the main deck of the ship, at bow and stern.

As a conclusion to the calculation of the energy balance of the two types of wind energy capture systems, we concluded that, depending on the ship speed, in ideal wind conditions and depending on the number of wind turbines running, the system balloon-vertical turbines 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.

The Flettner balloon can generate up to 1000 kWh. Because of this I had to calculate the number and diameter of the cables needed to transmit the electricity.

4. Original theoretical considerations regarding the influence of large vertical wind turbines (installed on the main deck) and of the Flettner balloon, on container ship maneuverability and stability

As a result to the calculations, it was proved that the angle of static inclination of the container vessel with the vertical wind turbines installed on its main deck does not exceed the normal angle of roll of the ship and can be considered negligible being less than 1%.

This means that the installation of the large vertical wind turbines on the main deck of a container ship will not affect the maneuverability of the ship.

If the wind blows perpendicular to the length of the Flettner balloon filled with helium, from the stern or bow of the ship, it does not affect the maneuverability of the ship. If rotational speed is higher, more electricity will generate, but this will not move the balloon, because it has two stabilizers that help it to maintain its position.

In order to perform the stability calculation, we determined the lift force, the mass of the Flettner balloon, the mass of the necessary lines to anchor the balloon to the ship, the mass of the cables necessary to transmit the electrical current from the balloon to the ship and the balloon mass gas.

As a conclusion to all the calculations I made, after the installation of the elements of the hybrid energy system, both the ship maneuverability and stability, do not change fundamentally.

There are no major differences in the maneuverability of the vessel compared to the vessel without the hybrid energy system installed.

In terms of stability, transversal ship stability has decreased:

GM`< GM $4{,}3184 < 4{,}3200,$

but the value is insignificant. The longitudinal ship stability, after the instalation of the unconventional energy sources, has been improved:

$GM_L < GM_L$ $227{,}281 < 227{,}518.$

After the installation of the hybrid system, the period of rolling frequency has been slightly increased:

T<T` $10{,}4956 < 10{,}4975.$

5. Carrying out a study on various types of naval propulsion, which use unconventional methods. The study and analysis of the best supercapacitor system suitable for my hybrid system. The propulsion system with is formed from a diesel engine and an electric one, wiring connection diagram to an automatic computerized generator control system

We call unconventional propulsion methods any other methods that differ from the classical propulsion of commercial ships, which do not use internal combustion engines to produce the mechanical work necessary to rotate the propeller shaft and therefore to move the ship.

Unconventional propulsion systems have many advantages:

- They do not pollute the atmosphere and the marine environment;
- They are easy to install on board of existing ships and do not require noticeable changes in the structure of the ship;
- The space for cargo or passengers is increased by reducing the space occupied by the main engine compartment (in the case of electrically propelled ships);
- In the case of mixed propelled ships engine-sail, fuel consumption is decreases and the loss of speed is partially covered by the traction force of the sail raised to a certain altitude.

Among the most used unconventional systems, some put into practice, others left only in the research stage, are:

- Rigid and / or mobile sails covered or not covered with photovoltaic cells;
- Electric engines;
- Sail raised to a certain altitude - kite.

I propose for use two engines, one diesel from MAN and one electric.

The high-power diesel engine will be able to operate while using diesel generators but also unconventional power sources. The electric motor will have as main source of power supply the unconventional power generators, respectively the four large vertical wind turbines installed on the ship's main deck and the Flettner balloon and as secondary source the diesel generators.

The two engines will not work simultaneously, their operation will be done in turn. The switching from one engine to another one will be done by an automatic adjustment system.

The diesel generators, the large vertical wind turbines and the Flettner balloon will be controlled by an automatic computerized system. During crossings when unconventional energy sources are turned on, we will use the electric engine. The main electricity generators will be the large vertical wind turbines and the Flettner balloon, but if the energy produced by them is not enough, the diesel generators will automaticaly start, at minimum power, in order to cover the existing energy deficit. By using diesel generators when minimum power is needed, we reduce fuel consumption to a minimum, thus reducing pollution and costs.

6. Research of CO_2, SO_x and NO_x emissions on the Busan - Tacoma route. Forcasting and analysis of the meteorological situation, calculation of the costs regarding the implementation and use of the unconventional energy system on the route. Calculation of the investment attenuation time after the installation of the hybrid system.

By using the unconventional hybrid power generator system proposed in this paper, shipowners can save a large amount of fuel, thus saving substantial founds and reducing environmental pollution.

