# РІЧКОВИЙ ТА МОРСЬКИЙ ТРАНСПОРТ

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## ROTOR SAILS AS A PERSPECTIVE SHIP POWER PLANT

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***Summary***

*Modern requirements for the environmental friendliness of ships require an increasing involvement of rotor sails. Rotor sails are an effective tool to save fuel and reduce carbon emissions. In article researched the possibility of rotor sails depending on the wind direction and wind speed in the region. For the experiment were taken 2 ships and wind force moments.*

*The world's leading supplier of auxiliary wind power plants Norsepower Oy Ltd. successfully inserts rotщк sails on vessels of various types.*

*Thanks to this technology, the vessel can significantly save fuel and reduce emissions. According to the analysis carried out by Norsepower and Sea-Cargo, new installation on board the ship "SC Connector" can provide a reduction in fuel consumption and its cost, as well as carbon dioxide emissions to 25%. the appropriate wind, the vessel will maintain a constant speed only by sail.*

*In the process of decarbonizing the world fleet and achieving the IMO goals for 2030 and 2050, the marine industry is actively looking for solutions to reduce emissions, so the developments of the past are useful. Rotor sail Norsepower – it is an upgraded version of flatner rotor or "turbosail", which rotates based on the Magnus effect, using wind energy to move the vessel*

*Modern development is fully automated, the system itself determines when the direction and speed of the wind is sufficient to provide fuel savings and the necessary thrust, after which the rotor sails start automatically.*

*The article discusses sea passages across the oceans, wind phenomena and features of rotor sails work during these passage. Rotor sails are original and very effective in terms of fuel economy by ship power plant. Proposed the best variation of localization rotor sails depending on the ship construction features. This article is a theorical base for the installation of rotor sails on large vessels.*

***Key words:*** *theoretical effectiveness, rotor sails, ship power plant, relative wind speed.*

# РОТОРНІ ВІТРИЛА ЯК ПЕРСПЕКТИВНА СУДНОВА ЕНЕРГЕТИЧНА УСТАНОВКА

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***Анотація***

*Сучасні вимоги щодо екологічності суден вимагають все більшого залучення роторних вітрил. Роторні вітрила є ефективним інструментом для економії палива та зниження викидів вуглецю. У статті досліджуються можливості роторних вітрил в залежності від напряму і швидкості вітру у даному регіоні. Для експерименту беруться 2 судна та моменти сил вітру.*

*Провідний світовий постачальник допоміжних вітроенергетичних установок Norsepower Oy Ltd. успішно встановлює роторні вітрила на судна різних типів.*

*Завдяки цій технології судно може значно зекономити паливо і скоротити викиди. Так, згідно аналізу, проведеного Norsepower і Sea-Cargo, нова установка на борту судна «SC Connector» може забезпечити зниження витрат палива і його вартості, а також викидів вуглецю до 25%. При відповідному вітрі судно буде підтримувати постійну швидкість руху тільки вітрилом.*

*У процесі декарбонізації світового флоту і досягнення цілей IMO на 2030 і 2050 роки, морська галузь активно шукає рішення для скорочення викидів, тому розробки минулого стають у пригоді. Роторне вітрило Norsepower – це модернізована версія ротора Флеттнера або «турбовітрила», що обертається на основі ефекту Магнуса, використовуючи енергію вітру для руху судна.*

*Сучасна розробка повністю автоматизована, система сама визначає, коли напрям вітру підходящий, а його швидкість достатня, щоб забезпечити економію палива і необхідну тягу, після чого роторні вітрила запускаються автоматично.*

*У статті розглядаються морські переходи через океани, вітрові явища та особливості роботи роторних вітрил під час цих переходів. Роторні вітрила є оригінальною і дуже ефективною з точки зору економії палива судновою енергетичною установкою. Запропоновано найкращий варіант розміщення роторних вітрил в залежності від конструктивних особливостей судна. Стаття є теоретичною базою для встановлення роторних вітрил на великі судна.*

***Ключові слова:*** *теоретична ефективність, роторні вітрила, суднова енергетична установка, відносна швидкість вітру.*

## 1. Introduction

To stop climate change need to reduce emissions of $CO_2$, that is the main engine of climate change. According to the analysis carried out by Norsepower and Sea-Cargo, new installation on board the ship "SC Connector" can provide a reduction in fuel consumption and its cost, as well as carbon dioxide emissions to 25%. The basis of the work included research [1-3]. The calculation of the vessel's courses is carried out according to the algorithm from the article [3]. Constructively, the authors focused on the DNV GL requirements [4].

DNV GL contains requirements, principles and permissible criteria for objects, personnel, organizations and/or operations [4]. The document contains certain design requirements, without which certification of rotor sails is impossible. 2018, the IMO approved a strategy to reduce emissions of harmful gases. According to the adopted strategy, emissions should be reduced by 40 percent by 2030, by 2050 on 70% [5]. Finnish company NORSEPOWER offers alternative ship power plants [6-8], significantly reduce emissions of harmful gases into the atmosphere.

Rotor sails are a great solution to this problem under three ship conditions:

– has necessary places on deck;

– effective speed meets the requirements of the charter;

– weather conditions favorable.

The development of rotor sails is gaining new relevance due to environmental trends and overall technological progress.

## 2. LITERATURE ANALYSIS AND FORMULATING THE PROBLEM

At work [1] described the need to reduce the amount of harmful emissions not only by optimizing ship power plants, also due to the optimization of route planning, port logistics, weather analytics and design of ship hulls in general.

For example, medium-tonnage tankers are taken and the economic component of the economy is described. Also, attention is paid to the placement of rotor sails and their effectiveness depending on the layout scheme.

In the article [3] the algorithm for calculating the course (bearing) on the rhumb line is proposed. The algorithm contains 6 real variations of calculation, which are effectively used in calculating rates in this work.

DNVGLST0511 [4] – this is a set of standards, without which certification of rotor sails is impossible.

"The objective of this standard is twofold.

It may serve as an independent technical standard for the design and construction of a wind assisted propulsion unit.

It also serves as procedural and technical basis for wind assisted propulsion systems to be installed on board ships, and more specifically for ships applying for the additional class notation WAPS." [4]

Paper [5] is the initial IMO strategy, which forms a general vision of the development of the world merchant fleet in the context of environmental.

Brochures [6-7] describe the technical features of rotor sails NORSEPOWER, their dimensions and tonnage, maximum power.

Presentation [8] – it is a presentation containing not only the technical specifics of rotor sails NORSEPOWER, but also specific vessels where they were installed, and features of their installation. well as a description of the design of the rotor sail.

In the context of all read, you can determine several advantages and disadvantages of rotor sails. Advantages: high energy efficiency, easy to use. Disadvantages: for large vessels, for example, container ships, the dimensions of rotor sails will increase significantly, with improper location can make it difficult to load the vessel.

There is a great prospect of developing rotor sails for large vessels, but it is necessary to calculate all the details of the work of rotor sails for such vessels, to show an analytical and graphic justification for their use.

## 3. METHODS AND MATERIALS

In the study of the effectiveness of rotor sails and their possible use on large container ships, it is profitable to use the method of numerical experiment and the method of selection. Optimization of any technical device requires numerical digital approximation, so mathematical modeling is the tool that can suggest the right solution to the problem in the absence of a live experiment.

The material for the study is the technical documentation [5-7] of finnish company NORSEPOWER, which describes the dimensions and technical characteristics of their rotor sails. Pilot charts with wind directions and speeds were also used. Ship routes are laid on electronic charts OpenCPN 5.2.4. Technical documentation of vessels “UMM QARN” and “MSC EMMA” was processed to determine suitable places for installation.

To ensure the charter speed of these vessels, the propeller thrust is usually sufficient 1700000 N. The calculation of the efficiency of rotor sails is carried out taking into account fuel savings by the main engine, that is, the thrust of the rotor sail compensates for the thrust of the propeller. Taking into account the required thrust of the propeller, it was determined the need to install 6 rotor sails with a diameter of 5 meters and a height of 30 meters.

Calculating the thrust of roto sails, we use the formula that characterizes the Magnus Effect: $P=0{,}5\pi(d\cdot H)\nu\cdot\omega\cdot\rho air$;

$\rho air = 1{,}2041\cdot 10^{-3} ton/м^3$ (air density);

$\nu$ – course wind speed (Vy), m/s;

$\omega$ – cylinder speed, $s^{-1}$

$d = 2R$ – diameter of cylinder, m;

H – cylinder height, m.

Accepted, that $\omega=2.5\cdot\nu$, then

$$P=1.25\pi(d\cdot H)\cdot\nu^2\cdot\rho air \quad (1)$$

From technical documentation of NORSEPOWER Co. [5,6] is known, that maximum working thrust of one cylinder with height 30 metres and 5 metres in diameter under favourable conditions 300000N, therefore, the mathematical modeling of the cylinders is adjusted taking into account these fuses.

The maximum number of revolutions per minute is 180 rpm, foundation height 3 meters, foundation weight 17 tons, rotor sail weight without foundation 38 tons. Nominal power of the electric motor 115 kW.

## 4. AIM AND TASKS

The aim: to explore the design capabilities of rotor sails and their effectiveness depending on the route of transition for large vessels.

Tasks:

– calculate thrust and relative efficiency of rotor sails on all segments of the passage on four routes;

– calculate fuel economy depending on the time of year of the ship's route;

– options for the location of rotor sails on selected vessels.

**5. RESEARCH RESULTS**

To study the effectiveness of rotor sails for large vessels, 4 passages were worked out on the routes Barcelona-Karachi, Nantes-Gibraltar, Murmansk-Puerto Cabello, Karwar-Nishtun. The passage from the port of Barcelona to the port of arachi (Fig.1) consists of four parts: the Mediterranean Sea, the Suez Canal, the Indian Ocean.

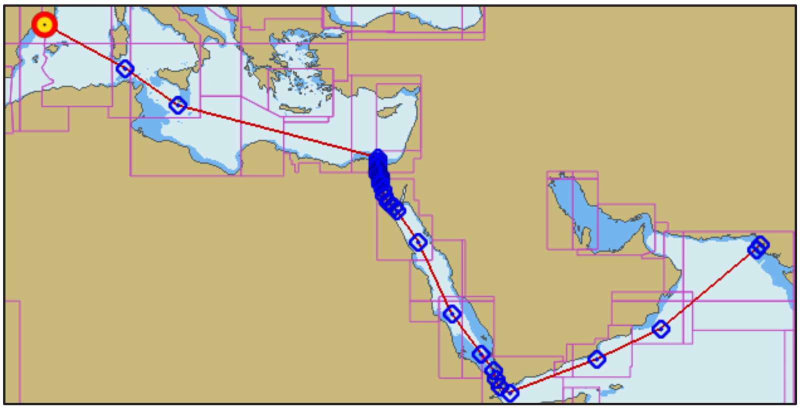

*Fig. 1. Passage from port of Barcelona to port of Karachi*

Passage from the port of Barcelona to the port of Karachi (Fig.1) has many turning points, which causes changes in the efficiency of rotor sails on this route. Tables 1, 2, 3 show the corresponding passage taking into account the wind direction, the course of the vessel and the wind speed.

