



**Tanque de
Provas Numérico**
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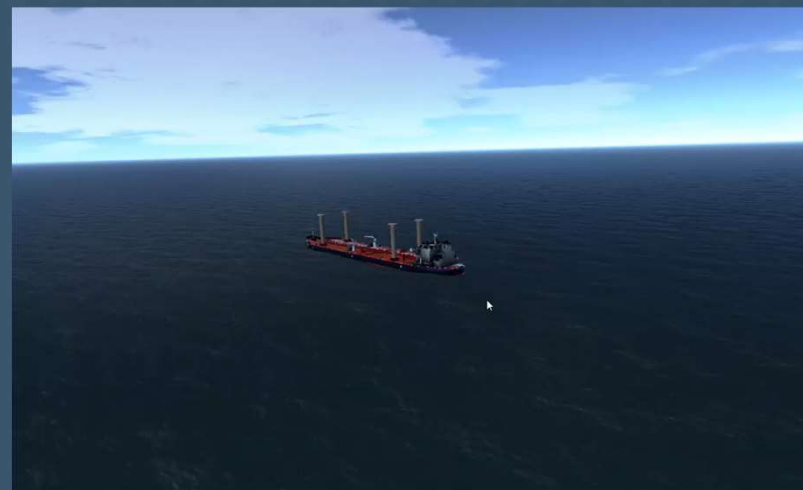
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PETROBRAS

