Blue WASP

Wind Assist Specialists

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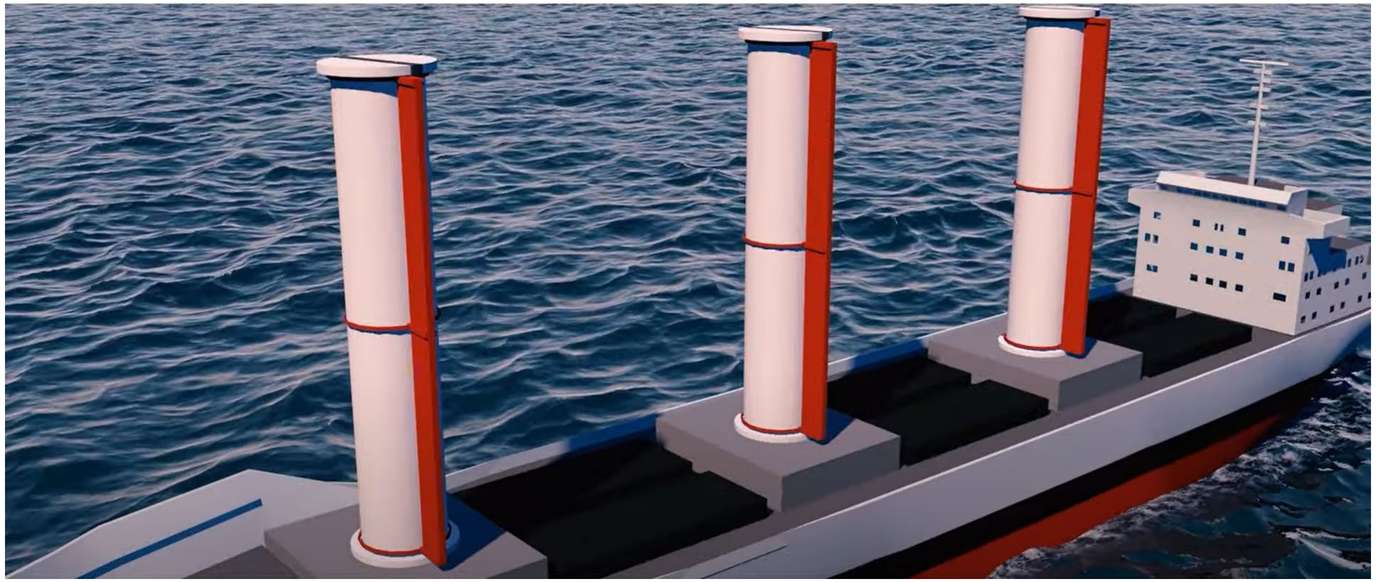
Performance evaluation of a Flettner rotor with flap

Dr. G. Bordogna, Blue Wasp Marine BV

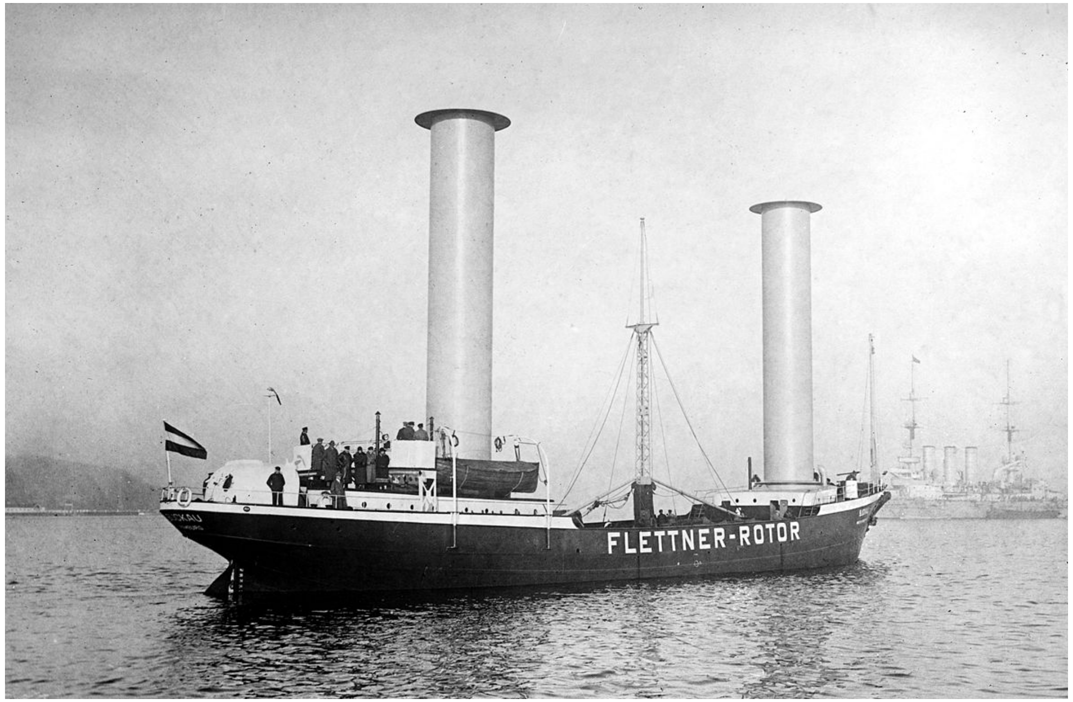


Presentation background & preface

- Results obtained during Wind Assist PhD research (2013-2020) at TUDelft
- Credit to co-authors Albert Rijkens and Nico van der Kolk
- In 2023 TUDelft started a new large research program on Wind Assisted Propulsion
- Blue Wasp Marine is an independent consultancy working with all wind assist technologies

