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New top-7 vessels wind projects and analysis of their practical possibilities for the transport fleet.

Valentyn Nastasenko[1,*], Vyacheslav Svyrydov[2], Artem Andreev[3]

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ABSTRACT

The article deals with ship wind energy systems, namely the analysis of their best modern projects. It is shown, that wind energy is one of the main directions of development of alternative energy, which saves fuel resources and reduces greenhouse gas emissions. Ship wind energy is givena constant attention, because at the beginning of the last century the basis of the transport fleet was mast sailboats. However, in the last 60 years, sailing systems have not received significant application. The purpose of the study is to analyze the technical capabilities of modern ship sailing systems. The objectives of the study are as follows: to identify the best modern projects, to analyze their advantages and disadvantages and to assess the real possibilities of their widespread implementation in the modern transport fleet. The scientific novelty of the study is the justification of this analysis and its criteria and the development of recommendations for further creation of the best ship wind systems. The relevance and importance of this work is due to the fact, that the right direction of research and development avoids unproductive waste of time, intellectual and material resources. Research results. The analysis of the TOP-7 projects proposed by Captain Watson in Sea Shepherd Ocean ACTION Reports is taken as a basis. It is shown, that the main disadvantage of this work is the inattention to the shortcomings of ship wind systems, which are due to the wind rose on the route and during the flight. First of all, because the stable annual wind processes in the world's oceans in the tropics and subtropics have a speed of up to 5 m / s, and the ship's own speed during cargo delivery reaches 7...10 m / s. Among other disadvantages are the main: the roll of the mast wind systems under the action of wind and the oscillation of the vessel during its gusts. On this basis, a new ranking of TOP-7 projects is proposed. General conclusions Two systems are considered to be the most expedient: "Eco Marine Power Wind-Solar Ship"? with side placement of sails and "Flettner Rotor Ship" with Flattener rotors, which realize the effect of Magnus for the movement of ships. Recommendations for their implementation are developed.

1. Introduction.

In modern conditions of human life and activity, emissions of harmful substances that occur when using traditional fuels based on oil and gas are growing daily. The largest share among them are greenhouse gas emissions of CO and CO_2, which lead to the threat of global warming and climate change on Earth. As the share of traditional fuels in the transport fleet is 6% of total costs, they form a share of 3% of total CO and CO_2 emissions.

According to the decision of the COP'26 Summit from October 31 to November 12, 2021, in order to reduce the threat of the greenhouse effect, it is necessary to reduce CO and CO_2

[1]Doctor of Technical Sciences, Professor of the Department of Transport Technologies and Mechanical Engineering of Kherson State Maritime Academy, Ukraine.

[2]Ph.D., Acting Associate Professor. Ship Engineering and Energy Department Kherson branch of the Admiral Makarov National University of Shipbuilding, Ukraine.

[3]Ph.D., Acting Associate Professor. Ship Engineering and Energy Department Kherson branch of the National University. Admiral Makarov Shipbuilding, Ukraine.

*Corresponding author: Valentyn Nastasenko. E-mail Address: nastasenko2004@ukr.net

emissions by 7.4% annually. The transition only of the transport fleet from traditional fuels for marine engines to alternative types of energy (wind, solar, hydrowave) can solve this problem by 40%. Therefore, a careful analysis of these possibilities is needed.

Wind energy is one of the main directions of development of alternative energy, which saves fuel resources and reduces greenhouse gas emissions, which are the main threat to global warming. Ship wind energy is givena constant attention, because in the first quarter of the last century the basis of the transport fleet was mast sailboats. With the commissioning of the Suez Canal, they were gradually replaced by mechanically propelled vessels, as the use of sail in the canal area was impossible and the shortest route from the Atlantic to the Indian Ocean was inaccessible for sails ships.

However, in the context of the expected fuel crisis [1] and the threat of a global greenhouse effect [2], at the end of the XX century there was a revival of sailing systems with for additional fuel economy on the ships with internal combustion engines (ICE), which are most common in the transport fleet.

Analysis of recent researches and publications. Selection of previously unsolved parts of the general problem, setting goals and objectives of the study.

Positive experience in the operation of oil tankers equipped with mast sail in the 60… 70s of the XXth century in Japan [3] gave some hope for their further spread in the transport fleet. However, this did not happen in the next 60 years, which requires a careful analysis of the situation.

