FUEL SAVING ANALYSIS ON MERCHANT VESSEL: WINGSAILS AS AN AUXILIARY PROPULSION SYSTEM

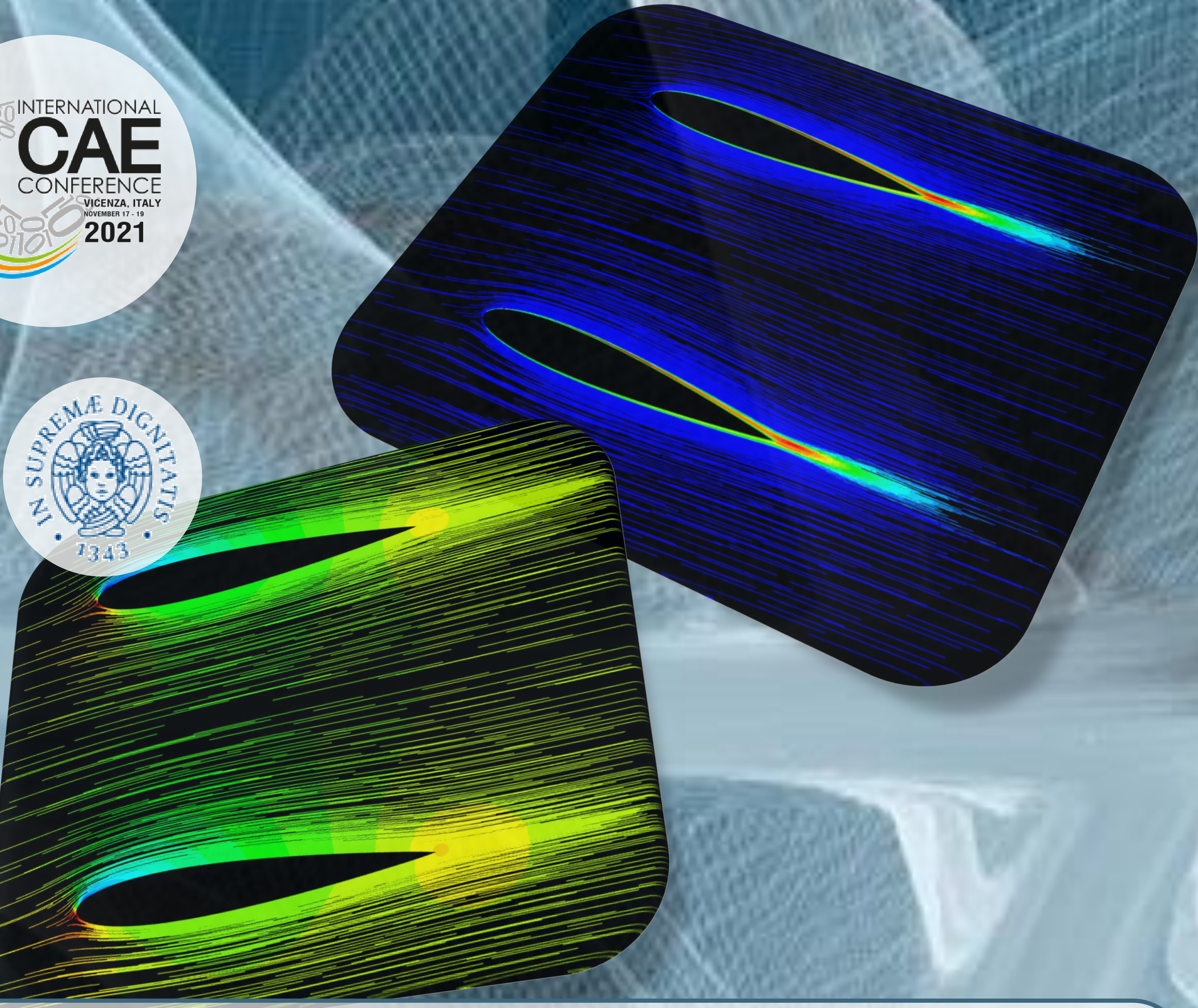
Filippo Giuntini[1]
Francesca Leonetti[1]

[1] MsC students in «Energy Engineering» at the Engineering School of the University of Pisa

The authors gratefully acknowledge the support of the Dr Stefania Zanforlin.