Charter speed of the vessel 17 knots, the time spent on the passage is calculated at this speed. The direction from which the wind blows is indicated in the tables as WD, the course angle of the wind is indicated as WCA. The course of the vessel between turning points is calculated on the basis of the algorithm from the article [3]. Course angle is calculated on the basis of the calculated courses of the vessel and the wind direction. The course angle of the wind is calculated by the formula in MS Excel:

$$=ABS(ABS(SC\_i-WD\_i) + IF(ABS(SC\_i-WD\_i)>180;-360;0)), \quad (2)$$

where SC_i – course of the vessel on this segment,

WD_i – direction from which the wind blows for this segment.

To calculate the thrust of the rotor sail is not taken absolute wind speed V (WS), but taken relative wind speed, namely Vy, that calculated by the formula:

$$Vy=V\cdot\sin(WCA\cdot\pi/180) \quad (3)$$

WCA – this is the angle between the wind direction and the diametrical plane of the vessel. The horizontal coordinate system of the vessel coincides in directions with the coordinate systems of the cylinders.

Table 1

**Basic table of passage "Barcelona – Karachi"**

| No | Latitude | Longitude | Dist. | Course | d | H | n | ρ | P (req.) | Vessel speed | Time |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 41º20.0'N | 002º14.0'E | - | | *[m]* | *[m]* | item | *[kg/m³]* | *[N]* | *[knots]* | *[hours]* |
| 2 | 38º17.0'N | 009º29.5'E | 381.8' | 118.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 22.46 |
| 3 | 35º35.9'N | 014º15.8'E | 280.3' | 125.2° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 16.49 |
| 4 | 31º41.0'N | 032º17.0'E | 930.4' | 104.6° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 54.73 |
| 5 | 31º25.0'N | 032º20.0'E | 16.2' | 170.9° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.95 |
| 6 | 31º19.4'N | 032º22.4'E | 6.0' | 159.9° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.35 |
| 7 | 31º06.0'N | 032º18.5'E | 13.8' | 194.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.81 |
| 8 | 30º48.5'N | 032º19.1'E | 17.5' | 178.3° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 1.03 |
| 9 | 30º42.9'N | 032º20.6'E | 5.8' | 167.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.34 |
| 10 | 30º42.0'N | 032º20.7'E | 0.9' | 174.5° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.05 |
| 11 | 30º37.0'N | 032º19.4'E | 5.1' | 192.6° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.30 |
| 12 | 30º35.4'N | 032º18.5'E | 1.8' | 205.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.10 |
| 13 | 30º34.3'N | 032º18.2'E | 1.1' | 193.2° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.07 |
| 14 | 30º33.3'N | 032º18.4'E | 1.0' | 170.2° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.06 |
| 15 | 30º32.5'N | 032º18.9'E | 0.9' | 151.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.05 |
| 16 | 30º31.0'N | 032º20.2'E | 1.9' | 143.3° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.11 |
| 17 | 30º28.5'N | 032º20.7'E | 2.5' | 170.2° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.15 |
| 18 | 30º26.3'N | 032º21.2'E | 2.2' | 168.9° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.13 |
| 19 | 30º21.5'N | 032º22.2'E | 4.9' | 169.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.29 |
| 20 | 30º16.8'N | 032º26.4'E | 5.9' | 142.4° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.35 |
| 21 | 30º15.3'N | 032º31.5'E | 4.7' | 108.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.27 |
| 22 | 30º14.5'N | 032º32.4'E | 1.1' | 135.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.07 |
| 23 | 30º12.5'N | 032º33.7'E | 2.3' | 150.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.14 |
| 24 | 30º11.6'N | 032º34.1'E | 1.0' | 159.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.06 |
| 25 | 30º03.7'N | 032º34.3'E | 7.9' | 178.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.47 |
| 26 | 29º58.4'N | 032º35.2'E | 5.4' | 171.6° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.32 |
| 27 | 29º57.2'N | 032º35.0'E | 1.2' | 188.2° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.07 |
| 28 | 29º56.1'N | 032º34.1'E | 1.4' | 215.3° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.08 |
| 29 | 29º55.2'N | 032º32.9'E | 1.4' | 229.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.08 |
| 30 | 29º54.0'N | 032º32.8'E | 1.2' | 184.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.07 |
| 31 | 29º51.2'N | 032º33.2'E | 2.8' | 172.9° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.17 |
| 32 | 29º46.6'N | 032º31.0'E | 5.0' | 202.5° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.29 |
| 33 | 29º35.0'N | 032º30.5'E | 11.6' | 182.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.68 |
| 34 | 29º10.0'N | 032º43.6'E | 27.5' | 155.5° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 1.62 |
| 35 | 28º45.0'N | 032º54.0'E | 26.7' | 160.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 1.57 |
| 36 | 28º15.0'N | 033º13.6'E | 34.7' | 150.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 2.04 |
| 37 | 28º06.9'N | 033º21.4'E | 10.6' | 139.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 0.63 |
| 38 | 27º47.4'N | 033º45.0'E | 28.6' | 133.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 1.68 |
| 39 | 27º28.9'N | 034º04.2'E | 25.2' | 137.4° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 1.48 |
| 40 | 25º00.0'N | 036º00.0'E | 181.9' | 145.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 10.70 |
| 41 | 19º00.0'N | 039º00.0'E | 397.5' | 155.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 23.38 |
| 42 | 15º30.0'N | 041º41.8'E | 261.2' | 143.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 15.36 |
| 43 | 14º02.0'N | 042º49.0'E | 109.6' | 143.6° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 6.45 |
| 44 | 13º13.0'N | 043º01.7'E | 50.6' | 165.9° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 2.98 |
| 45 | 12º36.0'N | 043º19.3'E | 40.9' | 155.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 2.40 |
| 46 | 12º03.9'N | 044º13.8'E | 62.3' | 121.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 3.66 |
| 47 | 15º00.0'N | 052º09.0'E | 495.2' | 69.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 29.13 |
| 48 | 17º38.0'N | 057º57.3'E | 370.4' | 64.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 21.79 |
| 49 | 24º23.3'N | 066º34.6'E | 631.2' | 50.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 37.13 |
| 50 | 24º44.9'N | 066º57.2'E | 29.9' | 43.6° | 5 | 30 | 6 | 1.204 | 1700000 | 17.00 | 1.76 |
| | | Distance | 4511.0' | | | | | | | Cons = | 1105.63mt |

Table 2

## Estimates of the efficiency of rotor sails in January and April for the passage from the port of Barcelona to the port of Karachi