The main purpose of the study is to analyze the technical capabilities of modern ship sailing systems to reduce greenhouse gas emissions.

The objectives of the study are as follows: to identify the best modern projects, to analyze their advantages and disadvantages and to assess their real possibilities for widespread implementation in the modern transport fleet.

The scientific novelty of the study is the rationale of this analysis and its criteria and the development of recommendations for further development of the best ship wind systems.

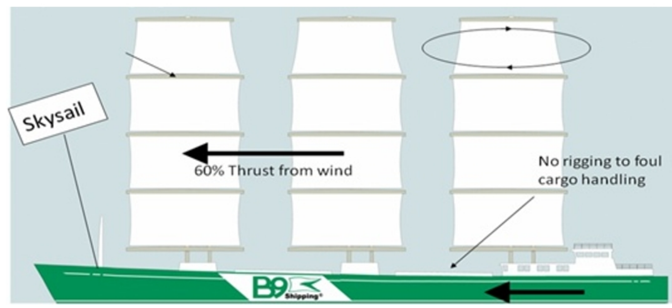
The implementation of the proposed study is relevant and of great scientific and practical importance, as in recent years the number of projects of ships with wind energy has increased significantly. As a result of these researches, in the study [4] Captain Paul Watson singled out the TOP-7 projects recognized as the best at present. The peculiarity of Captain Watson's publications is that the shortcomings of wind systems are not defined. However, the definition of shortcomings changes the real practical value of these projects, which is fully consistent with the previously performed researchby Professor Nastasenko [5].

The peculiarity of Professor Nastasenko's publications is that they identify the advantages and disadvantages of ship wind systems. However, these works are little known to a wide range of researchers in this field. This is confirmed by the fact that in the study [4], dated September 25, 2020, there is no referencenietherto the study [5] and nor to a number of other previously published studies [6, 7]. Therefore, there is a need to eliminate this shortcoming, which is the 2ndpurpose of this study.

Retation of the main material of the study - analysis of the knownrankings and development of a new ranking of TOP-7 projects of ship wind systems.

In the study [4] the concept of B9 Sail Cargo Ship (fig. 1) *is on the 1st place, or on the 7th according to ranking* [8].

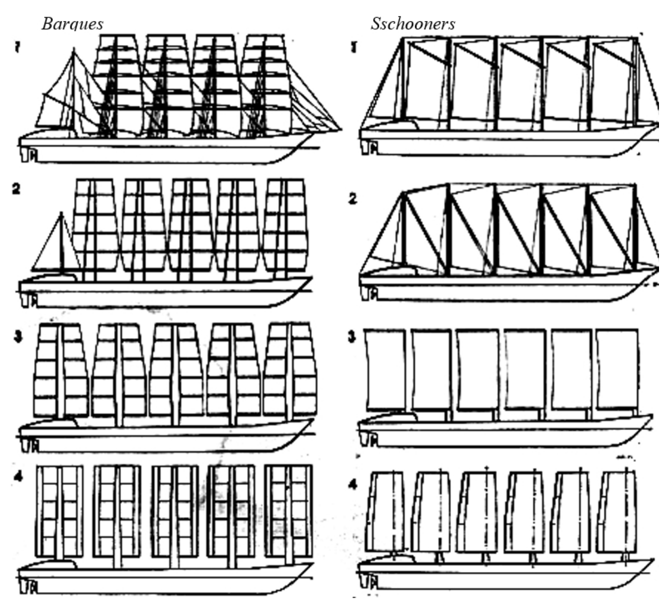
Figure 1: The concept of the B9 Sail Cargo Sailing Ship [8] (UK).



Source: Authors.

According to the main types of modern mast sailing systems, which are shown in Fig. 2 [3], the selected system B9 corresponds to the project of barques 3 W. Prolls:

Figure 2: Mast system of sail for ships and options for its implementation [3].



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Barques:1 - classic barque with a deadweight of 16.6 thousand tons with a sail capacity of 6200 m^2; 2 – University of Michigan project; 3 – project of W. Prolls; 4 – JAMDA project (Japan).

Schooners: 1 – project P. Shenzle; 2 – project by F. McLear; 3 – Princeton University project (rotary masts); 4 – project by L. Bergesson (sail-wing).

Features of the ship B9 – there is no rigging on the links of the spars, so there are best conditions for turning the sail at an angle to the wind, and the masts rotate. There is no rigging, which simplifies the handling of cargo, and the automated operation of the system reduces the number of crew members and increases the level of safety of its use.