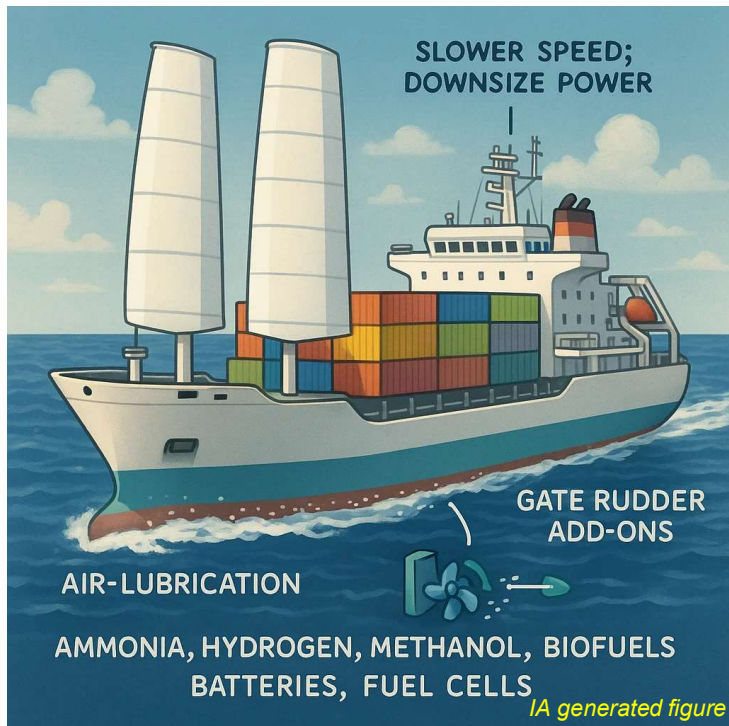


EVALUATING THE IMPACT OF WIND- ASSISTED SHIP PROPULSION ON THE MANEUVERABILITY OF A SUEZMAX TANKER

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Introduction



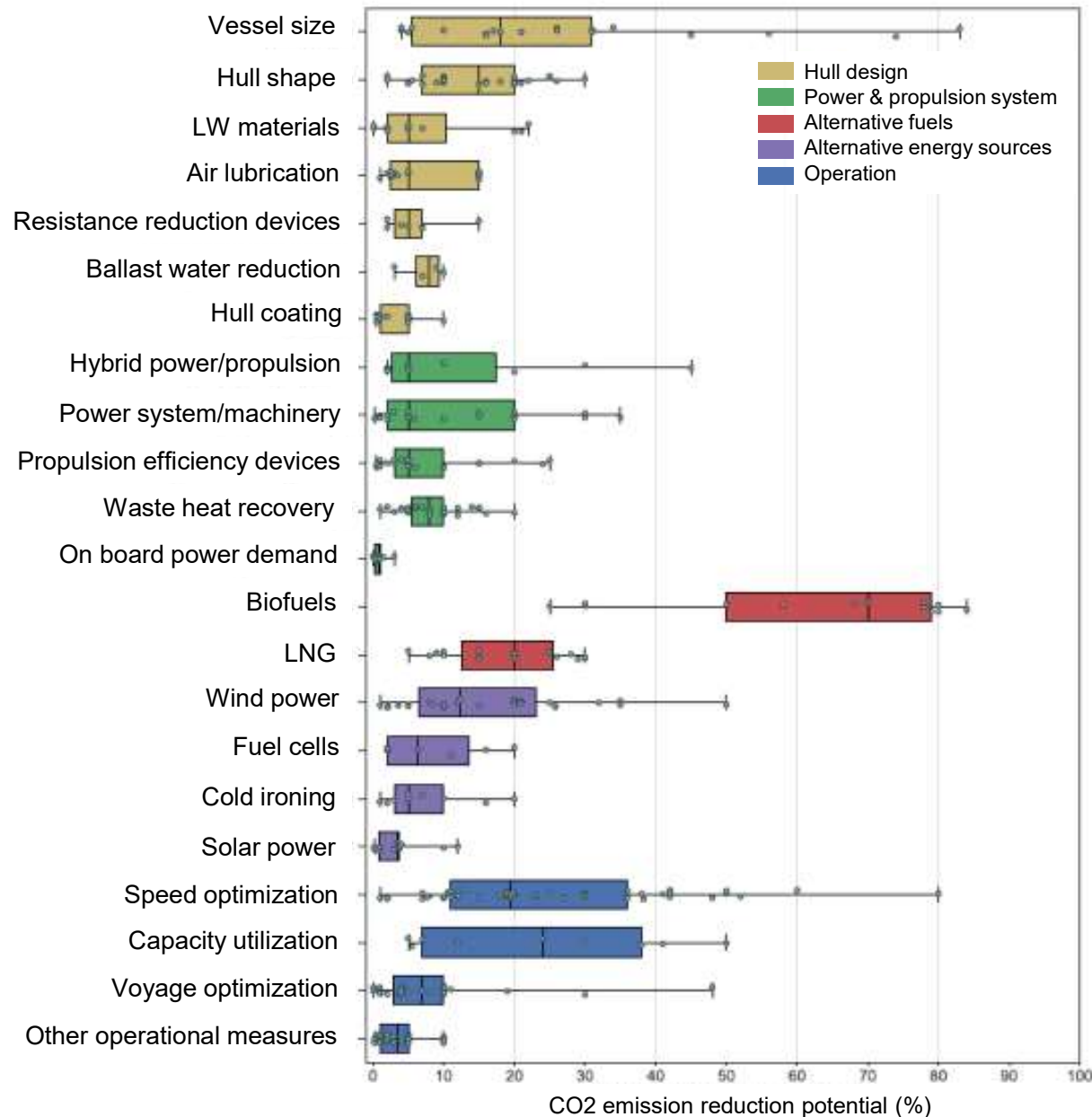
Growing concern over fossil-fuel emissions is pushing clean-energy R&D. Although very **efficient**, shipping is a big CO₂ source, and the IMO wants net-zero ships by 2050.

IMO decarbonization toolkit

- **Operations**: sail slower; downsize installed power.
- **Hydro/Aero**: air-lubrication and **wind-assist** systems.
- **Propulsion**: gate rudders and other drag-cutting add-ons.
- **Energy**: shift to ammonia, hydrogen, methanol, biofuels—plus batteries and fuel cells.