| JANUARY | | | | | | | APRIL | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. | WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. |
| | º | [m/s] | [m/s] | [N] | % | [mt] | º | º | [m/s] | [m/s] | [N] | % | [mt] |
| 315.0° | 163.7° | 12.9 | 3.61 | 554481 | 32.62 | 30.52 | 315.0° | 163.7° | 12.9 | 3.61 | 554481 | 32.62 | 30.52 |
| 315.0° | 170.2° | 12.9 | 2.20 | 205571 | 12.09 | 8.31 | 315.0° | 170.2° | 10.3 | 1.76 | 131566 | 7.74 | 5.32 |
| 315.0° | 149.6° | 10.3 | 5.20 | 1149498 | 67.62 | 154.20 | 315.0° | 149.6° | 10.3 | 5.20 | 1149498 | 67.62 | 154.20 |
| 315.0° | 144.1° | 10.3 | 6.03 | 1547940 | 91.06 | 3.62 | 315.0° | 144.1° | 10.3 | 6.03 | 1547940 | 91.06 | 3.62 |
| 315.0° | 155.1° | 10.3 | 4.33 | 797312 | 46.90 | 0.69 | 315.0° | 155.1° | 10.3 | 4.33 | 797312 | 46.90 | 0.69 |
| 315.0° | 121.0° | 10.3 | 8.81 | 1800000 | 105.88 | 3.59 | 315.0° | 121.0° | 10.3 | 8.81 | 1800000 | 105.88 | 3.59 |
| 315.0° | 136.7° | 10.3 | 7.05 | 1800000 | 105.88 | 4.55 | 315.0° | 136.7° | 10.3 | 7.05 | 1800000 | 105.88 | 4.55 |
| 315.0° | 148.0° | 10.3 | 5.45 | 1265585 | 74.45 | 1.05 | 315.0° | 148.0° | 10.3 | 5.45 | 1265585 | 74.45 | 1.05 |
| 315.0° | 140.5° | 10.3 | 6.54 | 1800000 | 105.88 | 0.24 | 315.0° | 140.5° | 10.3 | 6.54 | 1800000 | 105.88 | 0.24 |
| 315.0° | 122.4° | 10.3 | 8.68 | 1800000 | 105.88 | 1.33 | 315.0° | 122.4° | 10.3 | 8.68 | 1800000 | 105.88 | 1.33 |
| 315.0° | 109.2° | 10.3 | 9.71 | 1800000 | 105.88 | 0.46 | 315.0° | 109.2° | 10.3 | 9.71 | 1800000 | 105.88 | 0.46 |
| 315.0° | 121.8° | 10.3 | 8.74 | 1800000 | 105.88 | 0.29 | 315.0° | 121.8° | 10.3 | 8.74 | 1800000 | 105.88 | 0.29 |
| 315.0° | 144.8° | 10.3 | 5.93 | 1496460 | 88.03 | 0.22 | 315.0° | 144.8° | 10.3 | 5.93 | 1496460 | 88.03 | 0.22 |
| 315.0° | 163.3° | 10.3 | 2.96 | 371741 | 21.87 | 0.05 | 315.0° | 163.3° | 10.3 | 2.96 | 371741 | 21.87 | 0.05 |
| 315.0° | 171.7° | 10.3 | 1.48 | 92776 | 5.46 | 0.03 | 315.0° | 171.7° | 10.3 | 1.48 | 92776 | 5.46 | 0.03 |
| 315.0° | 144.8° | 10.3 | 5.93 | 1495967 | 88.00 | 0.55 | 315.0° | 144.8° | 10.3 | 5.93 | 1495967 | 88.00 | 0.55 |
| 315.0° | 146.1° | 10.3 | 5.74 | 1400140 | 82.36 | 0.45 | 315.0° | 146.1° | 10.3 | 5.74 | 1400140 | 82.36 | 0.45 |
| 315.0° | 145.2° | 10.3 | 5.87 | 1465791 | 86.22 | 1.03 | 315.0° | 145.2° | 10.3 | 5.87 | 1465791 | 86.22 | 1.03 |
| 315.0° | 172.6° | 10.3 | 1.32 | 73675 | 4.33 | 0.06 | 315.0° | 172.6° | 10.3 | 1.32 | 73675 | 4.33 | 0.06 |
| 315.0° | 153.8° | 10.3 | 4.54 | 876289 | 51.55 | 0.59 | 315.0° | 153.8° | 10.3 | 4.54 | 876289 | 51.55 | 0.59 |
| 315.0° | 179.2° | 10.3 | 0.15 | 918 | 0.05 | 0.00 | 315.0° | 179.2° | 10.3 | 0.15 | 918 | 0.05 | 0.00 |
| 315.0° | 164.3° | 10.3 | 2.78 | 328490 | 19.32 | 0.11 | 315.0° | 164.3° | 10.3 | 2.78 | 328490 | 19.32 | 0.11 |
| 315.0° | 156.0° | 10.3 | 4.18 | 743266 | 43.72 | 0.10 | 315.0° | 156.0° | 10.3 | 4.18 | 743266 | 43.72 | 0.10 |
| 315.0° | 136.3° | 10.3 | 7.11 | 1800000 | 105.88 | 2.05 | 315.0° | 136.3° | 10.3 | 7.11 | 1800000 | 105.88 | 2.05 |
| 315.0° | 143.4° | 10.3 | 6.13 | 1601381 | 94.20 | 1.24 | 315.0° | 143.4° | 10.3 | 6.13 | 1601381 | 94.20 | 1.24 |
| 315.0° | 126.8° | 10.3 | 8.23 | 1800000 | 105.88 | 0.32 | 315.0° | 126.8° | 10.3 | 8.23 | 1800000 | 105.88 | 0.32 |
| 315.0° | 99.7° | 10.3 | 10.13 | 1800000 | 105.88 | 0.35 | 315.0° | 99.7° | 10.3 | 10.13 | 1800000 | 105.88 | 0.35 |
| 315.0° | 85.9° | 10.3 | 10.25 | 1800000 | 105.88 | 0.36 | 315.0° | 85.9° | 10.3 | 10.25 | 1800000 | 105.88 | 0.36 |
| 315.0° | 130.9° | 10.3 | 7.77 | 1800000 | 105.88 | 0.31 | 315.0° | 130.9° | 10.3 | 7.77 | 1800000 | 105.88 | 0.31 |
| 315.0° | 142.1° | 10.3 | 6.32 | 1699979 | 100.00 | 0.69 | 315.0° | 142.1° | 10.3 | 6.32 | 1699979 | 100.00 | 0.69 |
| 315.0° | 112.5° | 10.3 | 9.50 | 1800000 | 105.88 | 1.29 | 315.0° | 112.5° | 10.3 | 9.50 | 1800000 | 105.88 | 1.29 |
| 315.0° | 132.9° | 10.3 | 7.54 | 1800000 | 105.88 | 3.02 | 315.0° | 132.9° | 10.3 | 7.54 | 1800000 | 105.88 | 3.02 |
| 315.0° | 159.5° | 10.3 | 3.59 | 549374 | 32.32 | 2.18 | 315.0° | 159.5° | 10.3 | 3.59 | 549374 | 32.32 | 2.18 |
| 315.0° | 155.0° | 10.3 | 4.34 | 803193 | 47.25 | 3.09 | 315.0° | 155.0° | 10.3 | 4.34 | 803193 | 47.25 | 3.09 |
| 315.0° | 164.9° | 10.3 | 2.68 | 306676 | 18.04 | 1.53 | 315.0° | 164.9° | 10.3 | 2.68 | 306676 | 18.04 | 1.53 |
| 315.0° | 175.3° | 10.3 | 0.84 | 29879 | 1.76 | 0.05 | 315.0° | 175.3° | 10.3 | 0.84 | 29879 | 1.76 | 0.05 |
| 315.0° | 178.1° | 10.3 | 0.34 | 5005 | 0.29 | 0.02 | 315.0° | 178.1° | 10.3 | 0.34 | 5005 | 0.29 | 0.02 |
| 315.0° | 177.6° | 10.3 | 0.43 | 7910 | 0.47 | 0.03 | 315.0° | 177.6° | 10.3 | 0.43 | 7910 | 0.47 | 0.03 |
| 315.0° | 169.9° | 7.7 | 1.35 | 77877 | 4.58 | 2.04 | 0.0° | 145.1° | 10.3 | 5.88 | 1471810 | 86.58 | 38.59 |
| 0.0° | 155.1° | 10.3 | 4.32 | 794772 | 46.75 | 45.54 | 0.0° | 155.1° | 10.3 | 4.32 | 794772 | 46.75 | 45.54 |
| 135.0° | 8.7° | 10.3 | 1.55 | 101930 | 6.00 | 3.84 | 0.0° | 143.7° | 10.3 | 6.09 | 1579304 | 92.90 | 59.47 |
| 135.0° | 8.6° | 10.3 | 1.53 | 99594 | 5.86 | 1.57 | 135.0° | 8.6° | 10.3 | 1.53 | 99594 | 5.86 | 1.57 |
| 90.0° | 75.9° | 10.3 | 9.97 | 1800000 | 105.88 | 13.14 | 45.0° | 120.9° | 10.3 | 8.82 | 1800000 | 105.88 | 13.14 |
| 90.0° | 65.1° | 10.3 | 9.33 | 1800000 | 105.88 | 10.60 | 45.0° | 110.1° | 10.3 | 9.65 | 1800000 | 105.88 | 10.60 |
| 90.0° | 31.1° | 10.3 | 5.31 | 1198936 | 70.53 | 10.77 | 45.0° | 76.1° | 10.3 | 9.98 | 1800000 | 105.88 | 16.16 |
| 90.0° | 20.9° | 10.3 | 3.66 | 570626 | 33.57 | 40.74 | 45.0° | 24.1° | 10.3 | 4.20 | 751764 | 44.22 | 53.68 |
| 90.0° | 25.3° | 10.3 | 4.39 | 821419 | 48.32 | 43.86 | 45.0° | 19.7° | 10.3 | 3.47 | 510995 | 30.06 | 27.28 |
| 90.0° | 40.0° | 10.3 | 6.61 | 1800000 | 105.88 | 163.81 | 45.0° | 5.0° | 10.3 | 0.89 | 33785 | 1.99 | 3.07 |
| 90.0° | 46.4° | 10.3 | 7.45 | 1800000 | 105.88 | 7.75 | 45.0° | 1.4° | 7.7 | 0.19 | 1557 | 0.09 | 0.01 |
| | | | | | Econ | 572.25 | | | | | | Econ | 494.71 |
| | | | | | % | 51.76% | | | | | | % | 44.74% |

Table 3

**Estimation of the efficiency of rotor sails in July and October for the passage from the port of Barcelona to the port of Karachi**