Unfortunately, the legislation in force does not allow ships to enter in ports with unconventional energy sources. Because of this, unconventional energy sources in the paper will be used only during transoceanic crossings or during long voyages.

Using this hybrid system not only helps us to save fuel, but also protects the environment.

By using the hybrid system, emissions will be reduced to the following values: CO_2 2,53%, SO_x 0.87%, NO_x 2,66% compared to a conventional system.

The hybrid system in this case would reduce fuel consumption costs by 96.62%, in ideal wind conditions.

The weather forecast in the North Pacific Ocean is favorable, with strong winds during the year, especially during the winter months, the hybrid system proving to be effective.

Approximate total costs for implementing the hybrid system consisting of four large vertical wind turbines and a Flettner balloon filed with helium are: $ 700,000.

Table A V.1: Amortization of the investment at a ship, at a speed of 18 Nd

Ship speed 18 Nd	Hybrid system
Costs $	700000
Heavy fuel oil HFO in tons, bought at a price of 350$/t	2000
Amortization of the investment - in NM with the hybrid system in working status	11111
Marine gas oil MGO in tons, bought at a price of 507$/t	1381
Amortization of the investment - in NM with the hybrid system in working status	9206

7. Original method of scientific research using the Ansys Fluent simulator

By using the Ansys Fluent program I have studied the forces exerted by the Flettner balloon, driven by the high wind at different angles of inclination, in two planes, on the surface but also on the balloon. Also with the help of the Ansys Fluent program I have studied the forces that appear around the ship due to the location of the four large vertical wind turbines on the main deck of the container ship.

As a result to the application of forces, the behavior of the ship in different sea conditions have been studied (calm, light wind, strong wind at the sea surface but also at high altitude).

The values of the forces have been numerically calculated on Ansys Fluent.

The meteorological data used in Ansys Fluent is variable, depending on the period and on the navigation area. This data was collected from the SPOS weather program.

I have studied the nautical modifications and maneuvering characteristics of the ship in the case of propulsion with the Flettner balloon installed above the ship and with the 4 large vertical wind turbines located on the main deck.

The wind speed at sea surface and at high altitude was based on the data obtained from annual statistics and according to the Beaufort scale, using the *SPOS* program.

I have also used the Ansys Fluent program to calculate the velocity and pressure distribution formed by the wind around the large vertical wind turbines and the Flettner balloon.

By all the above, I consider that all the objectives of the thesis have been met.

Chapter 10 presents directions for future research.

I believe that the results obtained by carrying out this work are remarkable, because the Flettner balloon and large vertical wind turbines are relevant devices in capturing wind energy and shaping the wind flow regardless of wind direction, on a container ship.

This research paper paves the way for future research and development perspectives in the related field, green energy sources, hybrid power supply systems, from unconventional sources (wind energy) and conventional sources (fossil fuels).

I consider that the research can be continued for the increase of electrical storage capacity produced by the Flettner balloon and of the four large vertical wind turbines.

Extension research can also be done regarding the electricity production with the help of the Flettner balloon at altitude of more than 300 meters.

Studies may also be extended to the design and construction of ships with a mixed propulsion system, for descovering new body shapes, new ship bulb shapes, in order to reduce ship-water friction.

Another possible research can be the instalation of Flettner rotors which are using the Magnus effect on the main deck of the ship, instead of the large vertical wind turbines.

The operation of the wind turbines involves researching and finding optimal solutions for the practical application of the results obtained, in order to reduce fuel consumption, the amount of gas emitted by ship engines and finally to reduce the degree of air pollution. .

The shape of the Flettner balloon, but also of the ship, is an interesting research topic, CFD studies will be validated on models (with the passage of results in nature through similarity) or on prototypes.

Being a Ph.D. thesis dealing with research on the design and operation of container ships to improve energy efficiency, of hybrid energy sources - the classic one combined with the use of green energy, the author thanks you for any suggestions or recommendations that may lead to the improvement of the system or continuing the research carried out.

Annexes:

- Annex I – Contains electrical wire diagram for connecting conventional and unconventional generators to the main power bar of the ship, drawn in the AutoCAD program and their legend;
- Annex II - Contains tables with alternative and conventional energy generating sources part of the proposed hybrid system and tables with the ship's electrical consumers, divided into various segments;
- Annex III - Contains tables with the NO_x emissions calculations classified by different consumers, with different fuels, calculated for the Busan-Tacoma route;
- Annex IV - Contains the results of the simulations performed in the Ansys Fluent program.