This concept applies to a cargo ship that uses a propulsion system of sail, which is generated by wind energy to cover 60% of the traction power of the ship, and the rest is taken from auxiliary engines running on biogas. This reduces environmental damage [9].

However, it is unclear how the combination of thrust from the sail and the engine, because a simple power distribution is possible only on paper - if the engine is running, it forms the vessel's own speed, which must be subtracted from the wind speed, which will reduce the power used by the sail [5].

In addition, the main disadvantages of mast sailing systems are not taken into account [5]: namely:

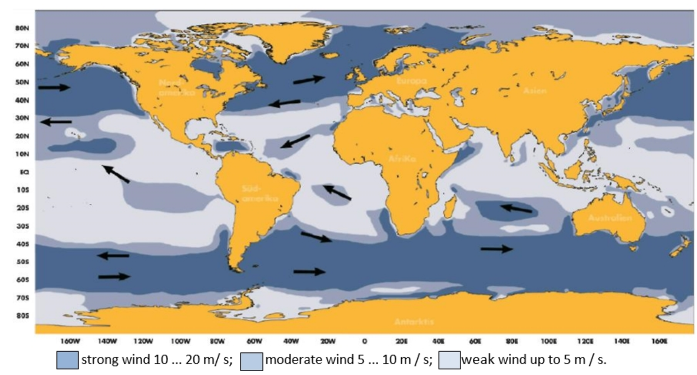
1. Creation of only thrust, which can be used only for the movement of the vessel in limited conditions, so these systems are useless when entering ports and on berthings.
2. Require special knowledge, skills and abilities to manage a ship with sail for command and rank and file and to create a broad system of their training, including simulators and computer programs for them.
3. They depend on the wind rose, which varies depending on the geography of the voyage and the season.
4. Dependence on variable wind speeds during the day and during the voyage, which does not guarantee timely delivery of cargo and requires duplication of the sail system by engine room with internal combustion engine, fuel tanks and systems for their maintenance, which are additional cargo and reduce transport efficiency and require availability (placement and maintenance) of aengine room personnel.
5. Relative unreliability and danger of sail and masts usage in stormy conditions, which increases insurance risks and rates.
6. The need for high sailage and the number of masts for large vessels, which increases the cost of their production and operation.
7. Inability to use the deck for the carriage of goods, which impairs the transport efficiency of the vessel.
8. Formation of the roll and reduction of the stability of the vessel due to the high masts and the center of action of wind forces on them, as well as the oscillation of the vessel during its gusts, which worsens transportationconditions.
9. Complications of passage under bridges and maneuvering in the narrowwidths of navigation, which worsens the operating conditions and the possibility of transport efficiency of the vessel.
10. Problems of initial strength for high heavy-duty masts and their fatigue strength due to aging and operation, which requires additional costs for their maintenance and repair.

From this list, the basis of which is given in [5], removed the factors, which his eliminate modern television technology and automation removes:

- limitation of course visibility during navigation from the afthouse, which requires additional video surveillance systems on the bow of the vessel and their costs;
- in the absence or unreliable automation - an increase in the number of crew to work with sail and its systems, which leads to problems with maintenance of the personnel.

However, the biggest negative factor of wind systems is the dependence on the average annual speed of stable wind currents in the oceans, which in the tropics and subtropics are up to 5 m/s and only in the "roaring latitudes of 40 degrees" exceed 10 m/s (Fig. 3).

Figure 3: Steady annual directions of wind flows in the oceans.



Source: Authors.

Therefore at own speed of cargoes delivery by the vessel, which equals 14...20 knots, the speed is:

$$\upsilon_{?} = \frac{(14\ldots20)\,(knots) \bullet 1854\left(\frac{m}{knot}\right)}{3600(s)} \approx 7,2\ldots10,3\left(\frac{m}{s}\right).$$