Introduction

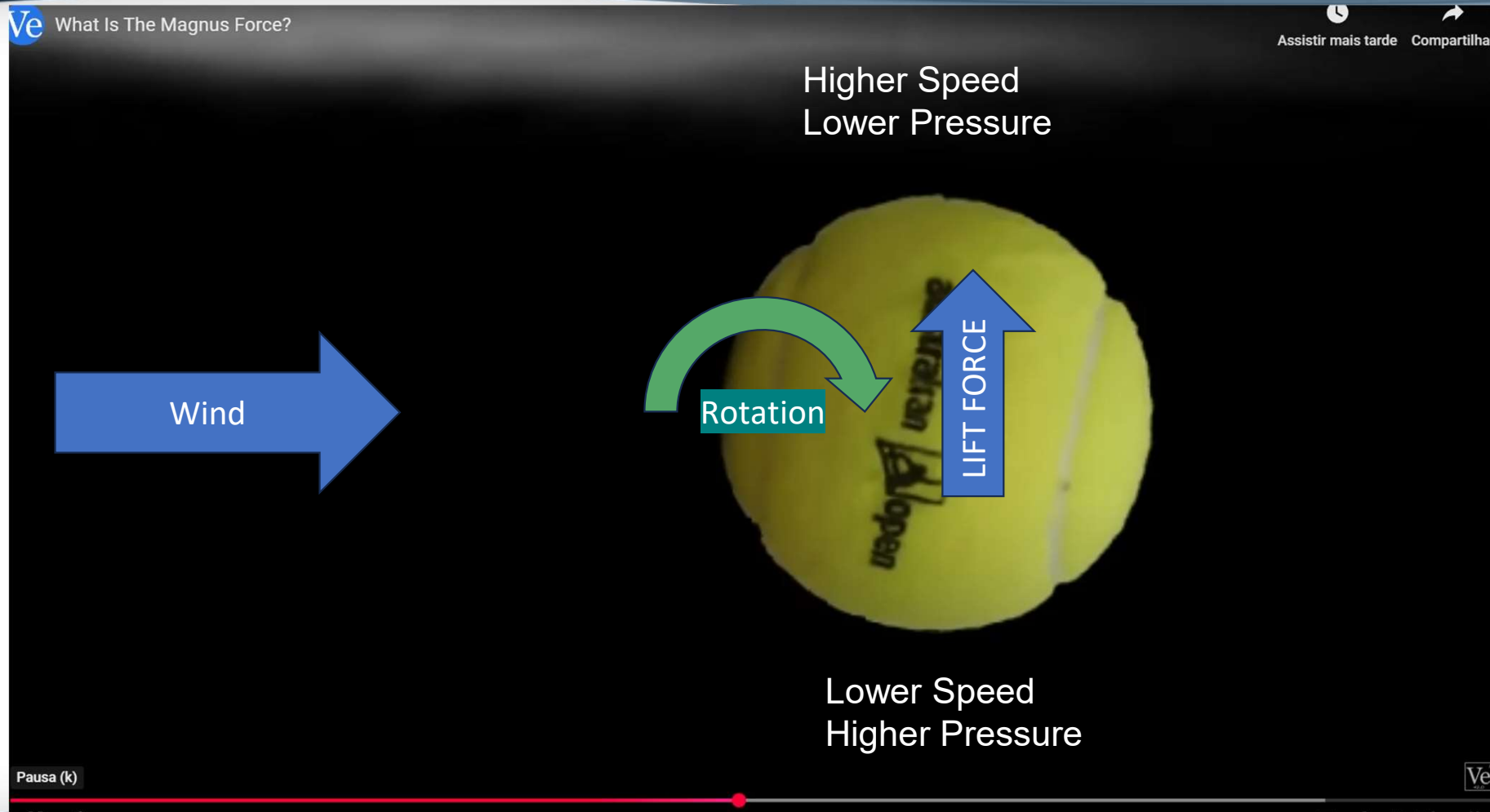
- WASP – Wind-Assisted Ship Propulsion;
- Wind power CO2 emission reduction potential of up to 24%;
- Objective of this paper: Evaluate the impact on a ship's maneuverability;
- CFD + Ship Maneuvering Simulation