Flettner rotor & flap concept

- Flettner rotor is a spinning cylinder that, thanks to the Magnus effect generates an aerodynamic lift
- It’s an active high-lift device, it requires a power input to function
- Today, several ships are fitted with this device
- **Flap addition**: the goal was to fix the separation point, increase CL/CD ratio and improve upwind performance



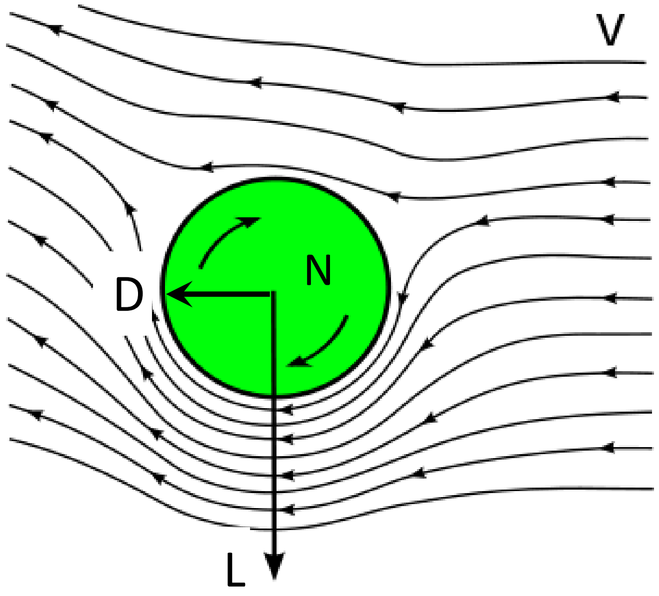
Backau ship equipped with 2 Flettner rotors (1924)

Magnus effect

Relations between forward speed and rotational velocity of the rotor are expressed with the velocity ratio or “k-factor”:

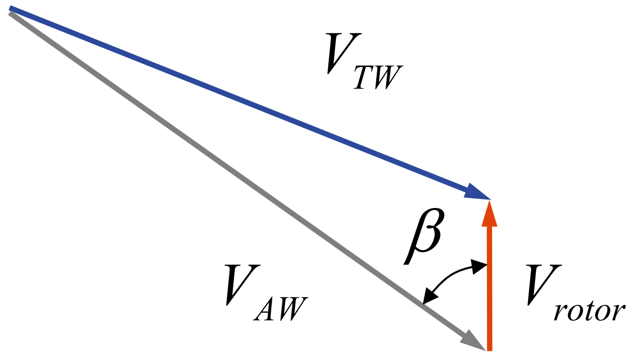
$$k = \frac{N \pi D}{V}$$

N = Rotational speed rotor
D = Diameter of the rotor
V = Wind speed

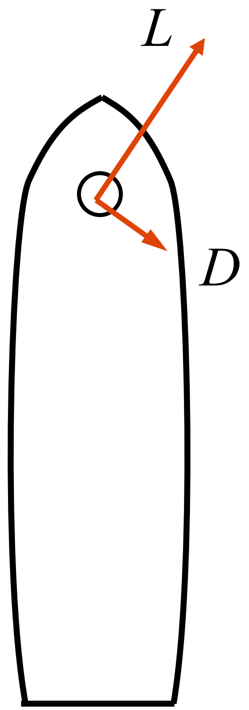


Importance of Lift-to-Drag ratio

Due to "motorsailing", WASP ships spend large amount of time sailing upwind



Wind propulsion only

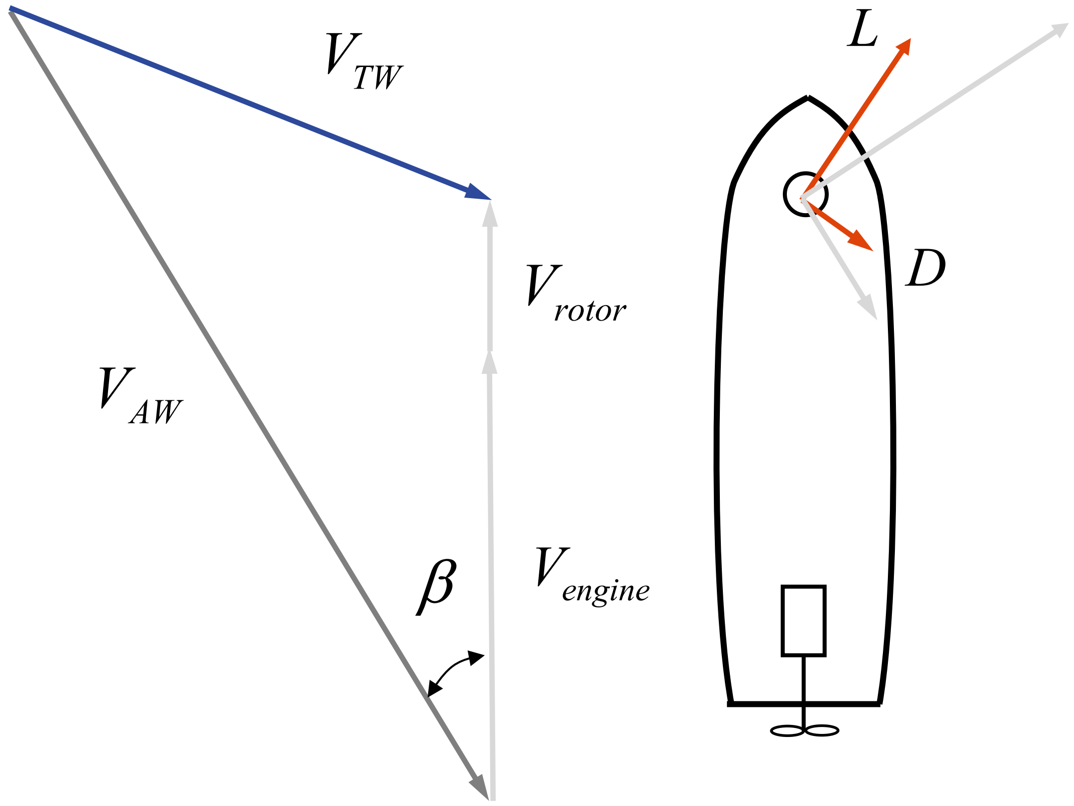


Importance of Lift-to-Drag ratio

Due to “motorsailing”, WASP ships spend large amount of time sailing upwind

Improving the lift/drag ratio would lead to great benefits to WASP ships

Wind assisted propulsion (wind + engine)