| JULY | | | | | | | OCTOBER | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. | WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. |
| º | º | *[m/s]* | *[m/s]* | *[N]* | *%* | *[mt]* | º | º | *[m/s]* | *[m/s]* | *[N]* | *%* | *[mt]* |
| 315.0° | 163.7° | 10.3 | 2.89 | 354868 | 20.87 | 19.54 | 315.0° | 163.7° | 10.3 | 2.9 | 354868 | 20.87 | 19.54 |
| 315.0° | 170.2° | 7.7 | 1.32 | 74006 | 4.35 | 2.99 | 315.0° | 170.2° | 10.3 | 1.8 | 131566 | 7.74 | 5.32 |
| 315.0° | 149.6° | 7.7 | 3.90 | 646592 | 38.03 | 86.74 | 315.0° | 149.6° | 7.7 | 3.9 | 646592 | 38.03 | 86.74 |
| 315.0° | 144.1° | 7.7 | 4.52 | 870716 | 51.22 | 2.04 | 315.0° | 144.1° | 7.7 | 4.5 | 870716 | 51.22 | 2.04 |
| 315.0° | 155.1° | 7.7 | 3.25 | 448488 | 26.38 | 0.39 | 315.0° | 155.1° | 7.7 | 3.2 | 448488 | 26.38 | 0.39 |
| 315.0° | 121.0° | 7.7 | 6.61 | 1800000 | 105.88 | 3.59 | 315.0° | 121.0° | 7.7 | 6.6 | 1800000 | 105.88 | 3.59 |
| 315.0° | 136.7° | 7.7 | 5.29 | 1190547 | 70.03 | 3.01 | 315.0° | 136.7° | 7.7 | 5.3 | 1190547 | 70.03 | 3.01 |
| 315.0° | 148.0° | 7.7 | 4.09 | 711891 | 41.88 | 0.59 | 315.0° | 148.0° | 7.7 | 4.1 | 711891 | 41.88 | 0.59 |
| 315.0° | 140.5° | 7.7 | 4.91 | 1025380 | 60.32 | 0.13 | 315.0° | 140.5° | 7.7 | 4.9 | 1025380 | 60.32 | 0.13 |
| 315.0° | 122.4° | 7.7 | 6.51 | 1800000 | 105.88 | 1.33 | 315.0° | 122.4° | 7.7 | 6.5 | 1800000 | 105.88 | 1.33 |
| 315.0° | 109.2° | 7.7 | 7.28 | 1800000 | 105.88 | 0.46 | 315.0° | 109.2° | 7.7 | 7.3 | 1800000 | 105.88 | 0.46 |
| 315.0° | 121.8° | 7.7 | 6.55 | 1800000 | 105.88 | 0.29 | 315.0° | 121.8° | 7.7 | 6.6 | 1800000 | 105.88 | 0.29 |
| 315.0° | 144.8° | 7.7 | 4.45 | 841759 | 49.52 | 0.12 | 315.0° | 144.8° | 7.7 | 4.4 | 841759 | 49.52 | 0.12 |
| 315.0° | 163.3° | 7.7 | 2.22 | 209105 | 12.30 | 0.03 | 315.0° | 163.3° | 7.7 | 2.2 | 209105 | 12.30 | 0.03 |
| 315.0° | 171.7° | 7.7 | 1.11 | 52186 | 3.07 | 0.01 | 315.0° | 171.7° | 7.7 | 1.1 | 52186 | 3.07 | 0.01 |
| 315.0° | 144.8° | 7.7 | 4.45 | 841482 | 49.50 | 0.31 | 315.0° | 144.8° | 7.7 | 4.4 | 841482 | 49.50 | 0.31 |
| 315.0° | 146.1° | 7.7 | 4.30 | 787579 | 46.33 | 0.26 | 315.0° | 146.1° | 7.7 | 4.3 | 787579 | 46.33 | 0.26 |
| 315.0° | 145.2° | 7.7 | 4.40 | 824507 | 48.50 | 0.58 | 315.0° | 145.2° | 7.7 | 4.4 | 824507 | 48.50 | 0.58 |
| 315.0° | 172.6° | 7.7 | 0.99 | 41442 | 2.44 | 0.04 | 315.0° | 172.6° | 7.7 | 1.0 | 41442 | 2.44 | 0.04 |
| 315.0° | 153.8° | 7.7 | 3.40 | 492913 | 28.99 | 0.33 | 315.0° | 153.8° | 7.7 | 3.4 | 492913 | 28.99 | 0.33 |
| 315.0° | 179.2° | 7.7 | 0.11 | 516 | 0.03 | 0.00 | 315.0° | 179.2° | 7.7 | 0.1 | 516 | 0.03 | 0.00 |
| 315.0° | 164.3° | 7.7 | 2.08 | 184775 | 10.87 | 0.06 | 315.0° | 164.3° | 7.7 | 2.1 | 184775 | 10.87 | 0.06 |
| 315.0° | 156.0° | 7.7 | 3.13 | 418087 | 24.59 | 0.06 | 315.0° | 156.0° | 7.7 | 3.1 | 418087 | 24.59 | 0.06 |
| 315.0° | 136.3° | 7.7 | 5.33 | 1209498 | 71.15 | 1.38 | 315.0° | 136.3° | 10.3 | 7.1 | 1800000 | 105.88 | 2.05 |
| 315.0° | 143.4° | 10.3 | 6.13 | 1601381 | 94.20 | 1.24 | 315.0° | 143.4° | 10.3 | 6.1 | 1601381 | 94.20 | 1.24 |
| 315.0° | 126.8° | 10.3 | 8.23 | 1800000 | 105.88 | 0.32 | 315.0° | 126.8° | 10.3 | 8.2 | 1800000 | 105.88 | 0.32 |
| 315.0° | 99.7° | 10.3 | 10.13 | 1800000 | 105.88 | 0.35 | 315.0° | 99.7° | 10.3 | 10.1 | 1800000 | 105.88 | 0.35 |
| 315.0° | 85.9° | 10.3 | 10.25 | 1800000 | 105.88 | 0.36 | 315.0° | 85.9° | 10.3 | 10.3 | 1800000 | 105.88 | 0.36 |
| 315.0° | 130.9° | 10.3 | 7.77 | 1800000 | 105.88 | 0.31 | 315.0° | 130.9° | 10.3 | 7.8 | 1800000 | 105.88 | 0.31 |
| 315.0° | 142.1° | 10.3 | 6.32 | 1699979 | 100.00 | 0.69 | 315.0° | 142.1° | 10.3 | 6.3 | 1699979 | 100.00 | 0.69 |
| 315.0° | 112.5° | 10.3 | 9.50 | 1800000 | 105.88 | 1.29 | 315.0° | 112.5° | 10.3 | 9.5 | 1800000 | 105.88 | 1.29 |
| 315.0° | 132.9° | 10.3 | 7.54 | 1800000 | 105.88 | 3.02 | 315.0° | 132.9° | 10.3 | 7.5 | 1800000 | 105.88 | 3.02 |
| 315.0° | 159.5° | 10.3 | 3.59 | 549374 | 32.32 | 2.18 | 315.0° | 159.5° | 10.3 | 3.6 | 549374 | 32.32 | 2.18 |
| 315.0° | 155.0° | 10.3 | 4.34 | 803193 | 47.25 | 3.09 | 315.0° | 155.0° | 10.3 | 4.3 | 803193 | 47.25 | 3.09 |
| 315.0° | 164.9° | 10.3 | 2.68 | 306676 | 18.04 | 1.53 | 315.0° | 164.9° | 10.3 | 2.7 | 306676 | 18.04 | 1.53 |
| 315.0° | 175.3° | 10.3 | 0.84 | 29879 | 1.76 | 0.05 | 315.0° | 175.3° | 10.3 | 0.8 | 29879 | 1.76 | 0.05 |
| 315.0° | 178.1° | 10.3 | 0.34 | 5005 | 0.29 | 0.02 | 315.0° | 178.1° | 10.3 | 0.3 | 5005 | 0.29 | 0.02 |
| 315.0° | 177.6° | 7.7 | 0.32 | 4449 | 0.26 | 0.02 | 0.0° | 137.4° | 7.7 | 5.2 | 1158867 | 68.17 | 4.21 |
| 315.0° | 169.9° | 7.7 | 1.35 | 77877 | 4.58 | 2.04 | 0.0° | 145.1° | 7.7 | 4.4 | 827893 | 48.70 | 21.71 |
| 315.0° | 159.9° | 7.7 | 2.65 | 299941 | 17.64 | 17.19 | 0.0° | 155.1° | 7.7 | 3.2 | 447059 | 26.30 | 25.62 |
| 315.0° | 171.3° | 7.7 | 1.16 | 57336 | 3.37 | 2.16 | 135.0° | 8.7° | 7.7 | 1.2 | 57336 | 3.37 | 2.16 |
| 315.0° | 171.4° | 7.7 | 1.15 | 56022 | 3.30 | 0.89 | 135.0° | 8.6° | 7.7 | 1.1 | 56022 | 3.30 | 0.89 |
| 315.0° | 149.1° | 7.7 | 3.96 | 665674 | 39.16 | 4.86 | 180.0° | 14.1° | 7.7 | 1.9 | 150928 | 8.88 | 1.10 |
| 315.0° | 159.9° | 7.7 | 2.65 | 299481 | 17.62 | 1.76 | 90.0° | 65.1° | 7.7 | 7.0 | 1800000 | 105.88 | 10.60 |
| 225.0° | 103.9° | 15.4 | 14.97 | 1800000 | 105.88 | 16.16 | 225.0° | 103.9° | 7.7 | 7.5 | 1800000 | 105.88 | 16.16 |
| 225.0° | 155.9° | 15.4 | 6.30 | 1691469 | 99.50 | 120.77 | 0.0° | 69.1° | 7.7 | 7.2 | 1800000 | 105.88 | 128.52 |
| 225.0° | 160.3° | 15.4 | 5.20 | 1149738 | 67.63 | 61.39 | 0.0° | 64.7° | 7.7 | 7.0 | 1800000 | 105.88 | 96.11 |
| 225.0° | 175.0° | 15.4 | 1.34 | 76017 | 4.47 | 6.92 | 0.0° | 50.0° | 7.7 | 5.9 | 1483300 | 87.25 | 134.99 |
| 225.0° | 178.6° | 12.9 | 0.32 | 4325 | 0.25 | 0.02 | 0.0° | 43.6° | 7.7 | 5.3 | 1202123 | 70.71 | 5.18 |
| | | | | | Econ | 372.90 | | | | | | Econ | 588.97 |
| | | | | | % | 33.73% | | | | | | % | 53.27% |

In the Mediterranean Sea and the Suez Canal in January, the northwest wind prevails, and after leaving the Suez Canal, the wind changes to the north and later to the southeast, on the final segments of the route, the wind changes to the east. Figure 1 illustrates a graphic plan for the passage from the port of Barcelona to the port of Karachi.

In April, on segments of the route, lying in the Indian Ocean, the wind direction changes to the northeast, which reduces the efficiency of rotor sails. In July, wind speed decreases on Mediterranean segments, and the direction in the Indian part of the route changes to the southwest, that reduces the theoretical total efficiency of rotor sails to 33.73% in July. In October, the wind speed in the Indian Ocean decreases, but the direction on the corresponding segments changes to the north, which positively affects the efficiency of rotor sails. The theoretical efficiency of rotor sails in October reaches 53.27%. All changes in the efficiency of rotor sails are shown graphically in the figure 2.

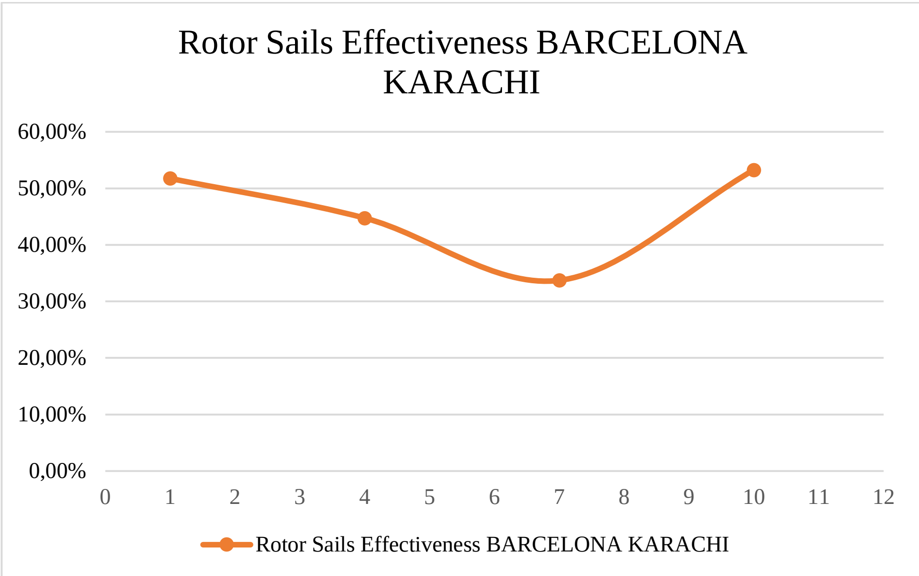


*Fig. 2. Efficiency of rotor sails on the route "Barcelona – Karachi"*

Analyzing tables 2, 3 and the graph of Figure 2, we can conclude that the least efficiency of rotor sails on the route "Barcelona – Karachi" on summer, and the largest in autumn. Each ribbon of tables 2 and 3 responses a specific segment, therefore, if necessary, you can change the turning points and calculate possible changes in the efficiency of rotor sails.

The passage "NANTES – GIBRALTAR" characterized by frequent changes of wind direction. Table 4 shows the underlying data for this passage.

From table 4 take fuel consumption engine without using rotor sails. In tables 5, 6 shown fuel economy, achieved through rotor sails in January and April and July and October respectively.

Table 4

**Basic table of passage “NANTES – GIBRALTAR”**

| No | Latitude | Longitude | Distance | Course | d | H | n | ρ | P (req.) | Vessel speed | Time |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 47º04.6’N | 002º27.0’W | - | | [m] | [m] | item | [kg/m³] | [N] | [knots] | [hours] |
| 2 | 47º00.0’N | 002º42.0’W | 11.23’ | 245.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.66 |
| 3 | 43º29.0’N | 009º58.0’W | 372.94’ | 235.5° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 21.94 |
| 4 | 43º17.0’N | 010º06.0’W | 13.36’ | 205.9° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.79 |
| 5 | 38º42.0’N | 010º06.0’W | 275.49’ | 180.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 16.21 |
| 6 | 36º47.0’N | 009º32.0’W | 118.31’ | 166.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 6.96 |
| 7 | 36º34.5’N | 009º17.0’W | 17.38’ | 136.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 1.02 |
| 8 | 35º54.0’N | 006º12.0’W | 154.88’ | 105.2° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 9.11 |
| 9 | 35º55.5’N | 005º36.5’W | 28.84’ | 87.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 1.70 |
| 10 | 35º59.0’N | 005º24.0’W | 10.73’ | 70.9° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.63 |
| 11 | 36º06.0’N | 005º22.0’W | 7.20’ | 13.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.42 |
| | | Distance | 1010.36’ | | | | | | | Cons = | 247.64 mt |