INTERNATIONAL CAE CONFERENCE VICENZA, ITALY 2021

CAN WE CONSIDER WIND A POTENTIAL RESOURCE?



INTRODUCTION

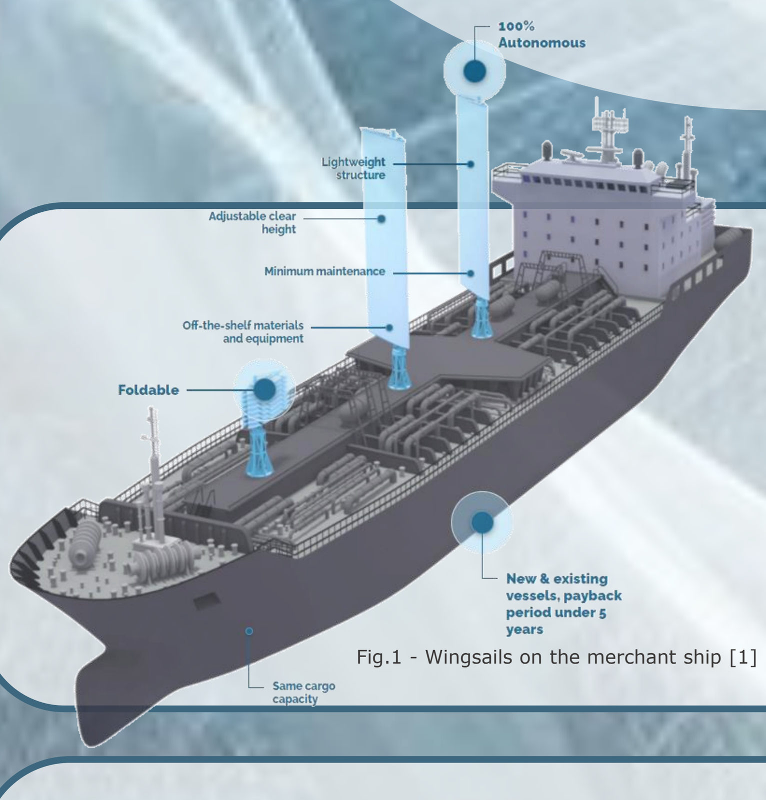


Fig.1 - Wingsails on the merchant ship [1]

Today the issue of decarbonisation has assumed significant importance: limiting carbon dioxide emissions is the main objective of a sustainable perspective. Since merchant shipping accounts for about 3% of CO_2 emissions [2], it is essential to reduce fuel consumption with alternative systems. The case study aims to evaluate the fuel savings on the transmediterranean merchant ship *RoPax Ciudad de Mahón* using foldable rigid wingsails with NACA0015 airfoil free to rotate 360 degrees around a pivot through automatic control. The evaluation is developed by comparing, under the same swept area, a single wingsail of $12\,m$ chord and two parallel wingsails of $9.98\,m$ chord, rigidly rotating around the same pivot. Both configurations feature a height of $35\,m$.