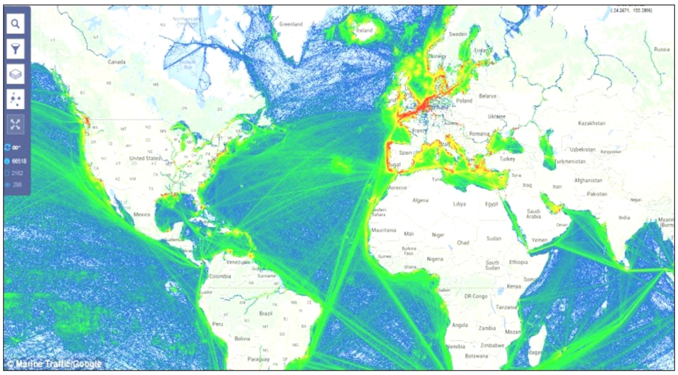
Wind of less than 7.2... 10.3 m/s speed does not catch up with the ship and the use of sail of any type is ineffective because it becomes an additional cargo that reduces the transport effeciency of the ship. The biggest problems arise when navigating in the tropics and subtropics, where the average annual wind speed is <5 m/s and often set calm for many months. The approximate average speeds of the sailboats that they are able to reach in the equatorial zone give information about the delivery of goods by a classic barque, namely - the famous tea clipper of the XIX century: "CuttiSark", which covered a distance of 19 thousand miles from the Chinese port of Fuzhou to London within 107... 110 days [9]. Its maximum average speed was the value of (1) in knots, or (2) in m/s:

$$\upsilon_{max} = \frac{19000(miles)}{107x24(hours)} = 7,4\,(knots) \tag{1}$$

$$\upsilon_{max} = \frac{7,4(knots) \bullet 1854\left(\frac{m}{knot}\right)}{3600(s)} = 3,8\left(\frac{m}{s}\right). \tag{2}$$

Since a significant number of ship routes pass through equatorial zones, where the average wind speed is <5 m/s and often there is a calm for many months (Fig. 4) [10].

Figure 4: Scheme of the main routes of ships in the world ocean [10].

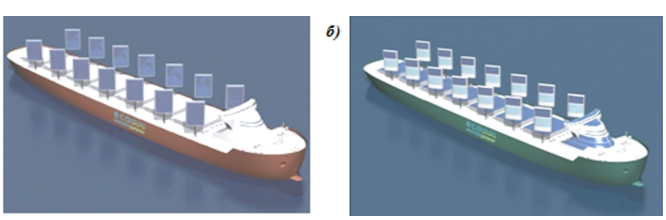


Source: Authors.

This limits the possibility of using sail. They are appropriate only in the "roaring" of the 40's and "crazy" latitudes of 50 degreeson pre-fixed routes. However, for them in modern sailing projects [11] the average speed of transportation is deliberately reduced to 10 m/s. In all other cases, sailing systems are suitable only for cruise ships sailing on fixed routes with wind speeds > 10 m/s and pleasure yachts of irregular service, which reproduce the romance of sailing.

In the 6th place in [4] is Eco Marine Power Wind-Solar Ship system (Fig. 5) [12], which has a large number of rigid rotary sails (Fig. 5.a,b), using wind and solar energy , for which they are equipped with solar panels [12]. In the new projects, the batteries installed not only on the sail, but also on the hatch covers and on the superstructures of the vessel (Fig. 5.b) [12]. They also have sections for working at night from infrared rays.

Figure 5: Project of a 2025 drycargo ship "Eco marinepower" (Japan) with rotary side sails and solar panels on them (a) and with solar panels on the hatch covers and vessel superstructures (b) [12].



Source: Authors.

The low-altitude sails are located on the sides of the hull, which allows it to pass under bridges, and most importantly - to use the deck for cargo and reduces roll and pitch. Therefore, this project has the greatest advantages for any type of sailboats in the transport fleet and the 6th place for this system - very low, in the new ranking it is offered the 1st.

However, rigid flat sails have a lower efficiency than concave flexible ones, so they need to be improved.

In the 5th place in [4] is the system SkySails / Kite Ship (Fig. 6) [13, 14]. This technology uses flexible lifting sails - towing kites to move the ship forward, which reduces the load on the main engine and reduces fuel consumption.

Figure 6: SkySails system with flexible lifting sails - kites (Germany) and conditions of use of wind at high altitude (use of wind in high altitudes): height above surface - height above sea level, traditional rigg - traditional equipment, Windrichtung - Wind direction, Mogliche - Opportunities [14].

Source: Authors.

Advantages of this system in comparison with a mast sail [5]:

1. Allows you to use the deck to transport goods.
2. Reduces roll and pitch of the vessel.
3. The speed of the wind and, accordingly, the thrust of the sail at an altitude of 200 m is greater than at the surface of the sea, where there is friction and braking on the water flow.
4. Easier to manufacture and maintain than a mast sail.
5. Does not interfere with the visibility of the vessel's course and oncoming obstacles.
6. More mobile when passing under bridges and narrow widths.
7. Has a lower total mass than masts and sails, which creates a reserve for transport effeciency the vessel.