Table 5

**Estimation of the efficiency of rotor sails in January and April for the passsage from the port of Nantes to the port of Gibraltar**

| JANUARY | | | | | | | APRIL | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. Econ. | WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. Econ. |
| º | º | *[m/s]* | *[m/s]* | *[N]* | *%* | *mt* | º | º | *[m/s]* | *[m/s]* | *[N]* | *%* | *mt* |
| 225° | 20.8° | 12.9 | 4.6 | 883926 | 52.00 | 1.43 | 45° | 159.2° | 10.3 | 3.6 | 565712 | 33.28 | 0.92 |
| 225° | 10.5° | 12.9 | 2.3 | 232762 | 13.69 | 12.52 | 0° | 124.5° | 10.3 | 8.5 | 1800000 | 105.88 | 96.78 |
| 225° | 19.1° | 12.9 | 4.2 | 756121 | 44.48 | 1.46 | 0° | 154.1° | 10.3 | 4.5 | 855039 | 50.30 | 1.65 |
| 225° | 45.0° | 10.3 | 7.3 | 1800000 | 105.88 | 71.49 | 0° | 180.0° | 10.3 | 0.0 | 0 | 0.00 | 0.00 |
| 45° | 121.8° | 10.3 | 8.7 | 1800000 | 105.88 | 30.70 | 0° | 166.8° | 10.3 | 2.3 | 233038 | 13.71 | 3.98 |
| 45° | 91.1° | 10.3 | 10.3 | 1800000 | 105.88 | 4.51 | 270° | 133.9° | 10.3 | 7.4 | 1800000 | 105.88 | 4.51 |
| 45° | 60.2° | 10.3 | 8.9 | 1800000 | 105.88 | 40.19 | 270° | 164.8° | 10.3 | 2.7 | 308581 | 18.15 | 6.89 |
| 270° | 177.0° | 10.3 | 0.5 | 12207 | 0.72 | 0.05 | 270° | 177.0° | 10.3 | 0.5 | 12207 | 0.72 | 0.05 |
| 270° | 160.9° | 10.3 | 3.4 | 480582 | 28.27 | 0.74 | 270° | 160.9° | 10.3 | 3.4 | 480582 | 28.27 | 0.74 |
| 270° | 103.0° | 10.3 | 10.0 | 1800000 | 105.88 | 1.87 | 270° | 103.0° | 10.3 | 10.0 | 1800000 | 105.88 | 1.87 |
| | | | | | Econom | 164.97 | | | | | | Econom | 117.38 |
| | | | | | % | 66.62% | | | | | | % | 47.40% |

Table 6

**Estimation of the efficiency of roto sails in July and October for the passage from the port of Nantes to the port of Gibraltar**

| JULY | | | | | | | OCTOBER | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. Econ. | WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. Econ. |
| º | º | *[m/s]* | *[m/s]* | *[N]* | *%* | *mt* | º | º | *[m/s]* | *[m/s]* | *[N]* | *%* | *mt* |
| 270° | 24.2° | 7.7 | 3.2 | 425976 | 25.06 | 0.69 | 315° | 69.2° | 10.3 | 9.6 | 1800000 | 105.88 | 2.91 |
| 0° | 124.5° | 10.3 | 8.5 | 1800000 | 105.88 | 96.78 | 0° | 124.5° | 10.3 | 8.5 | 1800000 | 105.88 | 96.78 |
| 0° | 154.1° | 10.3 | 4.5 | 855039 | 50.30 | 1.65 | 0° | 154.1° | 10.3 | 4.5 | 855039 | 50.30 | 1.65 |
| 0° | 180.0° | 10.3 | 0.0 | 0 | 0.00 | 0.00 | 0° | 180.0° | 10.3 | 0.0 | 0 | 0.00 | 0.00 |
| 0° | 166.8° | 10.3 | 2.3 | 233038 | 13.71 | 3.98 | 0° | 166.8° | 10.3 | 2.3 | 233038 | 13.71 | 3.98 |
| 0° | 136.1° | 10.3 | 7.1 | 1800000 | 105.88 | 4.51 | 0° | 136.1° | 10.3 | 7.1 | 1800000 | 105.88 | 4.51 |
| 0° | 105.2° | 10.3 | 9.9 | 1800000 | 105.88 | 40.19 | 0° | 105.2° | 10.3 | 9.9 | 1800000 | 105.88 | 40.19 |
| 0° | 87.0° | 10.3 | 10.3 | 1800000 | 105.88 | 7.49 | 0° | 87.0° | 10.3 | 10.3 | 1800000 | 105.88 | 7.49 |
| 0° | 70.9° | 10.3 | 9.7 | 1800000 | 105.88 | 2.78 | 0° | 70.9° | 10.3 | 9.7 | 1800000 | 105.88 | 2.78 |
| 45° | 32.0° | 10.3 | 5.4 | 1262301 | 74.25 | 1.31 | 270° | 103.0° | 10.3 | 10.0 | 1800000 | 105.88 | 1.87 |
| | | | | | Econom | 159.38 | | | | | | Econom | 162.16 |
| | | | | | % | 64.36% | | | | | | % | 65.48% |

As you can see, the winds on this route are very changeable: in January, southwest, northeast and westerly winds prevail, in April – western. This causes the lowest efficiency of rotor sails in April and the highest – in January. In July and October, efficiency is quite high due to the northerly winds.

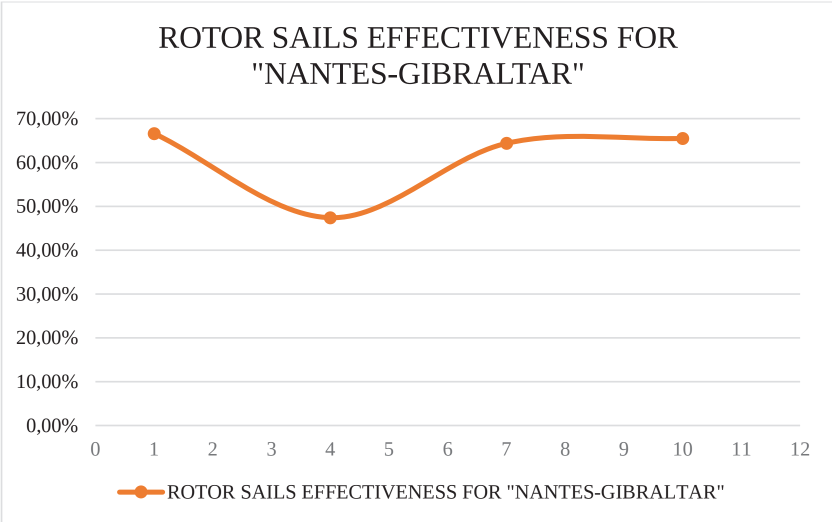


*Fig. 3. Efficiency of rotor sails on the route "NANTES – GIBRALTAR"*

Figure 3 understands that the efficiency of rotor sails as a ship power plant on the route "NANTES – GIBRALTAR" is generally stable except in spring. Figure 4 shows the graphical plan of the passage from the port of NANTES to the port of GIBRALTAR.

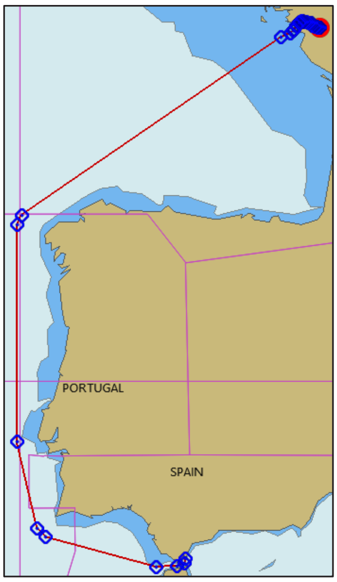


*Fig. 4. Passage NANTES-GIBRALTAR*

Passage from the port of Nantes to the port of Gibraltar (Fig. 4.) explains changes in wind direction if you impose it on meteorological wind maps.

To assess the capabilities of rotor sails in northern latitudes, the effectiveness of their work was calculated for the passage "Murmansk – Puerto Cabello". The initial data is written in a table 7.

Table 7

**Base table of the passage "MURRMANSK – PUERTO CABELLO"**

| No | Latitude | Longitude | Dist. | Course | d | H | n | ρ | P (req.) | Vessel speed | Time |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 68º59.5'N | 033º03.2'E | | º | *[m]* | *[m]* | *item* | *[kg/m³]* | *[N]* | *knots* | *[hours]* |
| 2 | 68º59.6'N | 033º02.8'E | 0.2' | 304.9° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.01 |
| 3 | 69º02.0'N | 033º03.3'E | 2.4' | 4.3° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.14 |
| 4 | 69º03.1'N | 033º04.0'E | 1.1' | 12.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.07 |
| 5 | 69º03.8'N | 033º09.0'E | 1.9' | 68.6° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.11 |
| 6 | 69º04.8'N | 033º19.2'E | 3.8' | 74.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.22 |
| 7 | 69º07.5'N | 033º28.6'E | 4.3' | 51.2° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.25 |
| 8 | 69º10.2'N | 033º32.8'E | 3.1' | 29.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.18 |
| 9 | 69º11.9'N | 033º32.6'E | 1.7' | 357.6° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.10 |
| 10 | 69º17.9'N | 033º32.1'E | 6.0' | 358.3° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.35 |
| 11 | 69º19.7'N | 033º35.5'E | 2.2' | 33.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.13 |
| 12 | 70º05.0'N | 033º35.5'E | 45.4' | 0.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 2.67 |
| 13 | 70º47.0'N | 032º00.0'E | 52.9' | 322.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 3.11 |
| 14 | 71º28.9'N | 029º05.0'E | 70.5' | 306.5° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 4.15 |
| 15 | 71º45.0'N | 025º50.0'E | 63.7' | 284.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 3.75 |
| 16 | 71º32.0'N | 022º18.0'E | 68.1' | 259.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 4.01 |
| 17 | 71º01.9'N | 018º49.0'E | 73.6' | 245.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 4.33 |
| 18 | 68º12.0'N | 010º00.0'E | 250.7' | 227.3° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 14.74 |
| 19 | 67º28.0'N | 008º58.5'E | 49.8' | 207.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 2.93 |
| 20 | 60º55.0'N | 002º04.4'W | 487.0' | 216.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 28.64 |
| 21 | 60º34.5'N | 002º25.0'W | 22.9' | 206.2° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 1.35 |
| 22 | 58º58.0'N | 004º58.0'W | 123.7' | 218.6° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 7.28 |
| 23 | 57º58.2'N | 006º16.4'W | 72.6' | 214.4° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 4.27 |
| 24 | 57º54.0'N | 006º30.1'W | 8.4' | 240.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.49 |
| 25 | 57º43.6'N | 006º46.3'W | 13.5' | 219.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.80 |
| 26 | 56º21.1'N | 007º30.4'W | 86.1' | 196.2° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 5.06 |
| 27 | 56º11.0'N | 007º30.4'W | 10.1' | 180.0° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.60 |
| 28 | 55º23.8'N | 006º27.4'W | 59.1' | 143.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 3.48 |
| 29 | 55º20.9'N | 006º08.1'W | 11.4' | 104.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.67 |
| 30 | 54º41.5'N | 005º13.7'W | 50.3' | 141.6° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 2.96 |
| 31 | 53º24.0'N | 005º19.0'W | 77.7' | 182.3° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 4.57 |
| 32 | 52º10.0'N | 006º07.0'W | 79.6' | 201.4° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 4.68 |
| 33 | 51º03.5'N | 008º23.0'W | 107.7' | 231.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 6.33 |
| 34 | 50º55.0'N | 008º48.8'W | 18.4' | 242.4° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 1.08 |
| 35 | 39º17.3'N | 031º02.7'W | 1166.3' | 233.3° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 68.61 |
| 36 | 18º39.0'N | 063º36.0'W | 2095.1' | 233.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 123.24 |
| 37 | 10º30.0'N | 068º01.0'W | 553.0' | 207.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 32.53 |
| 38 | 10º29.1'N | 068º00.8'W | 0.9' | 167.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.05 |
| 39 | 10º29.0'N | 068º00.5'W | 0.3' | 108.7° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.02 |
| | | Distance | 5745.6' | | | | | | | Cons.= | 1408.2 mt |

From the calculations of Table 7 it turns out that without the use of rotor sails, fuel consumption on the route "Murmansk – Puerto Cabello" will reach 1408.2 mt. Further performance calculations will be based on this figure. Tables 8, 9 calculated efficiency for this route at different times of the year.