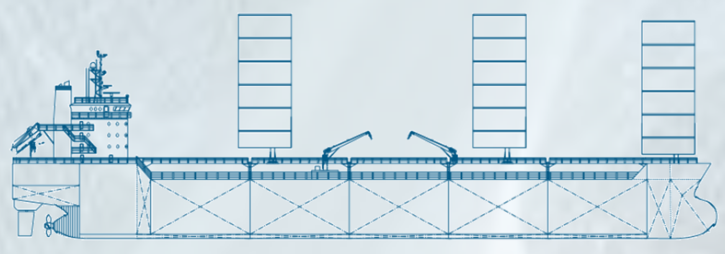


Fig.2 - Wingsails on the merchant ship [1]

METHODS

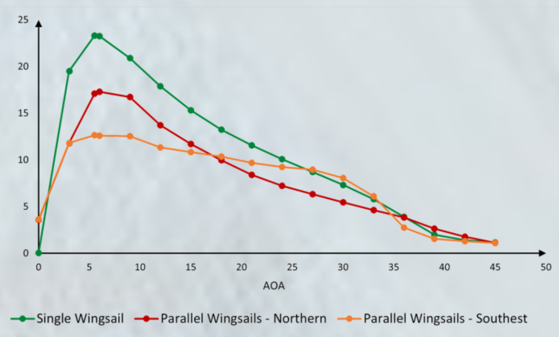


Fig.3 - Lift to drag ratio as a function of the angle of attack for the two different configurations for $Re = 3x10^6$. According to [3,4] the maximum aerodynamic efficiency is obtained around 6 degrees for both configurations. However, the values obtained are underestimated compared to the experimental data due to the model used.

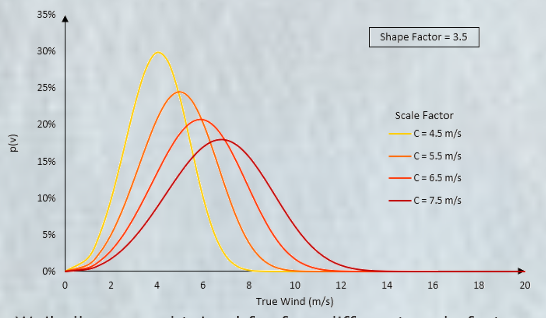


Fig.4 - Weibull curves obtained for four different scale factors with a fixed shape factor. The scale factor provides an idea of the windiness of the site and, being uniquely linked to the average velocity, it has been chosen in order to be consistent with the average velocities for the shipping route. The average velocities related to the chosen scale factors are $4, 5, 6, 7\ m/s$, respectively. The choice of the shape factor is consistent with a regular sea wind.

Transient 2D URANS simulations have been performed on the ANSYS-Fluent software, using a $k-\omega$ SST model and implementing two multi-block structured grids generated within ANSYS-Icem software. The model has been validated by comparing the angle of attack that maximizes aerodynamic efficiency c_l/c_d with experimental values obtained in [3,4] for a range of Reynolds number consistent with the expected velocity field in the considered shipping route. A statistical approach based on the probabilistic Weibull distribution has been adopted in order to evaluate the wind resource. Assuming a cruising speed of $8.3\ m/s$ and exploring all wind directions for the considered velocity fields, the apparent wind has been obtained. The values of the lift and drag coefficients, relating to these velocities, have been calculated in Microsoft Excel by interpolation of the previously obtained values. Once the lift and drag forces were obtained, the driving force and therefore the propulsive power and the heeling force have been derived. Lastly, fuel saving has been evaluated based on the best wind conditions, referring to the wind direction that maximizes the annual energy productivity.

Primary Propulsion Systems	No.	Power [kW]	Consumption HFO [g/kWh]	Consumption MDO [g/kWh]	Annual hr HFO	Annual hr MDO
Diesel Engines - Wärtsilä 9L38	4	5940	183	182	3564	396
Diesel Generators - Wärtsilä 6L20	2	870	193	192	5346	594

Table 1 - Traditional propulsion systems installed on the *RoPax Ciudad de Mahon* [5]: specifications and annual hours of operation. The systems use two types of fuel: HFO - *Heavy Fuel Oil* - is used in normal operating conditions for its economy, while MDO - *Marine Diesel Oil* - in port conditions. The evaluation of the HFO savings is based on the hypothesis of a consumption of MDO equal to 10% of the annual operating hours.