However, 14 years after the development and testing of the SkySails system in 2006, it has not been widely used, as it has its significant limitations and shortcomings:

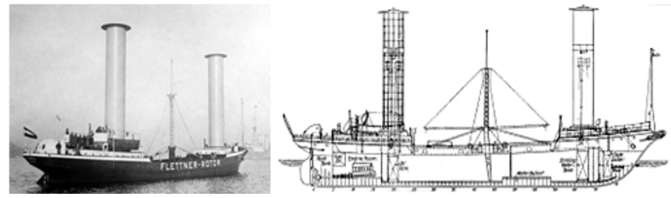
1. Thrust is most effective in a narrow sector ± 45^0 of the wind direction accompanying the ship's course. Further rotation of the sails after the wind reduces the course force and increases the transverse force of its action.
2. When the wind and sail deviate to the side from the direction course of the vessel (which happens in many cases), there are lateral forces on the hull, which must be compensated by turning the rudder, which reduces the useful work of the propeller and the efficiency of the sail as a whole [15].
3. Requires relatively sophisticated technology and devices for raising and lowering the sails and the ability and skills to use and monitor them.
4. Requires 3 crewmembersto be present for raising and lowering the sail and to place it in the bunker on the side of the vessel, which leads to their additional duties outside the watch-time and is dangerous in stormy conditions.

5. Requires special control of the sail and its control by the operator from thedeckhouse and special automated systems for its implementation using a separate PC and computer programs. Therefore, when working in one shift it requires 1 additional crewmember – the operator, 2 crewmembers for two shifts, which work only in windy weather. What will thesecrewmembers do in windless weather?
6. Requires special training of highly skilled operators who are well versed and able to anticipate the possible evolution of the kite during launch and descent, which is difficult to achieve in today's transport fleet, where crews are changed rather frequently.
7. The final training of crewmembers requires the introduction of a new training structure using special simulators and computer programs that still need to be created, which requires significant time and investment for their development and maintenance.
8. Limits the possibility of increasing the thrust by increasing the number of sails, as it complicates their control by eliminating their collision, intersection and twisting of their ropes during the evolution of sails and wind changes during ship movement, and especially when raising and lowering sails.
9. It is difficult to monitor the sail and control it at night and in poor visibility.
10. The use of the system is possible only on the high seas and is impossible in the narrowness of navigation (channels, canals) and at the port.
11. The lower threshold of sail use is limited by the speed of the vessel 14… 20 knots, or 7… 10 m/s, with which the cargo is most often delivered, so the minimum wind speed reduces its use to latitudes of 40… 50 degrees.
12. The upper threshold of sail use is limited by the wind speed of 17… 20 m/s, at higher speed the probability of its break increases and the general storm situation worsens, which ships are recommended to avoid.
13. Sail area "SkySails" - from 160 to 640 m^2, which is significantly inferior to the sail of mast systems, so their use is effective only for vessels of small (up to 10 thousand tons) displacement.
14. The relatively high cost of the system, which according to Zeppelin [14] is from 0.5 to 1.1 million €.

However, the main disadvantage of the SkySails system is the possibility of sinking the sail in case of unsuccessful launch and descent. As the weight of the sail filled with water reaches 80… 320t and increases proportionally with each 1 m/s of speed of the vessel, it poses a danger for its roll and flooding. It is impossible to lift a sail of this weight from the water in most cases, so they are cut down and flooded. As a result, the use of the SkySails system has not been carried out since 2008 and is very problematic in the future. Therefore, according to the new ranking, this project is placed on the penultimate place.

In the 4th place in [4] is the Flettner Rotor Ship system (Fig. 7) [16, 17]. The first ship of this type of schooner "Buckau" was built and tested in 1922 by a German engineer Anton Flettner.

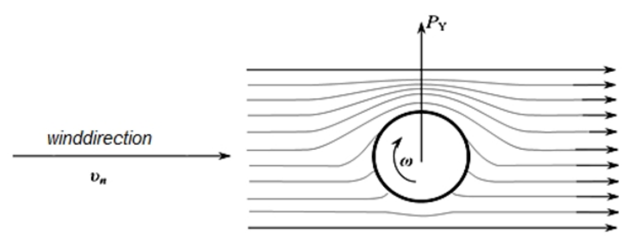
Figure 7: The first ship with Flettner rotary columns that form thrust based on the Magnus effect [16] (Germany).