Table 8

**Estimation of the efficiency of roto sails in January and April for the passage from the port of Murmansk to the port of Puerto Cabello**

| JANUARY | | | | | | | APRIL | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. Econ. | WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. Econ. |
| º | º | *[m/s]* | *[m/s]* | *[N]* | *%* | *[mt]* | º | º | *[m/s]* | *[m/s]* | *[N]* | *%* | *[mt]* |
| 225° | 79.9° | 12.9 | 12.65 | 1800000 | 105.88 | 0.0 | 180° | 124.9° | 7.7 | 6.32 | 1702003 | 100.12 | 0.0 |
| 225° | 139.3° | 12.9 | 8.39 | 1800000 | 105.88 | 0.6 | 180° | 175.7° | 7.7 | 0.57 | 14006 | 0.82 | 0.0 |
| 225° | 147.8° | 12.9 | 6.84 | 1800000 | 105.88 | 0.3 | 180° | 167.2° | 7.7 | 1.71 | 124602 | 7.33 | 0.0 |
| 225° | 156.4° | 12.9 | 5.15 | 1127232 | 66.31 | 0.3 | 180° | 111.4° | 7.7 | 7.18 | 1800000 | 105.88 | 0.5 |
| 225° | 150.3° | 12.9 | 6.36 | 1719944 | 101.17 | 0.9 | 180° | 105.3° | 7.7 | 7.44 | 1800000 | 105.88 | 1.0 |
| 225° | 173.8° | 12.9 | 1.38 | 80831 | 4.75 | 0.1 | 180° | 128.8° | 7.7 | 6.01 | 1534615 | 90.27 | 1.0 |
| 225° | 164.0° | 12.9 | 3.55 | 535562 | 31.50 | 0.2 | 180° | 151.0° | 7.7 | 3.73 | 593622 | 34.92 | 0.3 |
| 225° | 132.6° | 12.9 | 9.46 | 1800000 | 105.88 | 0.4 | 180° | 177.6° | 7.7 | 0.32 | 4414 | 0.26 | 0.0 |
| 225° | 133.3° | 12.9 | 9.35 | 1800000 | 105.88 | 1.6 | 180° | 178.3° | 7.7 | 0.23 | 2204 | 0.13 | 0.0 |
| 225° | 168.7° | 12.9 | 2.51 | 269155 | 15.83 | 0.1 | 180° | 146.3° | 7.7 | 4.28 | 779342 | 45.84 | 0.2 |
| 225° | 135.0° | 12.9 | 9.09 | 1800000 | 105.88 | 11.8 | 180° | 180.0° | 7.7 | 0.00 | 0 | 0.00 | 0.0 |
| 225° | 97.7° | 12.9 | 12.73 | 1800000 | 105.88 | 13.7 | 135° | 172.3° | 10.3 | 1.38 | 81016 | 4.77 | 0.6 |
| 225° | 81.5° | 12.9 | 12.71 | 1800000 | 105.88 | 18.3 | 135° | 171.5° | 10.3 | 1.52 | 97819 | 5.75 | 1.0 |
| 225° | 59.7° | 12.9 | 11.09 | 1800000 | 105.88 | 16.5 | 135° | 149.7° | 10.3 | 5.19 | 1146808 | 67.46 | 10.5 |
| 225° | 34.0° | 12.9 | 7.18 | 1800000 | 105.88 | 17.7 | 135° | 124.0° | 10.3 | 8.52 | 1800000 | 105.88 | 17.7 |
| 225° | 20.8° | 15.4 | 5.48 | 1279344 | 75.26 | 13.6 | 135° | 110.8° | 10.3 | 9.61 | 1800000 | 105.88 | 19.1 |
| 225° | 2.3° | 15.4 | 0.61 | 15965 | 0.94 | 0.6 | 135° | 92.3° | 10.3 | 10.27 | 1800000 | 105.88 | 65.0 |
| 180° | 27.8° | 15.4 | 7.19 | 1800000 | 105.88 | 12.9 | 0° | 152.2° | 12.9 | 5.99 | 1528848 | 89.93 | 11.0 |
| 180° | 36.1° | 15.4 | 9.10 | 1800000 | 105.88 | 126.4 | 225° | 8.9° | 10.3 | 1.58 | 106476 | 6.26 | 7.5 |
| 225° | 18.8° | 12.9 | 4.15 | 733242 | 43.13 | 2.4 | 225° | 18.8° | 10.3 | 3.32 | 469275 | 27.60 | 1.5 |
| 225° | 6.4° | 12.9 | 1.43 | 87540 | 5.15 | 1.6 | 225° | 6.4° | 10.3 | 1.15 | 56026 | 3.30 | 1.0 |
| 225° | 10.6° | 12.9 | 2.36 | 236290 | 13.90 | 2.5 | 225° | 10.6° | 10.3 | 1.89 | 151225 | 8.90 | 1.6 |
| 225° | 15.0° | 12.9 | 3.32 | 470398 | 27.67 | 0.6 | 225° | 15.0° | 10.3 | 2.66 | 301055 | 17.71 | 0.4 |
| 225° | 5.3° | 12.9 | 1.19 | 60315 | 3.55 | 0.1 | 225° | 5.3° | 10.3 | 0.95 | 38602 | 2.27 | 0.1 |
| 225° | 28.8° | 12.9 | 6.19 | 1629451 | 95.85 | 20.2 | 225° | 28.8° | 10.3 | 4.95 | 1042849 | 61.34 | 12.9 |
| 225° | 45.0° | 12.9 | 9.09 | 1800000 | 105.88 | 2.6 | 225° | 45.0° | 10.3 | 7.27 | 1800000 | 105.88 | 2.6 |
| 225° | 81.9° | 12.9 | 12.72 | 1800000 | 105.88 | 15.3 | 225° | 81.9° | 10.3 | 10.18 | 1800000 | 105.88 | 15.3 |
| 225° | 120.2° | 12.9 | 11.11 | 1800000 | 105.88 | 2.9 | 225° | 120.2° | 10.3 | 8.89 | 1800000 | 105.88 | 2.9 |
| 225° | 83.4° | 12.9 | 12.76 | 1800000 | 105.88 | 13.1 | 225° | 83.4° | 10.3 | 10.21 | 1800000 | 105.88 | 13.1 |
| 225° | 42.7° | 12.9 | 8.71 | 1800000 | 105.88 | 20.2 | 225° | 42.7° | 10.3 | 6.97 | 1800000 | 105.88 | 20.2 |
| 225° | 23.6° | 12.9 | 5.14 | 1124530 | 66.15 | 12.9 | 225° | 23.6° | 10.3 | 4.11 | 719699 | 42.34 | 8.3 |
| 225° | 6.8° | 12.9 | 1.52 | 97954 | 5.76 | 1.5 | 225° | 6.8° | 10.3 | 1.21 | 62691 | 3.69 | 1.0 |
| 225° | 17.4° | 12.9 | 3.84 | 626553 | 36.86 | 1.7 | 225° | 17.4° | 10.3 | 3.07 | 400994 | 23.59 | 1.1 |
| 225° | 8.3° | 15.4 | 2.23 | 211740 | 12.46 | 35.6 | 270° | 36.7° | 10.3 | 6.14 | 1604932 | 94.41 | 269.9 |
| 90° | 143.8° | 10.3 | 6.07 | 1566346 | 92.14 | 473.1 | 90° | 143.8° | 10.3 | 6.07 | 1566346 | 92.14 | 473.1 |
| 90° | 117.7° | 10.3 | 9.11 | 1800000 | 105.88 | 143.5 | 90° | 117.7° | 10.3 | 9.11 | 1800000 | 105.88 | 143.5 |
| 90° | 77.7° | 10.3 | 10.04 | 1800000 | 105.88 | 0.2 | 90° | 77.7° | 10.3 | 10.04 | 1800000 | 105.88 | 0.2 |
| 90° | 18.7° | 10.3 | 3.30 | 463543 | 27.27 | 0.0 | 90° | 18.7° | 10.3 | 3.30 | 463543 | 27.27 | 0.0 |
| | | | | | Econ. | 986.2 | | | | | | Econ. | 1104.2 |
| | | | | | % | 70% | | | | | | % | 78% |

Table 9

**Estimation of the efficiency of rotor sails in July and October for the passage from the port of Murmansk to the port of Puerto Cabello**

