Flettner rotor and rigid wingsail forces

Example of Flettner rotor (Maersk Pelican, Norsepower)
https://www.norsepower.com/

Example of rigid wingsail (Wallenius Marine)
https://www.theoceanbird.com/

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Flettner rotor and rigid wingsail forces

This program allows the calculation of orders of magnitude of the forces induced by a rigid wingsail or a Flettner rotor, that can be used as wind-assisted propulsion system for commercial ships. It is based on semi-empirical methods and lift and drag coefficients published in the literature. For more information, see the following references:

References:

[1]: Bordogna, G. (2020), "Aerodynamics of wind-assisted ships: Interaction effects on the aerodynamic performance of multiple wind-propulsion systems", Delft University of Technology, Delft. https://doi.org/10.4233/uuid:96eda9cd-3163-4c6b-9b9f-e9fa329df071

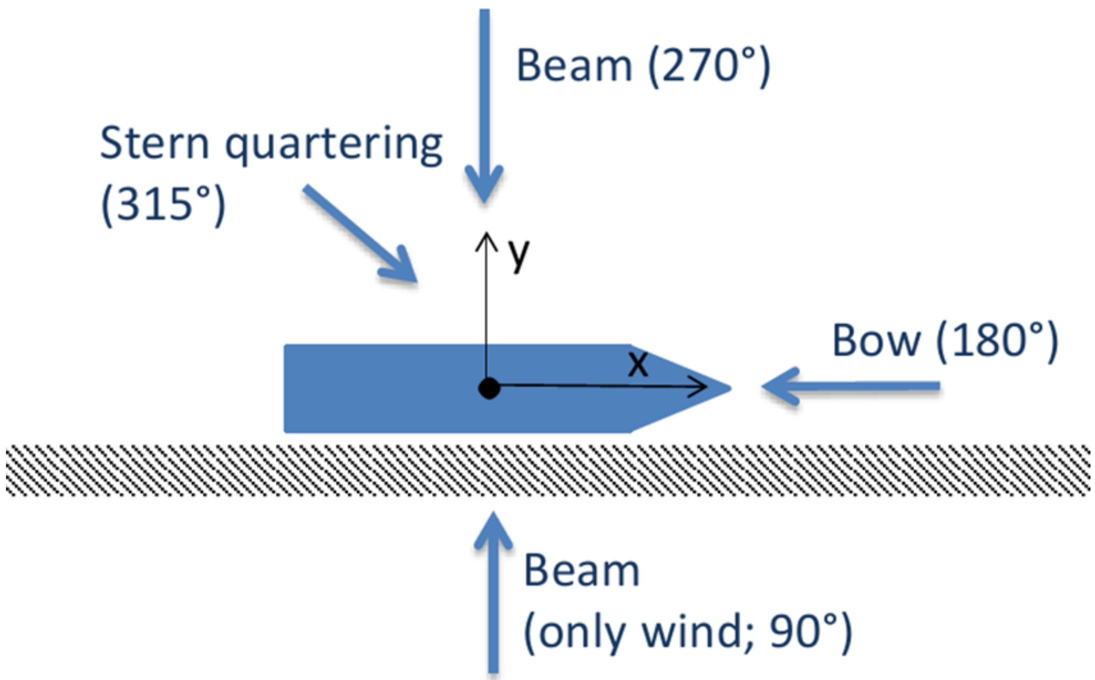
[2]: Reche, M. (2020), "Performance prediction program for wind-assisted cargo ships (Master's thesis)", Technical University of Denmark, Lyngby. https://www.researchgate.net/publication/344238090

[3]: Tranell, J. (2021), "Seakeeping capabilities of sailing cruise and passenger vessels (Master's thesis in Marine Technology)", NTNU, Trondheim.

[4]: Kramer, J.V. (2022), "Hydrodynamic aspects of sail-assisted merchant vessels (Doctoral thesis in Marine Technology)", NTNU, Trondheim.

COORDINATE SYSTEM AND RELATIVE DIRECTION OF WIND

The coordinate system has the X axis pointing forward, Y to port and Z upward. The origin is located at the position of the centre of gravity (COG). It corresponds to the coordinate system R2 of SIMBAD program.
The relative direction has been defined in the ship axis system in which wind blowing in the direction of the positive X-axis is defined as 0° and wind blowing in the positive Y2-axis as 90°.



INPUTS OF THE PROGRAM

The following inputs have to be introduced for each calculation:

- **waps, integer (1 or 2), rigid wingsail (1) or Flettner rotor (2)**
- **Vs, scalar, Ship velocity [kn]:**

The program takes into account apparent wind speed and angle, if the ship velocity is not nil. Nevertheless, as this program was developed in order to obtain the forces due to the wind in the port area, in addition to those induced on the ship's superstructures (insofar as the sails are non-retractable and the rotors are not tiltable), no account was taken of a drift angle or any dynamic effects due to roll or pitch.