Rotor sails

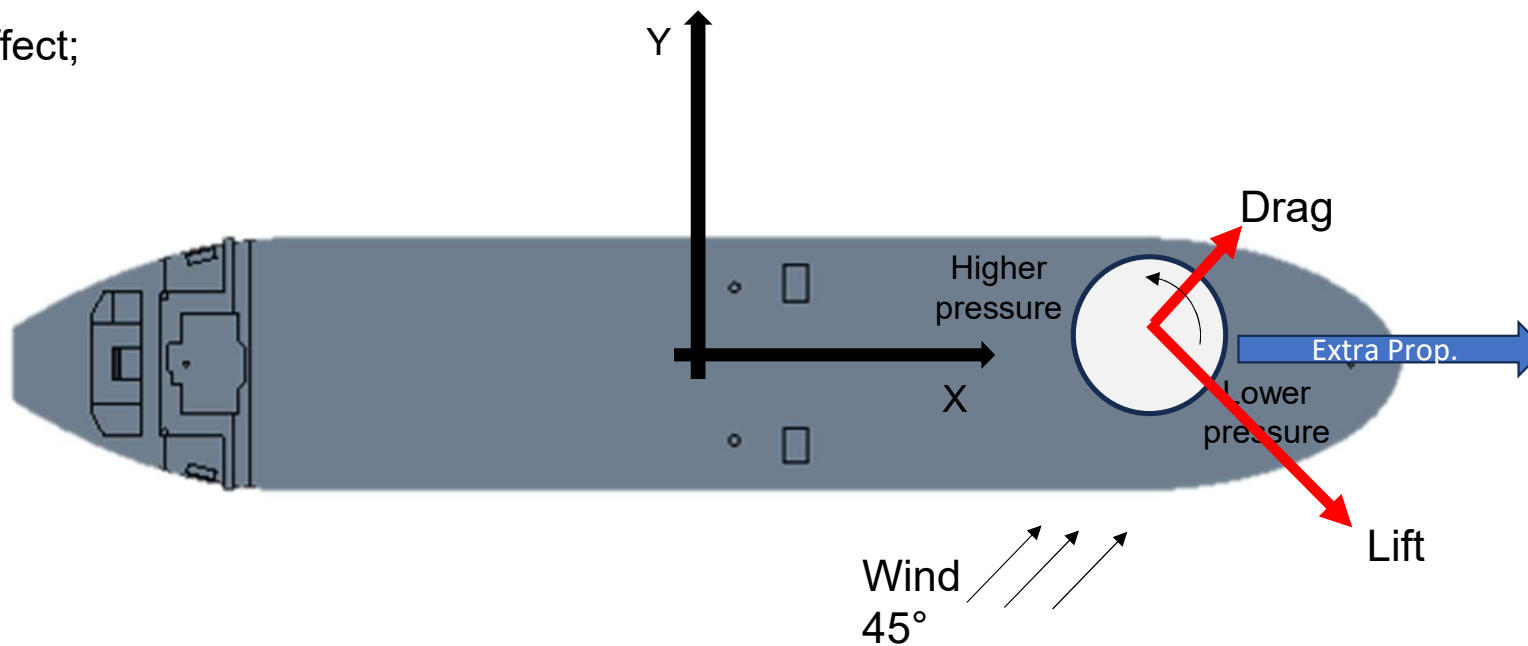


Rotor sails



Rotor sails

- Drag and lift forces;
- Magnus effect;

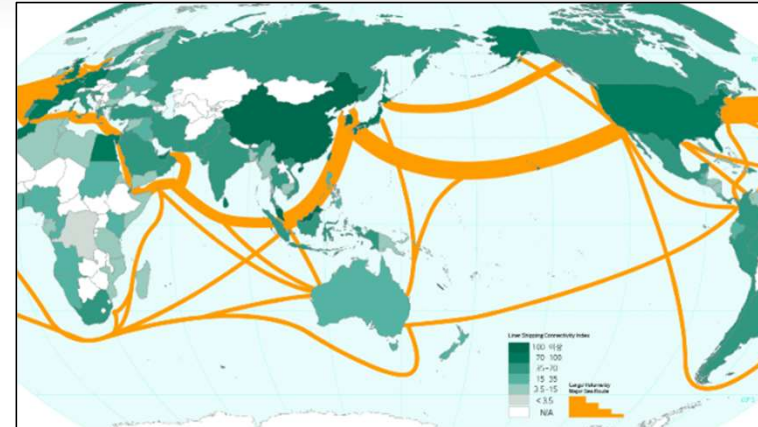


Source: Kwon et al. (2022)

Rotor sails

Fuel savings from rotor sails depend on factors like:

- Ship type and condition;
- Speed;
- Route;
- Wind conditions;
- Number and arrangement of sails.