| JULY | | | | | | | OCTOBER | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. Econ. | WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. Econ. |
| º | º | [m/s] | [m/s] | [N] | % | [mt] | º | º | [m/s] | [m/s] | [N] | % | [mt] |
| 135° | 169.9° | 7.7 | 1.35 | 77939 | 4.58 | 0.0 | 225° | 79.9° | 10.3 | 10.12 | 1800000 | 105.88 | 0.0 |
| 135° | 130.7° | 7.7 | 5.84 | 1452573 | 85.45 | 0.5 | 225° | 40.7° | 10.3 | 6.71 | 1800000 | 105.88 | 0.6 |
| 135° | 122.2° | 7.7 | 6.53 | 1800000 | 105.88 | 0.3 | 225° | 32.2° | 10.3 | 5.47 | 1275430 | 75.03 | 0.2 |
| 135° | 66.4° | 7.7 | 7.06 | 1800000 | 105.88 | 0.5 | 225° | 156.4° | 10.3 | 4.12 | 721429 | 42.44 | 0.2 |
| 135° | 60.3° | 7.7 | 6.70 | 1800000 | 105.88 | 1.0 | 225° | 150.3° | 10.3 | 5.09 | 1100764 | 64.75 | 0.6 |
| 135° | 83.8° | 7.7 | 7.67 | 1800000 | 105.88 | 1.1 | 225° | 173.8° | 10.3 | 1.10 | 51732 | 3.04 | 0.0 |
| 135° | 106.0° | 7.7 | 7.41 | 1800000 | 105.88 | 0.8 | 225° | 16.0° | 10.3 | 2.84 | 342760 | 20.16 | 0.2 |
| 135° | 137.4° | 7.7 | 5.22 | 1159286 | 68.19 | 0.3 | 225° | 132.6° | 10.3 | 7.57 | 1800000 | 105.88 | 0.4 |
| 135° | 136.7° | 7.7 | 5.29 | 1190235 | 70.01 | 1.0 | 225° | 133.3° | 10.3 | 7.48 | 1800000 | 105.88 | 1.6 |
| 135° | 101.3° | 7.7 | 7.56 | 1800000 | 105.88 | 0.6 | 225° | 11.3° | 10.3 | 2.01 | 172259 | 10.13 | 0.1 |
| 135° | 135.0° | 7.7 | 5.45 | 1264864 | 74.40 | 8.3 | 225° | 45.0° | 10.3 | 7.27 | 1800000 | 105.88 | 11.8 |
| 135° | 172.3° | 7.7 | 1.03 | 45571 | 2.68 | 0.3 | 225° | 97.7° | 10.3 | 10.19 | 1800000 | 105.88 | 13.7 |
| 135° | 171.5° | 7.7 | 1.14 | 55023 | 3.24 | 0.6 | 225° | 81.5° | 10.3 | 10.17 | 1800000 | 105.88 | 18.3 |
| 90° | 165.3° | 10.3 | 2.60 | 288452 | 16.97 | 2.6 | 225° | 59.7° | 10.3 | 8.87 | 1800000 | 105.88 | 16.5 |
| 90° | 169.0° | 10.3 | 1.96 | 164252 | 9.66 | 1.6 | 225° | 34.0° | 10.3 | 5.75 | 1405018 | 82.65 | 13.8 |
| 90° | 155.8° | 10.3 | 4.21 | 754041 | 44.36 | 8.0 | 225° | 20.8° | 10.3 | 3.66 | 568597 | 33.45 | 6.0 |
| 225° | 2.3° | 10.3 | 0.41 | 7095 | 0.42 | 0.3 | 225° | 2.3° | 12.9 | 0.51 | 11087 | 0.65 | 0.4 |
| 225° | 17.2° | 10.3 | 3.04 | 393102 | 23.12 | 2.8 | 225° | 17.2° | 12.9 | 3.80 | 614222 | 36.13 | 4.4 |
| 225° | 8.9° | 7.7 | 1.19 | 59893 | 3.52 | 4.2 | 180° | 36.1° | 7.7 | 4.55 | 880253 | 51.78 | 61.8 |
| 225° | 18.8° | 7.7 | 2.49 | 263967 | 15.53 | 0.9 | 180° | 26.2° | 7.7 | 3.40 | 491503 | 28.91 | 1.6 |
| 225° | 6.4° | 7.7 | 0.86 | 31514 | 1.85 | 0.6 | 225° | 6.4° | 12.9 | 1.43 | 87540 | 5.15 | 1.6 |
| 225° | 10.6° | 7.7 | 1.41 | 85064 | 5.00 | 0.9 | 225° | 10.6° | 12.9 | 2.36 | 236290 | 13.90 | 2.5 |
| 225° | 15.0° | 10.3 | 2.66 | 301055 | 17.71 | 0.4 | 225° | 15.0° | 12.9 | 3.32 | 470398 | 27.67 | 0.6 |
| 225° | 5.3° | 10.3 | 0.95 | 38602 | 2.27 | 0.1 | 225° | 5.3° | 12.9 | 1.19 | 60315 | 3.55 | 0.1 |
| 225° | 28.8° | 10.3 | 4.95 | 1042849 | 61.34 | 12.9 | 225° | 28.8° | 12.9 | 6.19 | 1629451 | 95.85 | 20.2 |
| 225° | 45.0° | 10.3 | 7.27 | 1800000 | 105.88 | 2.6 | 225° | 45.0° | 12.9 | 9.09 | 1800000 | 105.88 | 2.6 |
| 225° | 81.9° | 10.3 | 10.18 | 1800000 | 105.88 | 15.3 | 225° | 81.9° | 12.9 | 12.72 | 1800000 | 105.88 | 15.3 |
| 225° | 120.2° | 10.3 | 8.89 | 1800000 | 105.88 | 2.9 | 225° | 120.2° | 12.9 | 11.11 | 1800000 | 105.88 | 2.9 |
| 270° | 128.4° | 10.3 | 8.06 | 1800000 | 105.88 | 13.1 | 225° | 83.4° | 12.9 | 12.76 | 1800000 | 105.88 | 13.1 |
| 270° | 87.7° | 10.3 | 10.27 | 1800000 | 105.88 | 20.2 | 225° | 42.7° | 12.9 | 8.71 | 1800000 | 105.88 | 20.2 |
| 270° | 68.6° | 10.3 | 9.57 | 1800000 | 105.88 | 20.7 | 225° | 23.6° | 12.9 | 5.14 | 1124530 | 66.15 | 12.9 |
| 270° | 38.2° | 10.3 | 6.36 | 1721381 | 101.26 | 26.7 | 225° | 6.8° | 12.9 | 1.52 | 97954 | 5.76 | 1.5 |
| 270° | 27.6° | 10.3 | 4.77 | 967011 | 56.88 | 2.6 | 225° | 17.4° | 12.9 | 3.84 | 626553 | 36.86 | 1.7 |
| 225° | 8.3° | 9.0 | 1.30 | 72050 | 4.24 | 12.1 | 270° | 36.7° | 10.3 | 6.14 | 1604932 | 94.41 | 269.9 |
| 90° | 143.8° | 9.0 | 5.31 | 1199233 | 70.54 | 362.2 | 90° | 143.8° | 10.3 | 6.07 | 1566346 | 92.14 | 473.1 |
| 90° | 117.7° | 10.3 | 9.11 | 1800000 | 105.88 | 143.5 | 90° | 117.7° | 10.3 | 9.11 | 1800000 | 105.88 | 143.5 |
| 90° | 77.7° | 10.3 | 10.04 | 1800000 | 105.88 | 0.2 | 90° | 77.7° | 10.3 | 10.04 | 1800000 | 105.88 | 0.2 |
| 90° | 18.7° | 10.3 | 3.30 | 463543 | 27.27 | 0.0 | 90° | 18.7° | 10.3 | 3.30 | 463543 | 27.27 | 0.0 |
| | | | | | Econ. | 672.8 | | | | | | Econ. | 1134.3 |
| | | | | | % | 48% | | | | | | % | 81% |

The direction of the wind varies according to the navigation region and the time of year. In January, southwest and east wind prevails, in April – southeast, east wind. April and October for this passage are the most effective periods of rotor sails. Figure 5 shows a graph of efficiency.

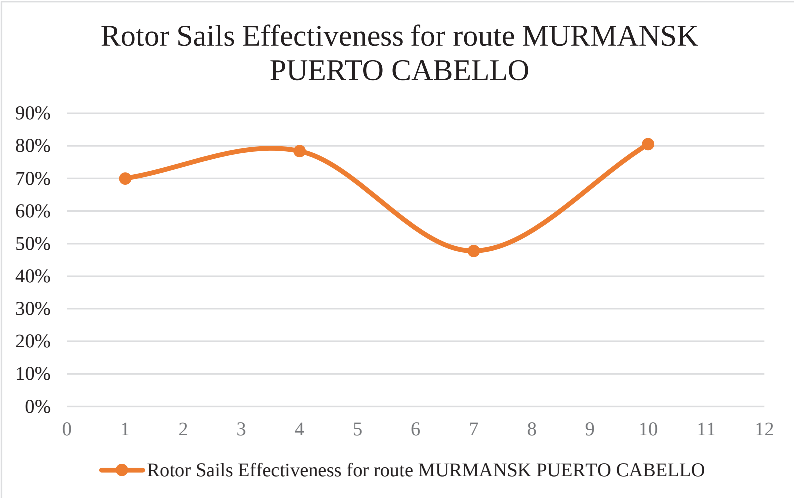


*Fig. 5. Efficiency of rotor sails on the route MURMANSK – Puerto Cabello*

As can be seen from Figure 5, the most unfavorable winds for this route blow in July, and the most favorable in April and October. In July, the theoretical effectiveness is the lowest – 48%. And the largest theoretical effectiveness in April – 78% and October – 81%. The most difficult for calculations is the segment between the points 34 i 35, since the prevailing wind is very volatile here, you have to focus on the general wind trends in the North Atlantic Ocean.

Figure 6 shows graphically the route of the passage from the port of Murmansk to the port of Puerto Cabello, which allows you to match it with pilot charts and check the correctness of the wind recorded for calculations.

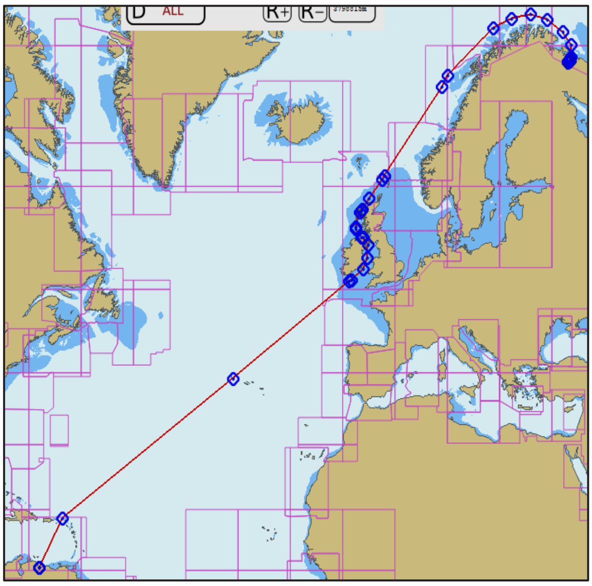

*Fig. 6. Passage "MURMANSK – PUERTO CABELLO"*

Figure 6 clearly shows that the vessel must pass the most inconvenient place for calculating the wind.

On figure 7 shows changes in the efficiency of rotor sails depending on the time of year. The most difficult for calculations is the segment between 40º and 30º N, how much the wind is there is the rotational nature of movement.

Now let's calculate the theoretical efficiency of rotorsails for the Indian Ocean, for this we will take the passage from the port of Karwar to the port of Nishtun. Table 10 describes the basic data for the passage from the port of Karwar to the port of Nishtun. Tables 11, 12 show the effectiveness of rotor sails depending on the time of year for the passage "KARWAR – NISHTUN".

Table 10

**Base table of the passage plan "KARWAR – NISHTUN"**

| No | Latitude | Longitude | Dist. | Course | d | H | n | ρ | P (req.) | Vessel speed | Time |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 14º48.1'N | 074º06.9'E | | º | m | m | item | *[kg/m³]* | *[N]* | *[knots]* | [hours] |
| 2 | 14º48.6'N | 074º07.1'E | 0.5' | 21.1° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.0 |
| 3 | 14º48.7'N | 074º06.4'E | 0.7' | 278.4° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.0 |
| 4 | 14º48.8'N | 074º03.3'E | 3.0' | 271.9° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 0.2 |
| 5 | 15º05.0'N | 068º15.0'E | 337.5' | 272.8° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 19.9 |
| 6 | 15º20.0'N | 062º23.0'E | 340.6' | 272.5° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 20.0 |
| 7 | 15º35.0'N | 056º30.0'E | 341.2' | 272.5° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 20.1 |
| 8 | 14º49.1'N | 052º12.3'E | 253.3' | 259.5° | 5 | 30 | 6 | 1.204 | 1700000 | 17.0 | 14.9 |
| | | Distance | 1276.8' | | | | | | | Cons= | 312.9 mt |

From table 10 follows, that without the help of rotor sails, fuel consumption will be 312.9 mt. Total Passage Duration 75.11 hours. With a standard calculation for 6 rotor sails, it becomes clear that the capacity of this ship's power plant is more than enough for the Indian Ocean. And this can be clearly seen in tables 11 and 12.