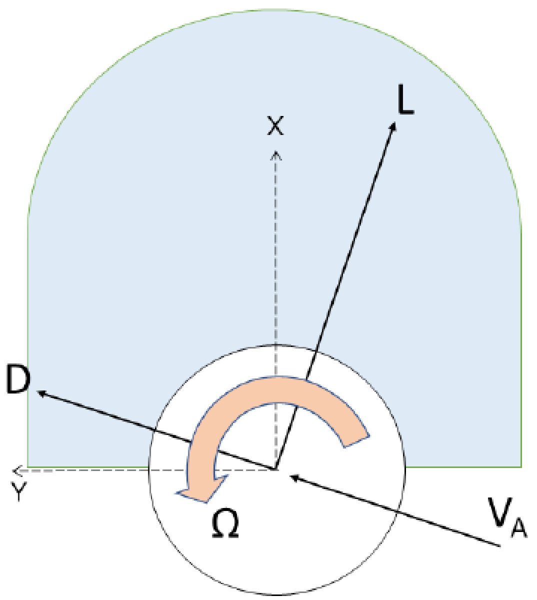
- **AoA, scalar, Angle of Attack [deg] or SR [-]:**

There is a positive lift force (in the positive X-direction) contributing to positive driving force for wind angles between 0° and 180°, at the following conditions:

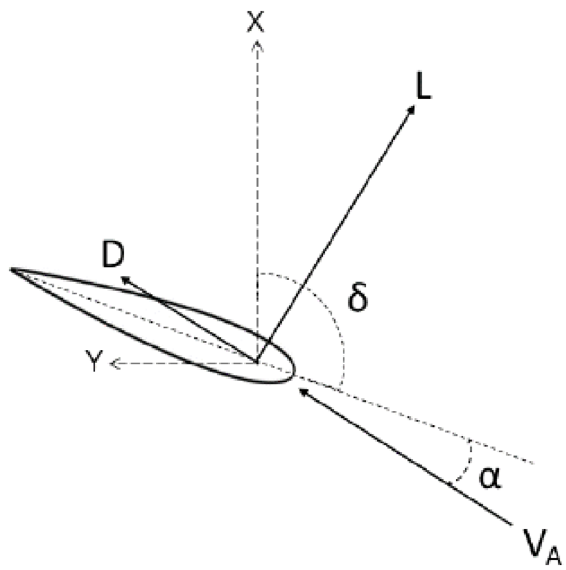
> **- The Angle of Attack for the wingsail is positive,**
>
> **- The spin ratio (SR) of the Flettner rotor is positive, this means that the Flettner rotor spins in the anticlockwise direction.**

For a positive lift force for wind angles between 180° and 360°, the wingsail Angle of Attack, respectively the Spin Ratio for the rotor, is to be negative.

INPUTS OF THE PROGRAM



DEFINITION OF POSITIVE SPIN RATIO AND LIFT FORCE (TOWARDS THE POSITIVE X-DIRECTION) FOR THE FLETTNER ROTOR (FROM REF. [3])



DEFINITION OF POSITIVE ANGLE OF ATTACK (ALPHA) FOR THE RIGID WINGSAIL (FROM REF. [3])

Note: the Spin Ratio for the Flettner rotor is the ratio of the tangential velocity (induced by the rotational speed) and the apparent wind velocity. The aspect ratio is defined by the ratio of the height and diameter for the rotor and of the height and cord for the wingsail)