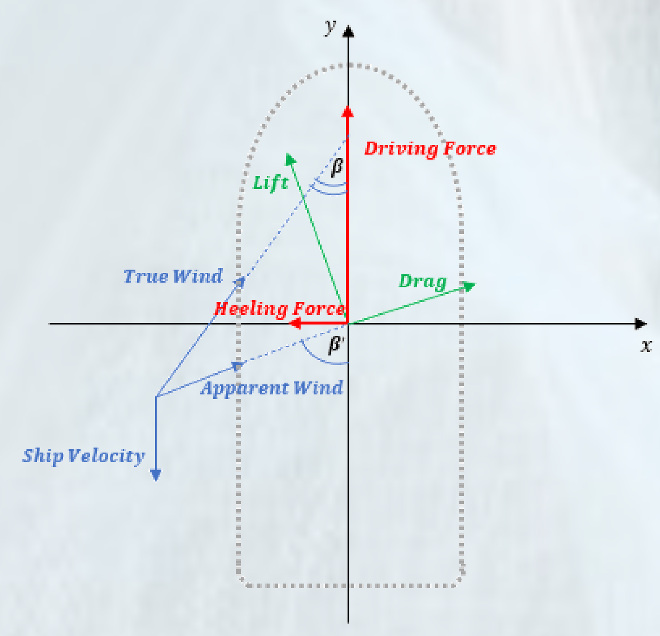


Fig.5 - Definition of velocities and forces involved. In light blue we report the velocity triangle which shows the relative velocity that hits the wingsail as a composition of the true wind and cruising speed. The absolute and relative wind form the β and β' angles with the ship's axis, respectively. Lift and drag forces produced by the relative wind on the airfoil are shown in green. The driving and heeling forces deriving from the decomposition along the axes of lift and drag are shown in red.

RESULTS

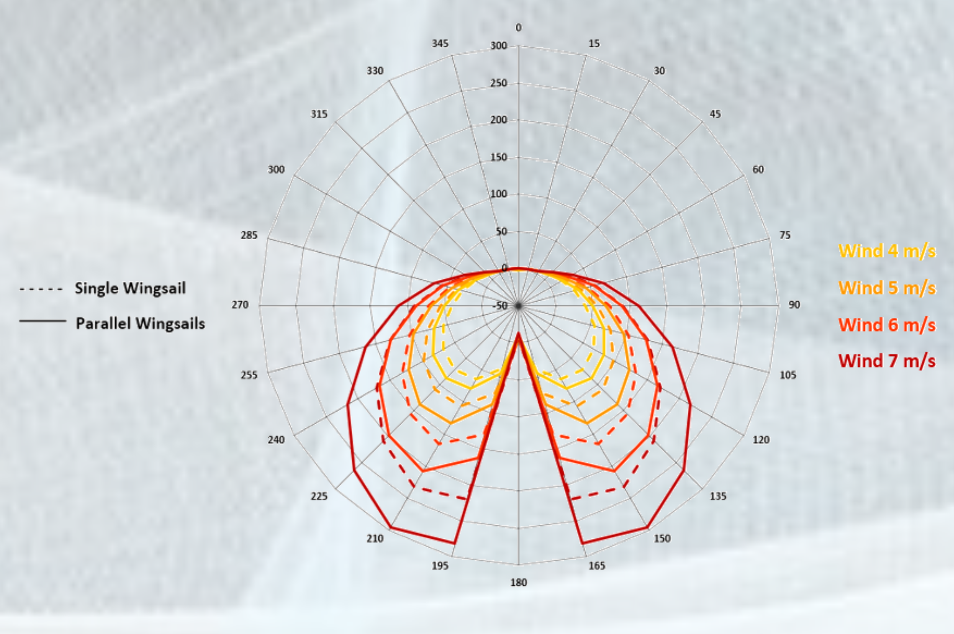


Fig.6 - Polar diagram of the propulsive power $[kW]$ as a function of β [deg]. The results refer to the four average wind intensities derived from Weibull distributions, corresponding to four different Reynolds number values for each configuration. For the single wingsail, for increasing velocities: $Re_1 = 3.3x10^6$, $Re_2 = 4.1x10^6$, $Re_3 = 4.9x10^6$, $Re_4 = 5.8x10^6$. For parallel wingsails: $Re_1 = 2.7x10^6$, $Re_2 = 3.3x10^6$, $Re_3 = 4.0x10^6$, $Re_4 = 4.6x10^6$.