Average fuel savings measured on ships using rotor sails. Source: EMSA(2023)

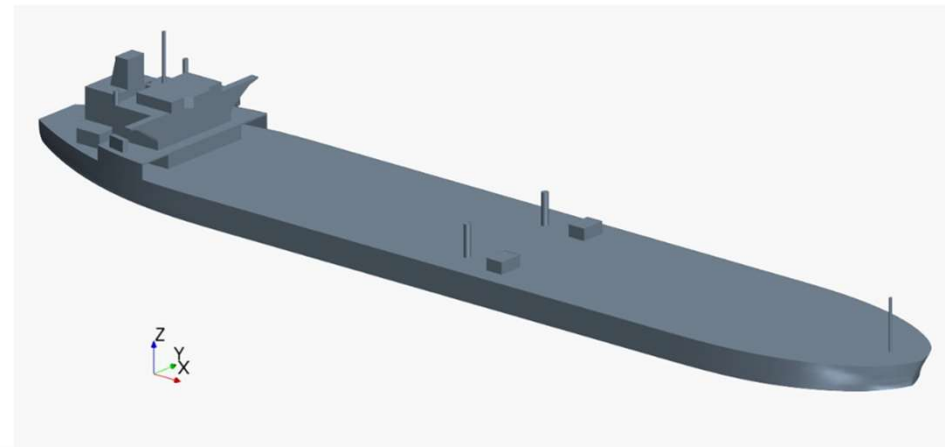
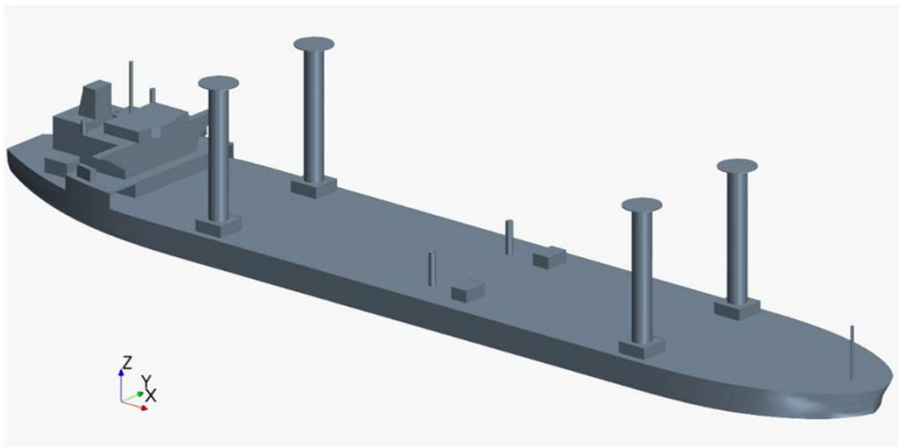
Ship Name	Ship Type	Nº of Rotors	Rotor Height [m]	Rotor Diameter [m]	Average Fuel Savings
M/V Annika Braren	General Cargo	1	18.0	3.0	2.0% - 4.5%
M/V Estraden	Ro-Ro	2	18.0	3.0	6.1%
M/V Copenhagen	Hybrid Ferry	1	30.0	5.0	4.0%
M/T Maersk Pelican	Tanker	2	30.0	5.0	8.2%
M/V SC Connector	Ro-Ro	2	35.0	5.0	20.0% - 25.0%
M/V Afros	Bulk Carrier	4	16.0	2.0	12.5%
M/T Sea Zhoushan	VLOC	5	24.0	4.0	8.0%