Wind tunnel experiments

Model experiments at the Politecnico di Milano wind tunnel

Features

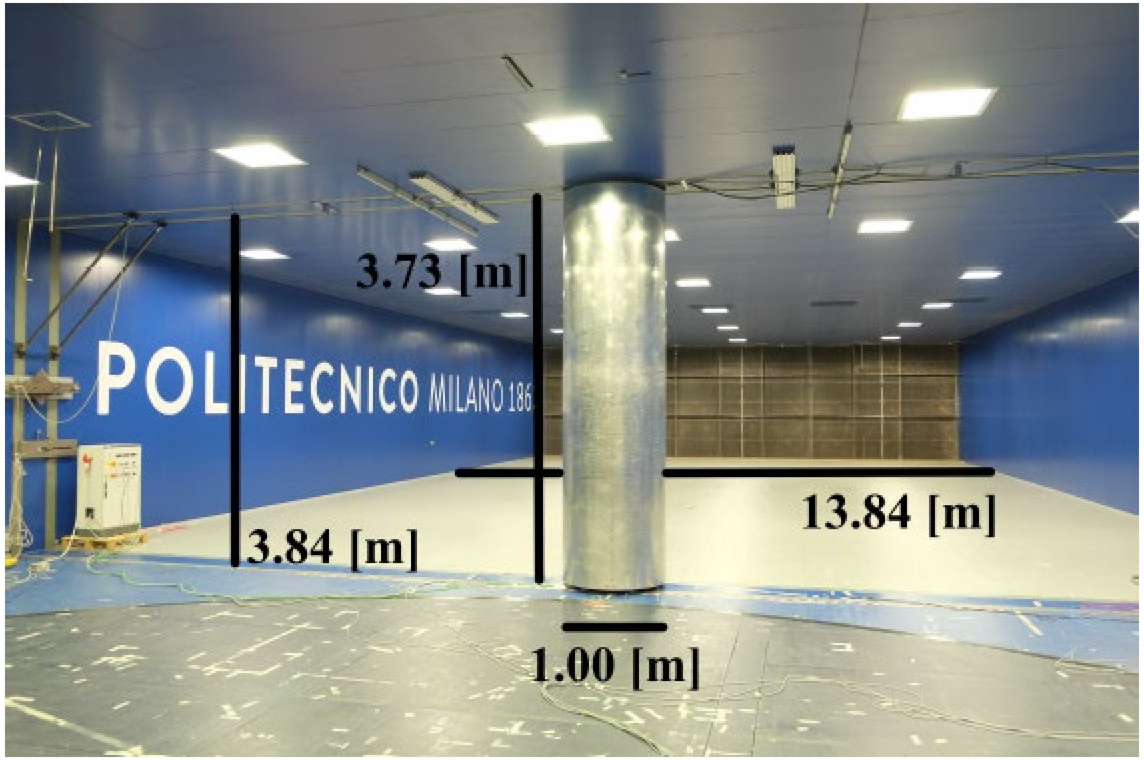
Length = 36 m

With = 13.8 m

Height = 3.8 m

Max wind speed = 15 m/s

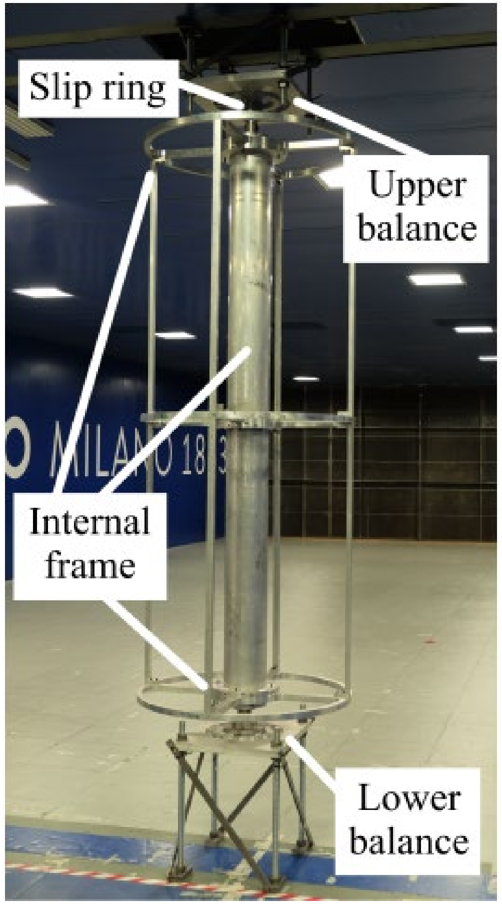
Benchmark tests with the “Delft Rotor”