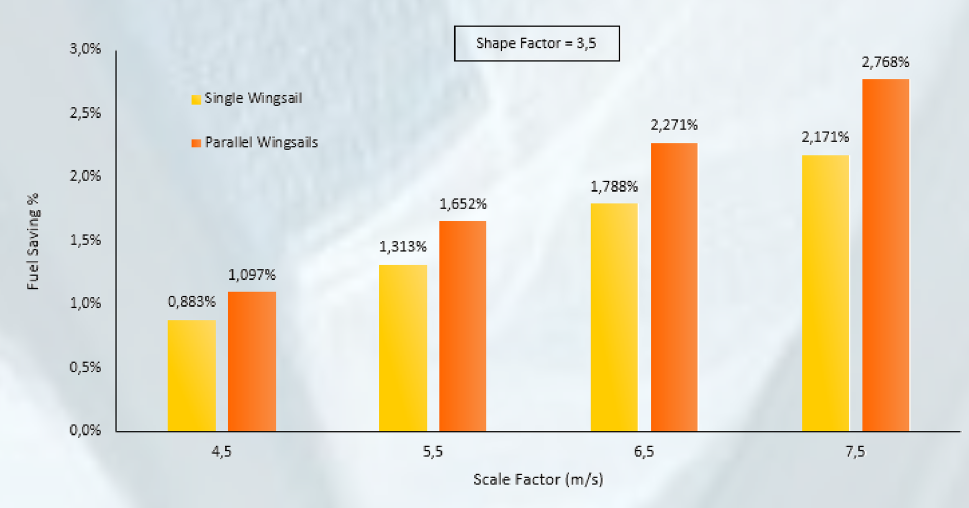


Fig.7 - Fuel saving [%] in the best wind conditions, referring to the wind direction that maximizes the annual energy productivity. For the single wingsail, for increasing average velocities, the optimal wind conditions are: $\beta_1 = 135°$, $\beta_2 = 150°$, $\beta_3 = 135°$, $\beta_4 = 135°$; for parallel wingsails: $\beta_1 = 135°$, $\beta_2 = 150°$, $\beta_3 = 135°$, $\beta_4 = 135°$.