Source: Authors.

It uses special vertical rotating cylinders with individual rotation drive, which reproduce the Magnus effect as propulsion for the ship. The principle of action of the effect is explained by the tightening of the airflow in front of the rotating rotor, which increases the flow velocity in front of it and reduces its pressure according to Bernoulli's law (Fig. 8). An example of action is the progressive motion of a spinning top.

Figure 8: Scheme to explain the Magnus effect.



Source: Authors.

The advantages of this system - the action at a minimum crosswind speed of 3 m/s, which allows to use it when vessel is moving in the tropics and subtropics. Disadvantages of the system:

1. Winds shall be of side type, with a tailwind or headwind there will be lateral forces, whichrequires tackmovements and increases vessel's track and the associated costs as well.
2. The use of additional mechanical and energy systems for the rotation of rotors (preference is given to internal combustion engines with a reduction gear, because their efficiency is higher than the total efficiency of electric motors powered by ship electric generators).
3. Creating only traction.
4. Intrinsic resistance of rotors to the counter air flow, including when the vessel is moving, which may be greater than the thrust produced by them.
5. The need for deck space of the vessel for the location of rotors and drive systems for their rotation.

Modern projects [17] are becoming more common and use from 1 to 6 columns (Fig. 9). The shipping company Maersk most often uses these systems on its vessels [18]. However, in "Buckau" schooner the mast and columns rest on the keel of the vessel (Fig. 7), which rationally distributes the load on it, and in modern projects (Fig. 9) – installed on the deck of the vessel, which leads to its shear stress relative to the hull, submerged into the water, which is affected by the counterflow of water.

Figure 9: Modern ships with Glacier rotary columns [17].

Source: Authors.

It should be recognized, that this system is the most promising, which in the presence of space on the deck of the vessel is able to replace the mast sails. Therefore, it is proposed to put this concept in 2nd place, because the Glacier rotors have a wider range of useconsidering wind speed. However, a final conclusion about the advantage of using Glacier rotors over mast sails can be made only after more complete studies, as the determination of their number and placement conditions have not yet been definitively studied [19].

In 3rd place in [4] is the NYK ECO Ship 2030 system in the project of environmentally friendly container ship of 2030 for 8.6 thousand TEU (Fig. 10) [20]. This concept has many different technical features that reduce the total energy consumption up to 69% compared to the prototype ship and the complete elimination of carbon dioxide emissions.

Figure 10: Main view of NYK ECO Ship 2030 container ship with lifting sails and containercovers that are equipped with solar panels [20] (Japan).

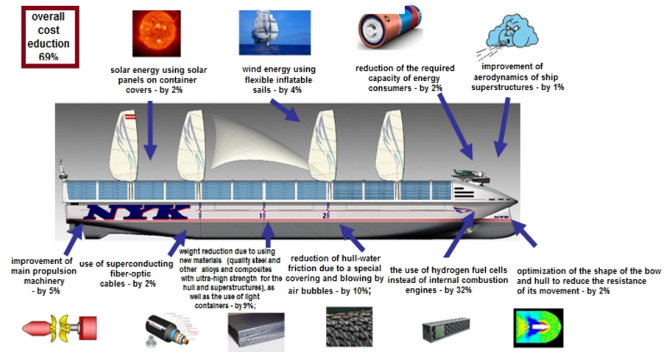
Source: Authors.

Technical features of this project are shown in fig. 11 [21].

The main advantage of the project [21] is the integrated use of a number of technical systems that reduce energy consumption by:

1. solar energy using solar panels on container covers – by 2%;

Figure 11: Main ways to reduce energy and fuel costs in the NYK Super Eco Ship 2030 project (Japan) [21].



Source: Authors.

2. wind energy using flexible inflatable sails – by 4%;
3. reduction of the required capacity of energy consumers – by 2%;
4. improvement of aerodynamics of ship superstructures – by 1%;
5. optimization of the shape of the bow and hull to reduce the resistance of its movement – by 2%;
6. the use of hydrogen fuel cells instead of internal combustion engines – by 32%;
7. reduction of hull-water friction due to a special covering and blowing by air bubbles – by 10%;
8. weight reduction due to using new materials (quality steel and other alloys and composites with ultra-high strength for the hull and superstructures), as well as the use of light containers – by 9%;
9. use of superconducting fiber-optic cables – by 2%;
10. improvement of main propulsion machinery – by 5%.