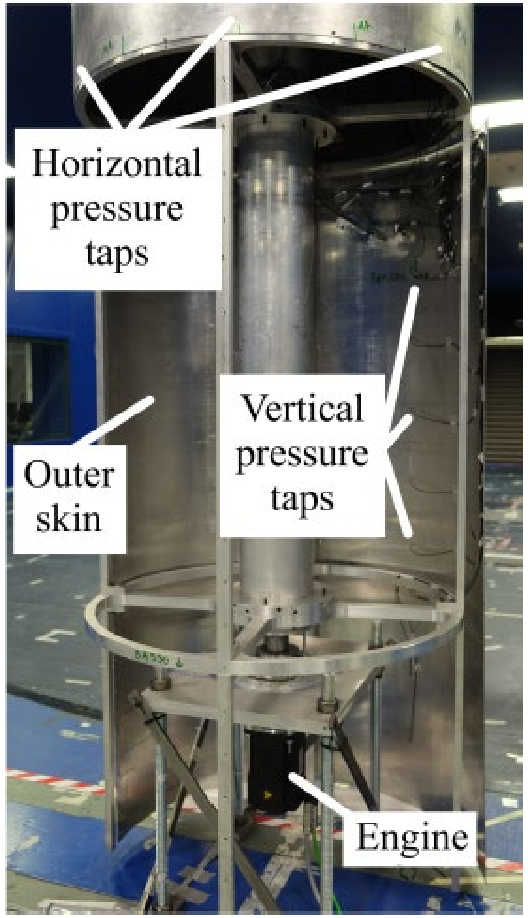


Wind tunnel experiments

Construction of the "Delft Rotor"

- Large scale Flettner rotor (D=1m and H=3.7m)
- No tip effects
- Very high Reynolds numbers
- Equipped with 2 force balances and 2 different pressure measurement systems

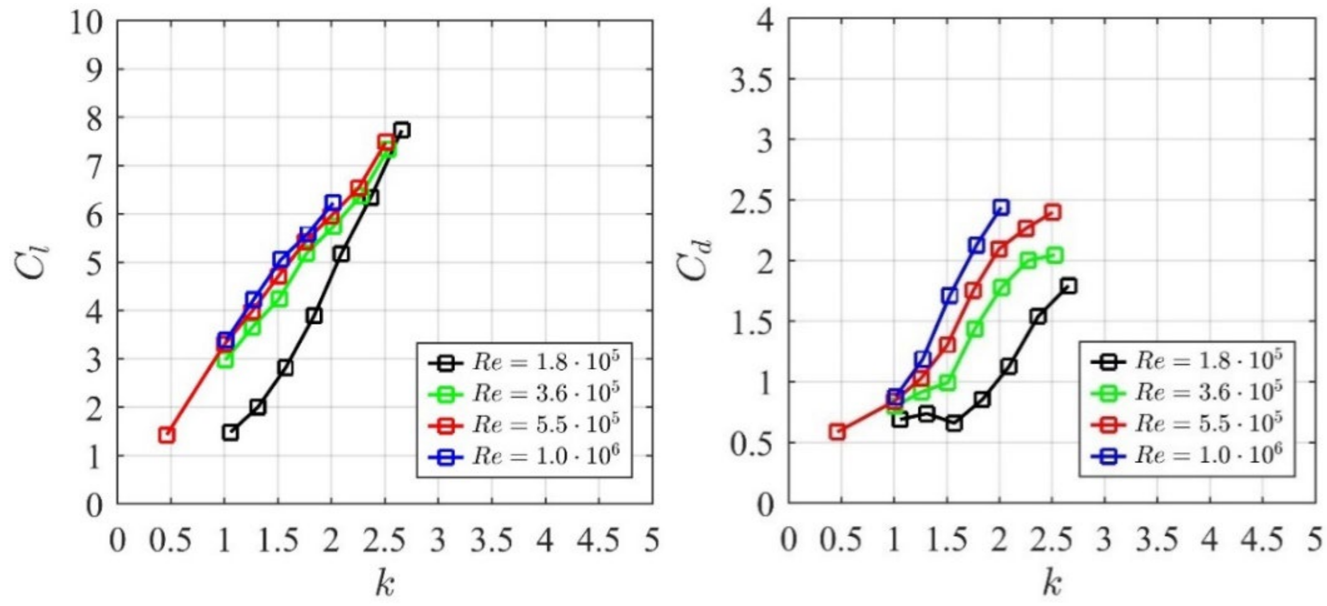




Results Delft Rotor

- Lift coefficients is not affected by the Reynolds number for $Re \geq 3.6 \cdot 10^5$
- Drag coefficients are still influenced by scale effects even for the highest Re tested
- Tests with flap are conducted at $Re = 3.6 \cdot 10^5$ to achieve a velocity ratio of up to $k = 5$