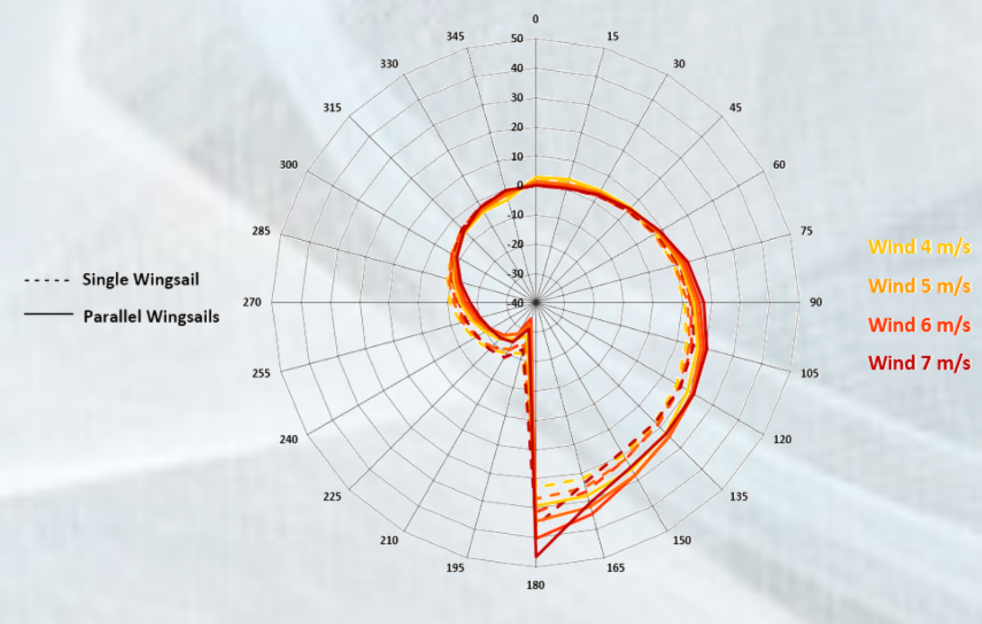


Fig.8 - Polar diagram of the heeling force $[kN]$ as a function of β [deg]. The results refer to the same considerations reported in Fig.6.

CONCLUSIONS

It is shown how the single wingsail leads to low fuel saving, and therefore to a little reduction of emissions. The second configuration, providing greater propulsive power, slightly increases the saving. However, it involves the use of more material, leading to higher costs and loads, and a greater heeling force, leading to greater stresses on the vessel. Since both configurations provide a fuel saving less than 3%, further evaluations in structural and economic terms must be carried out in order to evaluate the actual convenience of the installation. One way to increase savings could be the installation of a greater number of wingsails, subject to availability of space on board. Placing N wingsails far enough to avoid aerodynamic interference, would allow N times greater savings, but also N times greater heeling force.

Wingsails don't always bring an advantage. They must be retracted under two conditions:

- Total absence of wind, because cruising speed alone would produce a driving force in the direction opposite to the ship's motion.
- Wind blowing with $\beta \equiv \beta' = 180°$, $\beta \equiv \beta' = 0°$ with $\overrightarrow{v_{wind}} < \overrightarrow{v_{sail}}$. The consequence would be a driving force opposite to motion.

OUTLOOK

- Making the comparison between the two configurations under the same generated propulsive power, and therefore the same fuel saving, the parallel wingsails are expected to allow a further reduction of the chord and then a reduction of the materials, costs and loads the ship is subjected to. The reduced chord allows more space available for containers on the merchant ship.
- The configuration with parallel wingsails requires further analysis with 3D grids and more accurate numerical methods, such as LES.
- Up to now, all ongoing projects conceive wingsails without flaps, which, in naval world, only exist in competition sailing boats [6], and not in merchant vessels. Flaps could be a future way to improve the generated propulsive power by wingsails, as they are in sailing competitions.

REFERENCES

[1] Wingsail technology. (2020). Bound4Blue. Retrieved from November 2019, to January 2020, from https://bound4blue.com/en/

[2] https://ec.europa.eu/clima/policies/transport/shipping_en

[3] Eastman N. Jacobs, Kenneth E. Ward and Robert M. Pinkerton, "The characteristics of 78 related airfoil sections from tests in the variable-density wind tunnel", National Advisory Committee for Aeronautics; pp.8, 1935

[4] Lasse, G. and Niels, S., "Large eddy simulations of an airfoil in turbulent inflow", 4th PhD Seminar on Wind Energy in Europe: Book of Abstracts; The European Wind Energy Association: Brussels, Belgium, 2008; pp. 33–36.

[5] Daniel Gómez Díaz and Santiago Ordás Jiménez, "Study and analysis of the use of wind power for the propulsion of merchant vessels. Case study", Bachelor's Final Thesis, Barcelona School of Nautical Studies and Polytechnic University of Catalonia, March 2020

[6] Chen Li, Hongming Wang and Peiting Sun, "Numerical Investigation of a Two-Element Wingsail for Ship Auxiliary Propulsion", MDPI, Journal of Marine Science and Engineering, May 2020