Table 11

**Calculations of the efficiency of rotor sails in January and April for the passage from the port of Karwar to the port of Nishtun**

| JANUARY | | | | | | | APRIL | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. Econ. | WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. Econ. |
| *º* | º | *[m/s]* | *[m/s]* | *[N]* | *%* | *mt* | *º* | º | *[m/s]* | *[m/s]* | *[N]* | *%* | *mt* |
| 0° | 21.1° | 7.7 | 2.8 | 329106 | 19.36 | 0.03 | 315° | 66.1° | 7.7 | 7.1 | 1800000 | 105.88 | 0.14 |
| 0° | 81.6° | 7.7 | 7.6 | 1800000 | 105.88 | 0.18 | 315° | 36.6° | 7.7 | 4.6 | 899042 | 52.88 | 0.09 |
| 0° | 88.1° | 7.7 | 7.7 | 1800000 | 105.88 | 0.78 | 315° | 43.1° | 7.7 | 5.3 | 1180548 | 69.44 | 0.51 |
| 0° | 87.2° | 10.3 | 10.3 | 1800000 | 105.88 | 87.59 | 315° | 42.2° | 7.7 | 5.2 | 1143362 | 67.26 | 55.63 |
| 45° | 132.5° | 10.3 | 7.6 | 1800000 | 105.88 | 88.39 | 315° | 42.5° | 7.7 | 5.2 | 1153368 | 67.85 | 56.64 |
| 45° | 132.5° | 10.3 | 7.6 | 1800000 | 105.88 | 88.54 | 315° | 42.5° | 7.7 | 5.2 | 1153550 | 67.86 | 56.74 |
| 45° | 145.5° | 10.3 | 5.8 | 1445913 | 85.05 | 52.81 | 225° | 34.5° | 7.7 | 4.4 | 813326 | 47.84 | 29.71 |
| | | | | | Econom | 318.31 | | | | | | Econom | 199.46 |
| | | | | | % | 101.71% | | | | | | % | 63.74% |

Table 12

**Calculations of the efficiency of rotor sails in July and October for the passage from the port of Karwar to the port of Nishtun**

| JULY | | | | | | | OCTOBER | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. Econ. | WD | WCA | WS {V} | {Vy} | P | Effect. | Cons. Econ. |
| º | º | *[m/s]* | *[m/s]* | *[N]* | *%* | *mt* | º | º | *[m/s]* | *[m/s]* | *[N]* | *%* | *mt* |
| 270° | 111.1° | 12.9 | 12.0 | 1800000 | 105.88 | 0.14 | 0° | 21.1° | 7.7 | 2.8 | 329106 | 19.36 | 0.03 |
| 270° | 8.4° | 12.9 | 1.9 | 150156 | 8.83 | 0.01 | 0° | 81.6° | 7.7 | 7.6 | 1800000 | 105.88 | 0.18 |
| 270° | 1.9° | 15.4 | 0.5 | 11253 | 0.66 | 0.00 | 0° | 88.1° | 7.7 | 7.7 | 1800000 | 105.88 | 0.78 |
| 270° | 2.8° | 12.9 | 0.6 | 16248 | 0.96 | 0.79 | 315° | 87.2° | 7.7 | 7.7 | 1800000 | 105.88 | 87.59 |
| 225° | 47.5° | 15.4 | 11.4 | 1800000 | 105.88 | 88.39 | 315° | 87.5° | 7.7 | 7.7 | 1800000 | 105.88 | 88.39 |
| 225° | 47.5° | 15.4 | 11.4 | 1800000 | 105.88 | 88.54 | 315° | 47.5° | 7.7 | 5.7 | 1376178 | 80.95 | 67.69 |
| 225° | 34.5° | 12.9 | 7.3 | 1800000 | 105.88 | 65.74 | 225° | 34.5° | 7.7 | 4.4 | 813326 | 47.84 | 29.71 |
| | | | | | Econom | 243.62 | | | | | | Econom | 274.36 |
| | | | | | % | 77.85% | | | | | | % | 87.67% |

The highest efficiency of rotor sails at the Karwar-Nishtun crossing in January, the smallest in April. Figure 7 shows a graph of changes in the efficiency of rotor sails depending on the time of year.

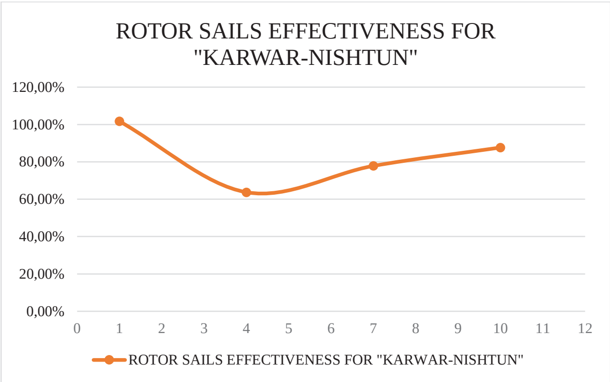


*Fig. 7. Effectiveness of rotor sails on the route "KARWAR – NISHTUN".*

According to the figure 7 the highest effectiveness is in January, and the lowest in April.

Figure 8 shows a graphical plan for the passage from the port of Karwar to the port of Nishtun.

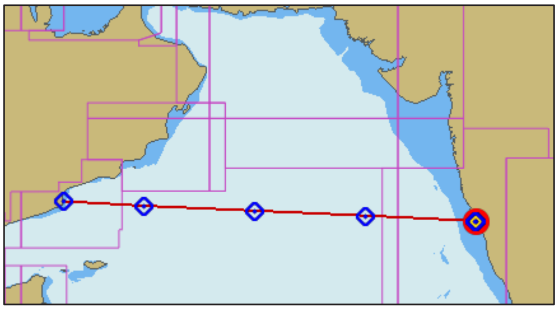

*Fig. 8. Passage "KARWAR – NISHTUN"*

Fig. 8 reveals the graphical features of the passage from the port of Karwar to the port of Nishtun. On Fig. 9 and 10 depicted prevailing winds on the planet depending on the time of year. The route of the vessel can be changed taking into account the time of year, if it is economically profitable.

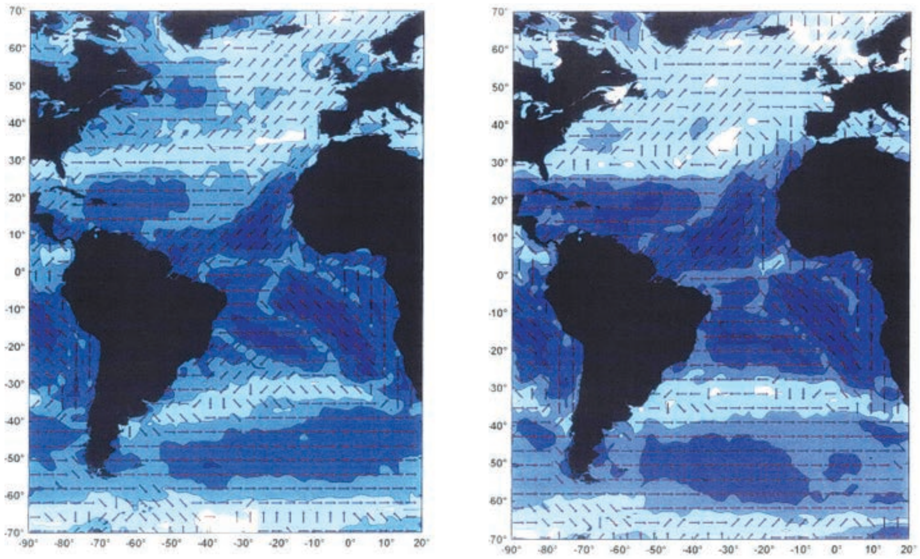

*Fig. 9. Perennial prevailing winds in January (left) and April (right)*

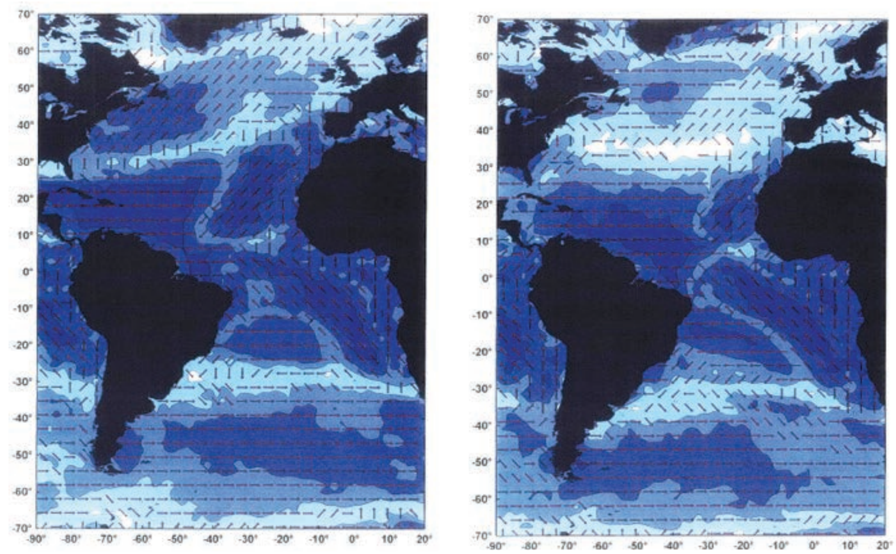

*Fig. 10. Perennial prevailing winds in July (left) and October (right)*

When viewing the wind directions, you can check that the selected wind directions are correct, and you can also use the PILOT CHARTS and check the wind speed.

To install rotor sails, it is proposed to select the company's equipment NORSEPOWER [6-8] and container ships "UMM QARN" and "MSC EMMA".

Main characteristics m/v "MSC EMMA" LOA: 366.32m, LPP: 350.00m, Breadth: 48.2 m.

Main characteristics m/v "UMM QARN" LOA: 368.52m, LPP:352.00m, Breadth:51.00m

From article [2] was selected the variate of cylinder locations "6.1", since it is the most effective in terms of thrust and safe in terms of the requirements of the SOLAS convention apparently for container carrier ship visibility (Fig.11.).

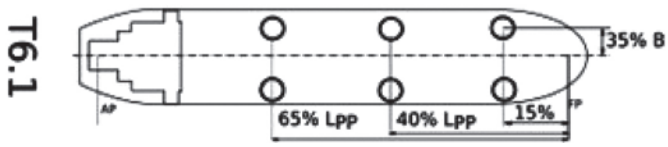


*Fig. 11. Cylinder localization scheme from source [2]*

This location option is suitable as for a container carrier "MSC EMMA" as same as for a container carrier ship "UMM QARN".

## 6. CONCLUSIONS

Based on the selected vessels, this option of positioning six rotor cylinders with a diameter of 5 meters will make it possible to significantly save fuel by reducing the load on the engine. The mathematical experiment allowed to calculate the possibilities of an alternative ship power plant on different routes. Such a ship power plant will be able to reduce carbon emissions into the atmosphere by 50% even before the IMO deadlines [5].

Thrust can also be increased if you strengthen the design of rotor sail. Modern technologies and old tested ideas can change world marine industry in amazing way.

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