INPUTS OF THE PROGRAM

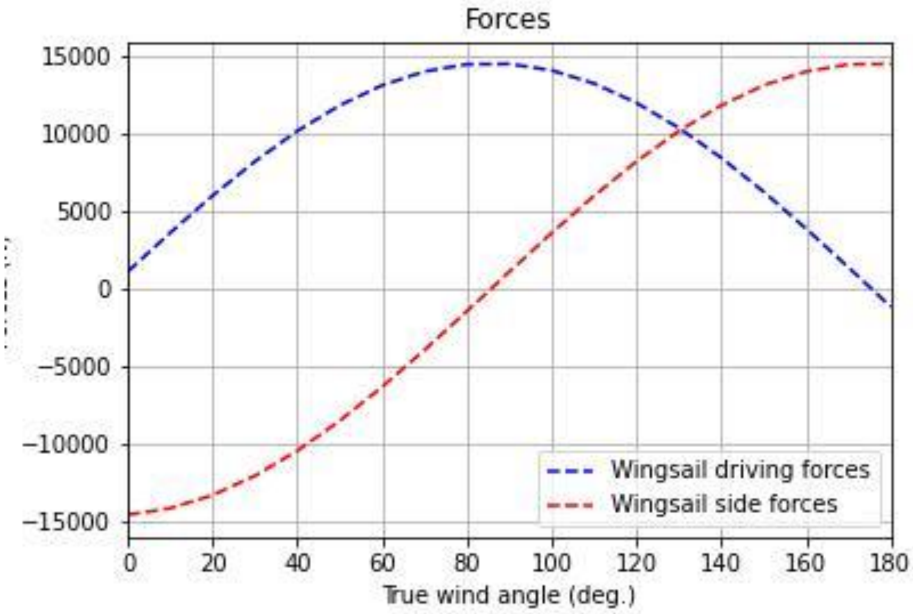
- **incl_stall**, boolean, Include or ignore sail stall.

If Stall is included for the wingsail, it will occur for an Angle of Attack (positive or negative) greater than 20 degrees. There is no Stall occurring for the Flettner rotor.

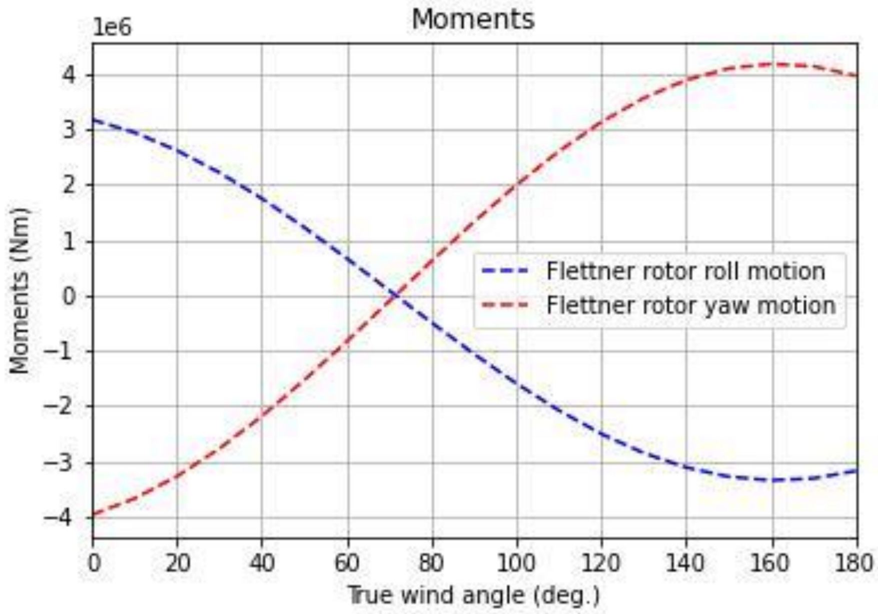
- **ABL**, boolean, takes into account for the atmospheric boundary layer in the true wind speed. The local velocities are calculated at each position z in the wind boundary layer.
- **H**, scalar, Height of sail or Flettner rotor
- **c**, scalar, Chord length for the wingsail (if waps == 1) or Diameter for the rotor (if waps =2)
- **f**, Scalar, Ship freeboard [m]
- **zg**, scalar, Position of Center of gravity above Mean Water Level [m]
- **xg**, scalar, Position of wingsail or rotor vs Center Of Gravity [m]
- **TWS10**, scalar, True wind speed at reference height 10 m [m / s]
- **TWA10**, scalar, True wind angle at reference height 10 m [0° - 360°]

OUTPUTS OF THE PROGRAM

The program provides rigid wingsail or Flettner rotor induced forces and moments.



INDUCED FORCES FOR A WIND SPEED OF 10M/S AND A NIL SHIP VELOCITY



INDUCED MOMENTS FOR A WIND SPEED OF 10M/S AND A NIL SHIP VELOCITY

INTERACTION EFFECTS BETWEEN MULTIPLE SAILS

When several sails are mounted close to each other, the flow field experienced by one may be affected by the presence of others, leading generally to a thrust reduction.

According to ref. [1], when the Flettner rotors are set 15 diameters apart, their aerodynamic coefficients become closer to those of the non-interacting ones. When they are in an arrangement at a spacing of 3 diameters, their percentage of change may reach average values of 20% with respect to the non-interacting rotors.

For the rigid wingsails, the overall interaction effects on the aerodynamic performance of several sails are generally not beneficial.

Nevertheless, for the both propulsion systems, an optimization of the sail arrangement and also operation can reduce the thrust loss and even increase the performance.