$$Re = \frac{VD}{\nu}$$

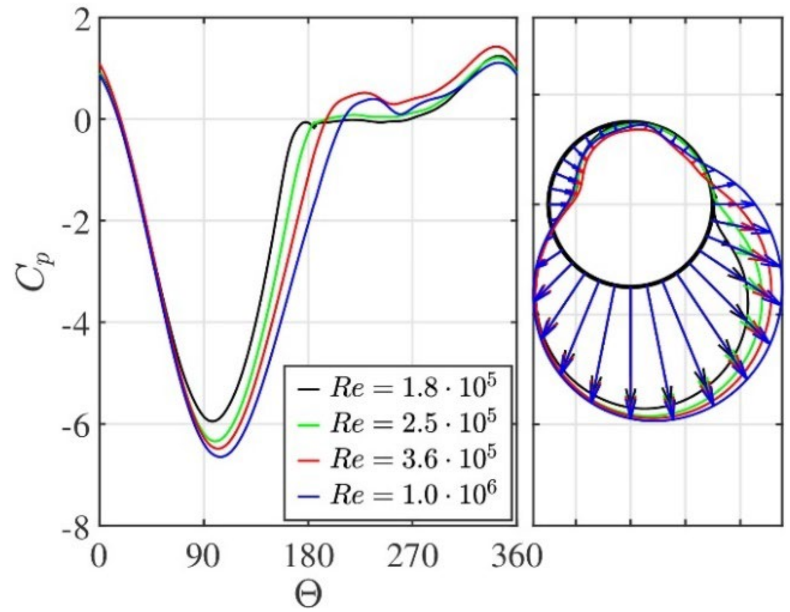


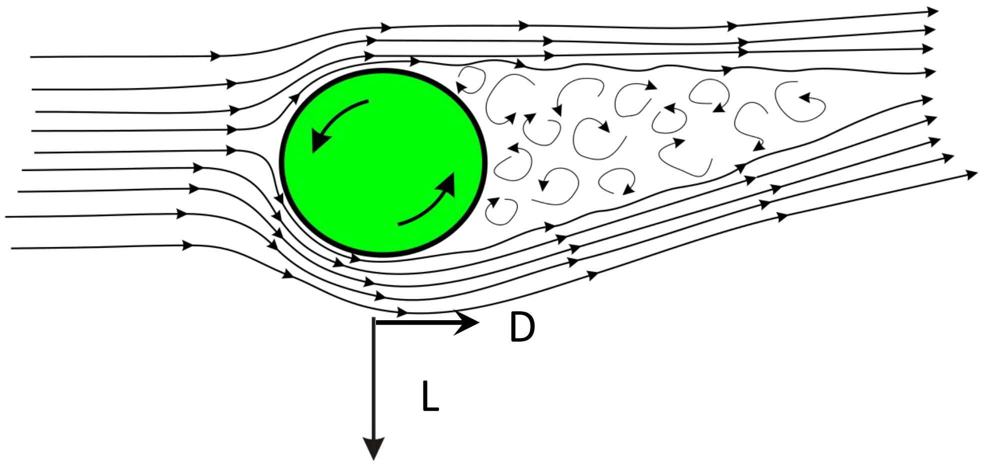
Results Delft Rotor

- Pressure distributions at Delft Rotor mid-span

- Effect of Re number on the pressure distribution especially at the rear of the cylinder

K=2



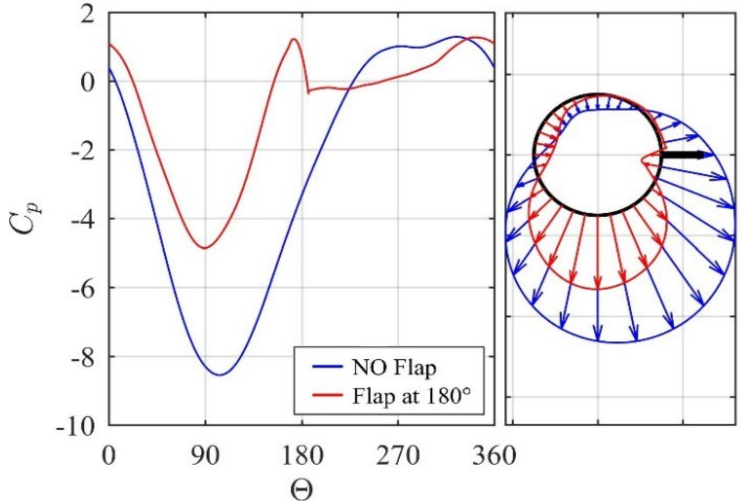


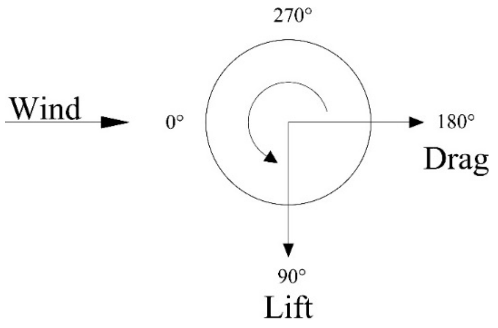
Delft Rotor with flap

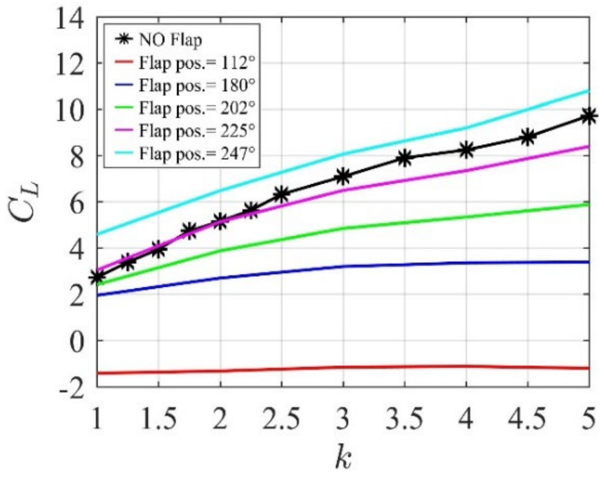
Results Delft Rotor with flap

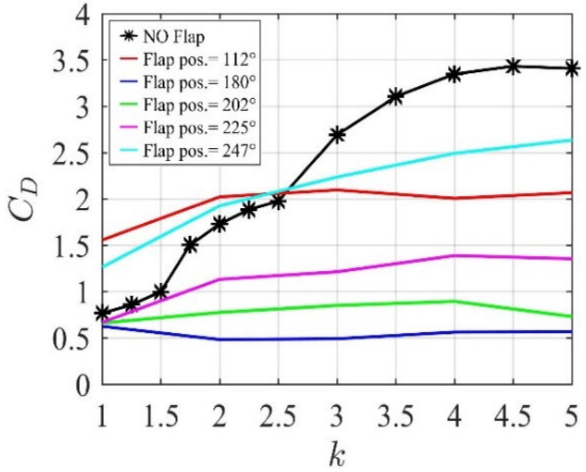
- Flap influences the separation point of the flow
- Drag is reduced
- Lift is reduced to a smaller extent
- Lift-to-drag ratio roughly doubles for the flap at 180 deg position