The combination of all technical solutions allows this project to take the 3rd place with dignityboth in the basic rankingand thenew one. However, the energy share of sails is only 4% of the ship's energy needs, and at the container ship's own speed of 20 knots, or 10 m/s, their effective use is possible only in latitudes of 40 degrees, where the average annual wind speed is > 10 m/s.

In the 2nd place in [4] is the STX Eoseas system (Fig. 12) [22]. This vessel is equipped with an innovative mast and sail concept, patented by STX France, which helps to use wind energy to move the vessel. The ship is 305 m long and 60 m wide. Flexible sails are used on masts over 100 m high. The problem of roll and pitch in gusts of wind is reduced by the large width of the vessel, but it increases the bending load on the masts.

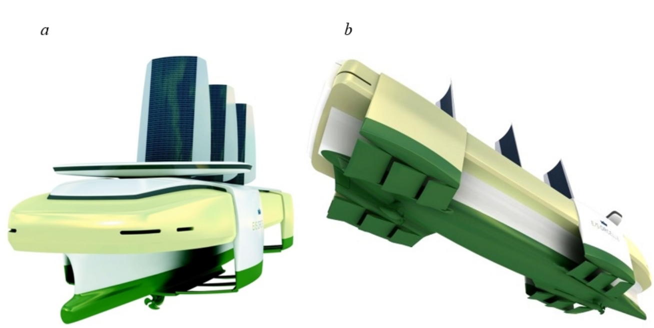
Figure 12: Mast sails in the"Eoseas" passenger ship project of STX Europe (France) [22].

Source: Authors.

It is not clearhow the problem of passing a ship under bridges is solved, because it is technically difficult to lower or tilt the masts, which increases the shortcomings of the system. Therefore, the modular principle of layout of the vessel in sectionsshould be consideredas the most attractive in this project, the sectionscan be inserted into the vessel or removed, depending on the number of passengers. Butdue to the design of the masts and the conditions of their operation, this project is not better than the project B9 [8]. It should be noted, that the speed of passenger ships reaches 20. . . 30 knots, so the areas of its effective operation will be limited to latitudes of 40 degrees and require additional internal combustion engines with engine rooms and crew to service them, similar to the B9 project.

In the 1st place in [4] is the E / S Orcellesystem (Fig. 13) [23], which combines 3 types of catchers of stable forms of energy, wind, sun and waves: 1) rigid liftablesails; 2) solar panels on them; 3) hydrowave oscillating platforms-fins, which convert the energy of waves. In total, these 3 systems produce full energy needed for ship operation.

Figure 13: 2025"E / S ORCELLE" ferry project (Sweden) with a system of rigid liftable sails with solar panels (a) and hydrowave fins (b) [23].



Source: Authors.

However, the hydrowave power plant has significant shortcomings [24] and in the modern design of the ship [25] it was abandoned. Therefore, further analysis is performed only for solar and wind systems.

The ship has 3 rigid rotary sails-platforms lifted by hydraulic cylinders. But the accompanying wind leads to the erection of hydraulic cylinders in the direction of their movement, which requires counteraction systems, and increasing wind pressure as the area of blowing sails can lead to a blow in the final phase of their rise. At a sail height of about 55 m, there are still problems with the roll and pitch of the ship, so in the modern design of the ship [25] designers invite readers to solve this problem together. Sails in [23] are not able to turn in the direction of wind, so their effectiveness is significantly reduced when changing its direction from the sternwind. In addition, the problem of transmission of thrust by the structures of the sail supports, which are installed on the roof of its superstructures, adds complexity. This leads to a constant shear stress of the mounting points of the sails relative to the submerged hull, which undergoes counter-water resistance. Therefore, the roof of the superstructure will "go" relative to the body. The proposed design of sails is problematic for dry cargo ships, but in addition to ferries, it can be used on container vessels [26].

Thus, the design of the sails is the worst project, which should be moved to 7th place.

The disadvantage of solar panels system "E / S ORCELLE" lays in the fact, that they do not cover the entire area of the sails, which reduces their efficiency compared to the project "Eco marinepower".