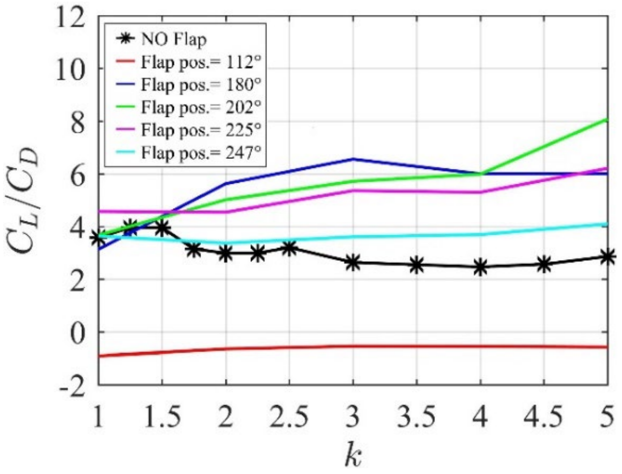
K=3





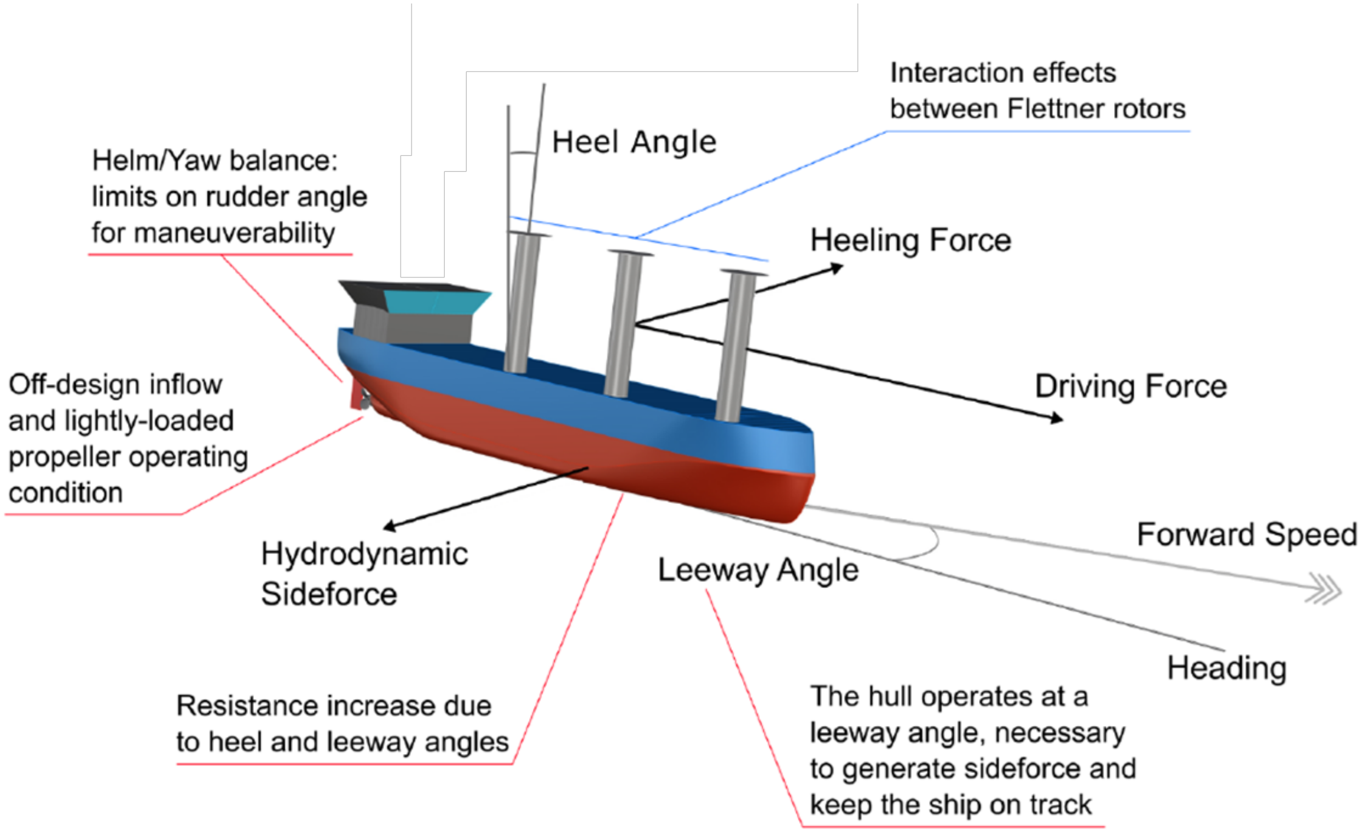






Performance prediction analysis

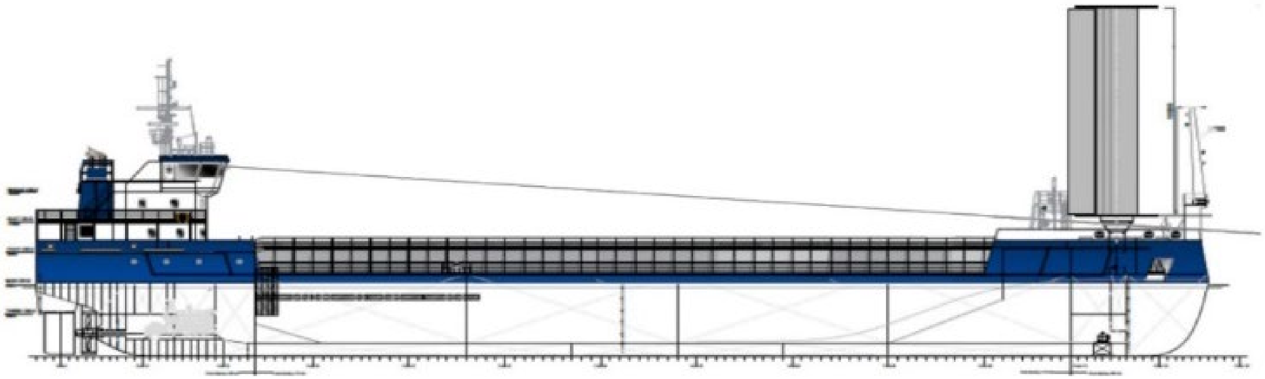
- Performance Prediction Programme for WASP ships
- Balances aerodynamic, hydrodynamic and main propulsor forces
- Aerodynamic properties of the rotors are based on the wind tunnel experiments
- Hydrodynamic coefficients are based on the Delft Wind-assist Series