Based on the analysis of ship wind systems, the criteria for their ranking for expert assessments with positive (1) and negative (-1) ranks are proposed, which are given in table 1:

Table 1: Proposed criteria for ranking the quality of ship wind systems.

№	Criterion	Rank
1	Minimal average annual wind speed v_w, which is suitable for use relative to the vessel's own speed v_s = 7… 10 m/s, in percent: $v_s / v_w \times 100\%$	1
2	Sail area, or the minimum thrustincrease to the base main enginepower, in percent × 100%	1
3	Efficiency of sails (0.2 for flat, 0.3… 0.4 for concave), in percent × 100%	1
4	Ability to rotate and use the sails when changing the direction of the wind, in percent × 100%	1
5	Possibility of combination with solar and other systems, in percent × 100%	1
6	Possibility of passing under bridges, in percent × 50%	1
7	The roll of deck usage, in percent × 50%	1
8	The roll of the vessel under the action of wind, in percent × 50%	-1
9	Ship pitch during gusts of wind, in percent × 50%	-1
10	The need for accommodationspace on the ship, in percent × 50%	-1
11	Increase in risks and insurance rates during operation, in percent × 50%	-1
12	Additional load on the the vessel'ssuperstructure, in percent × 50%	-1

Source: Authors.

The list of criteria is open for continuation.

The results of the analysis allow us to conclude that all projects of the TOP-7 sailing systems [4] have significant shortcomings. Taking them into account, it is proposed to change the initial ranking of the TOP-7 projects in the new order, which is given in table. 2:

Table 2: Proposed TOP-7 projects of ship wind systems.

Ranking	Project name	Project features
1	2	3
7 (1)	E/S Orcelle (Sweden)	Rigid liftablesails with solar panels on their surface and hydrowave fins that convert the energy of the waves.
6 (5)	Sky Sails /Kite Ship (Germany)	Flexible liftable sails are towing kites that are mounted on the bow of a vessel for its movement in the wind.
5 (2)	STX Eoseas (France)	5… 6 masts more than 100 m high with flexible lifting and rotating sails
4 (7)	B9 Sail Cargo Ship (UK)	Sails with rotary masts, which are installed on the axis of the vessel and do not have rigging for their attachment to the hull, which simplifies their rotation and control
3 (3)	NYK ECO Ship 2030 (Japan)	Complex system of flexible lifting sails, solar panels and improvements of the smoothness of the hull, superstructures and all energy systems of the ship
2 (4)	Flettner Rotor Ship (Germany)	Vertical rotating cylinders that reproduce the Magnus effect as a ship's propulsion
1 (6)	Eco Marine Power Wind-Solar Ship (Japan)	A large number of rigid rotary sails, which are installed on both sides of the vessel's hull and use wind and solar energy

Source: Authors.

The updated ranking of TOP-7 projects is offered for discussion by specialists of ship. Perspective directions of further studies:

- a study of the thrust generated by the Gletcher rotors of the Flettner Rotor Ship system depending on their number and arrangement at the minimalside and maximal headwind and the ship's own movement;
- a study of the thrust, generated by the Eco Marine Power Wind-Solar Ship systems at the minimalside and maximal headwind and the ship's own movement.

General Conclusions.

1. The value of the work done is that it allows you to highlight the best options for the development of ship-based wind power systems, which avoids wasting time and money on the development of irrational projects.
2. All modern ship wind systems have their disadvantages and advantages.
3. As the average annual efficiency of sailing systems depends on the wind rose, they are recommended for operation in mid-latitudes with an average annual wind speed of 10 m/s and are not recommended for the tropics and subtropics with an average annual wind speed of up to 5m/s.
4. For all types of transport sailing vessels it is expedient to fix them on permanent routes with an average annual wind speed of 10 m/s.
5. Two systems should be considered the most expedient: "Eco Marine Power Wind-Solar Ship" with side placement of sails and "Flettner Rotor Ship" with rotors that realize the Magnus effect for the ship's movement.
6. To conclude on the benefits of these two systems, additional studyshould be conducted with PC process modeling and sea trials.
7. Restriction of ways to improve ship wind energy systems with the elimination of the 7th and 6th projects under the new rankingreduces the irrational costs of work hours and economic costs for their development and further promotion for widespread use in the transport fleet.
8. For all ship sailing systems it is expedient to have special training of officers and ratings and development of the corresponding infrastructure as well.

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The authors used drawings that have unlimited access in the open press.

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