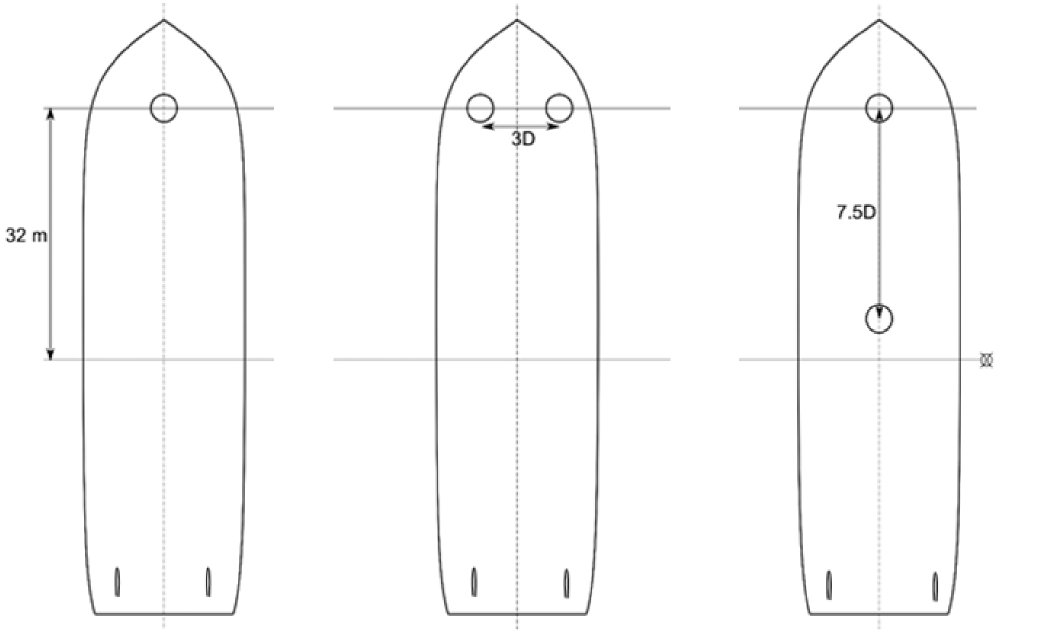


Case study

Configuration

- Comparison of the standard FR and the FR with flap
- Damen Combi Freighter 5000 with an overall length of 86 m
- Rotor dimensions D = 3m and H = 18m
- Different rotor numbers and positions



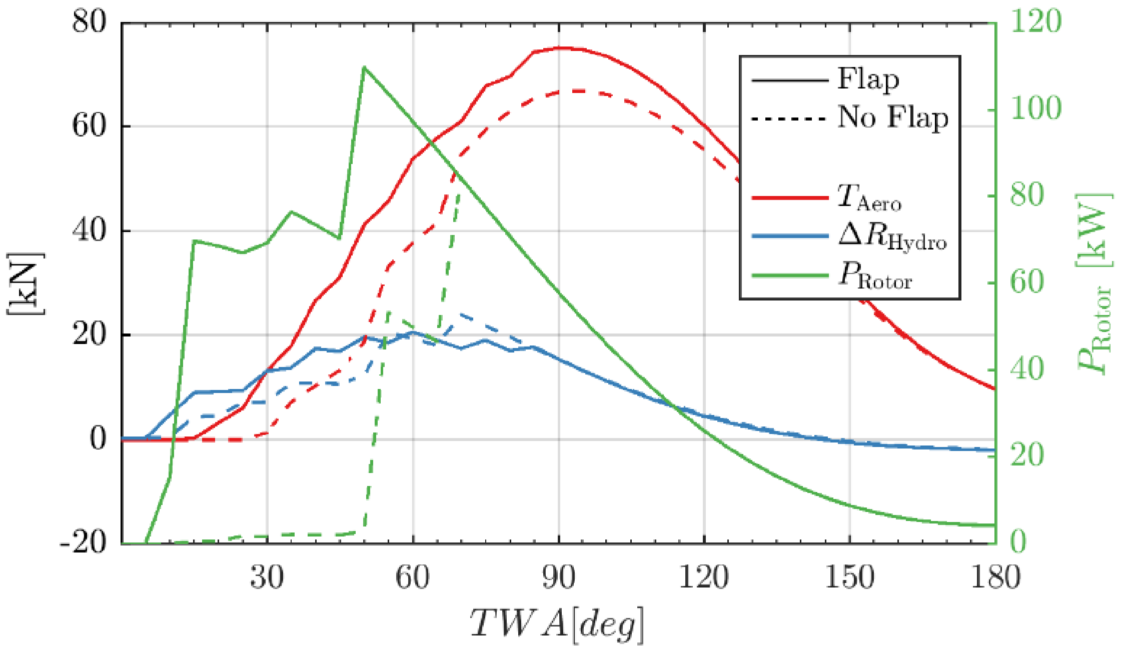


Tacking angle comparison

Results for two Flettner Rotors “Line”

- Aerodynamic thrust of the FR with Flap is greater or equal compared to the Standard FR
- FR with Flap has a considerably smaller tacking angle
- Tacking angle of Standard FR is 42 deg
- Tacking angle of FR with Flap is 30 deg

TWS = 20 kts and Vs = 11 kts

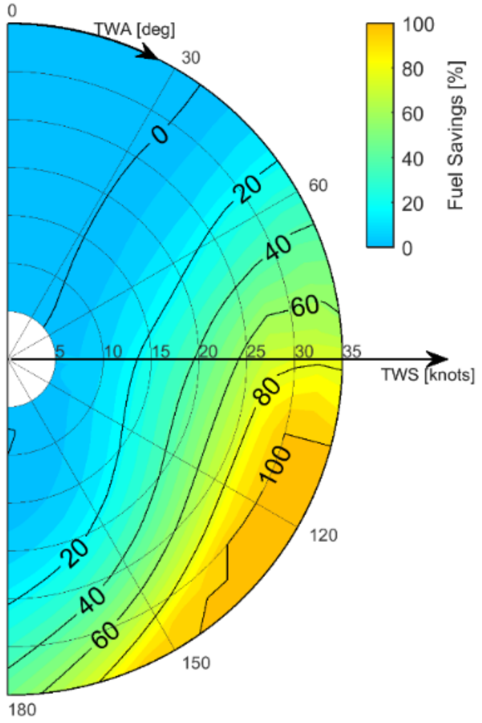


Fuel savings polar comparison

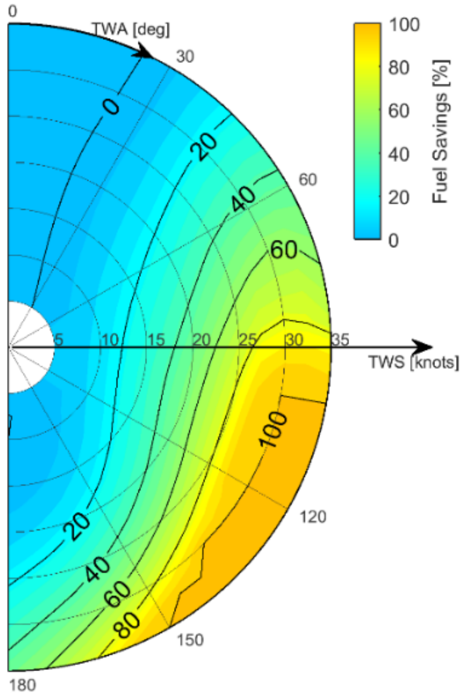
- Polar diagrams show the percentage fuel savings of the ship with rotors compared to the same vessel, operating in the same conditions, but without wind assistance
- FR with flap gives higher fuel savings particularly for $TWA < 90°$
- Ship is able to operate at smaller wind angles

Results for two Flettner rotors "Line": Vs=11 kts

Standard Flettner rotor



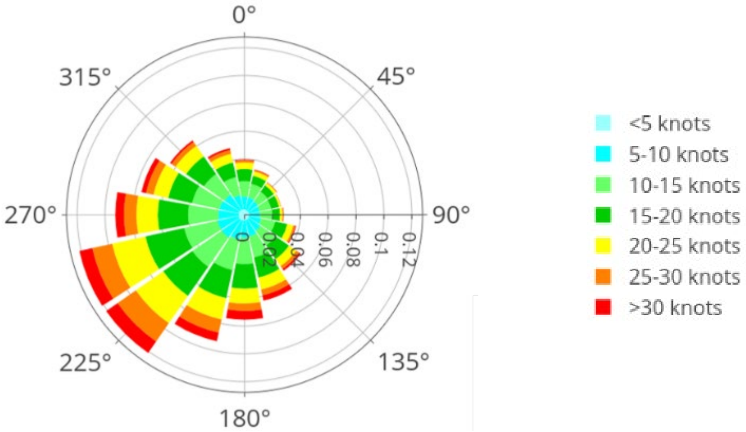
Flettner rotor + flap



Evaluation on shipping route

- Wind conditions of the North Sea region
- Fuel consumption polar diagrams are multiplied with the wind scatter diagrams for an S-N and N-S route

Wind rose: Rotterdam – Trondheim route



Percentage fuel savings at a ship speed of 11 knots

Route	Two FR without flap	Two FR with flap	Increase
North Sea S-N	15.3%	18.1%	**18.3%**
North Sea N-S	11.4%	15.1%	**32.5%**

Conclusions

Aerodynamic characteristics

- Adding a flap to a FR can increase the lift-to-drag ratio up to a factor of 2

Performance improvements on a ship

- The higher lift-to-drag ratio of the FR with flap assures that it can attain a larger aerodynamic thrust than a Standard FR for upwind sailing conditions
- The improved lift-to-drag ratio of the FR with flap results in a smaller tacking angle which increases the operational profile

Fuel savings

- For the reference ship operating on the North Sea a performance increase of up to 32.5% is reported due to the additional flap on the Flettner Rotors

Contact Us

+39 3486725357

www.bluewaspmarine.com

info@bluewaspmarine.com

Westerstraat 10, UNIT A4147
3016 DH Rotterdam,
The Netherlands

Blue WASP
Wind Assist Specialists

@bluewaspmarine

@ blue_wasp_marine