Method

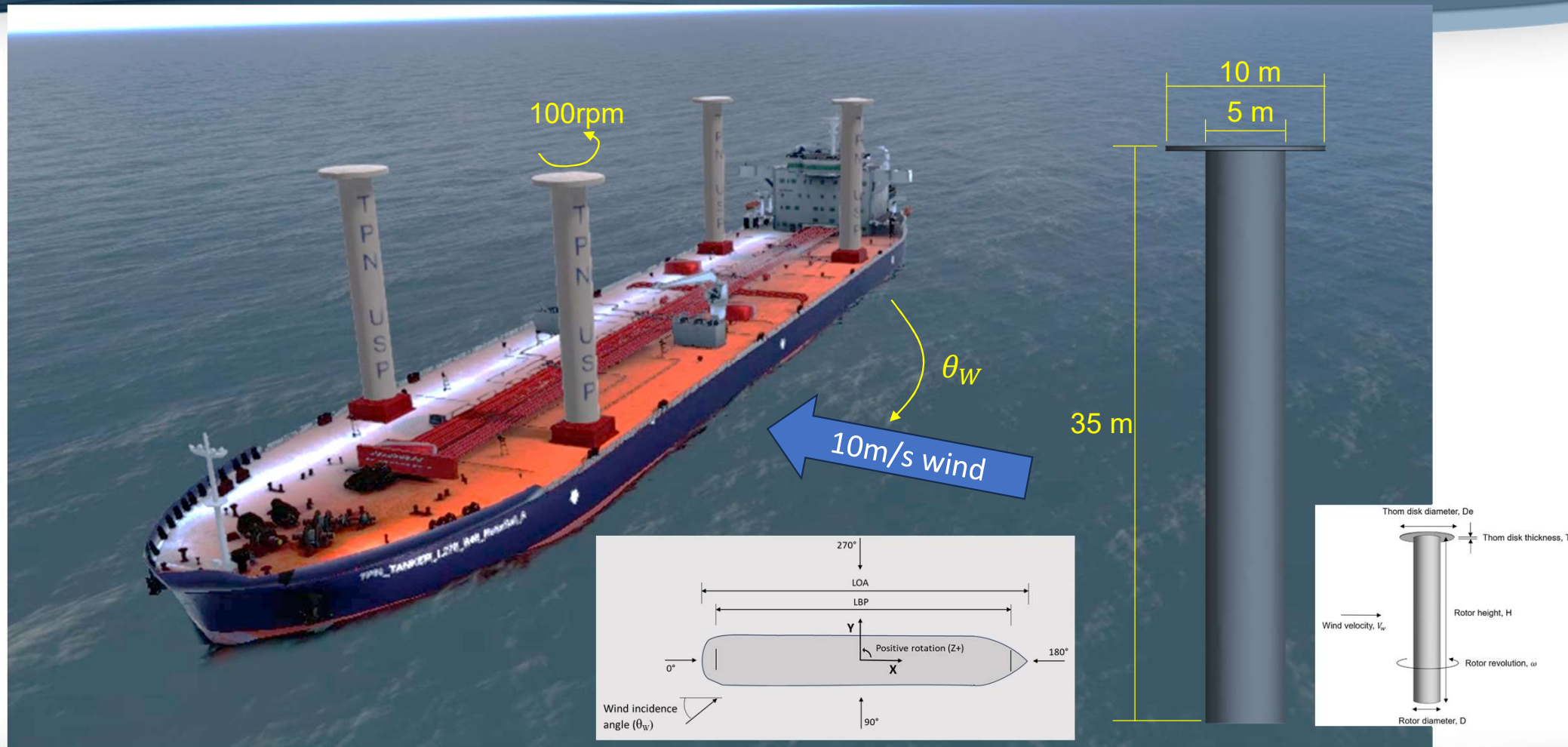
- Suezmax tanker
- Four rotor sails arranged symmetrically;
- Smaller geometry parts are not considered

Main characteristics of the Suezmax tanker used in this study.

	Unit	Value
Lenght Between Perpendiculars (L_{BP})	[m]	264.0
Lenght Overall (L_{OA})	[m]	275.0
Breadth (B)	[m]	48.0
Draft (T)	[m]	16.0
Depth (D)	[m]	21.0
Displacement (∇)	[t]	166229
Deadweight (DWT)	[t]	157700

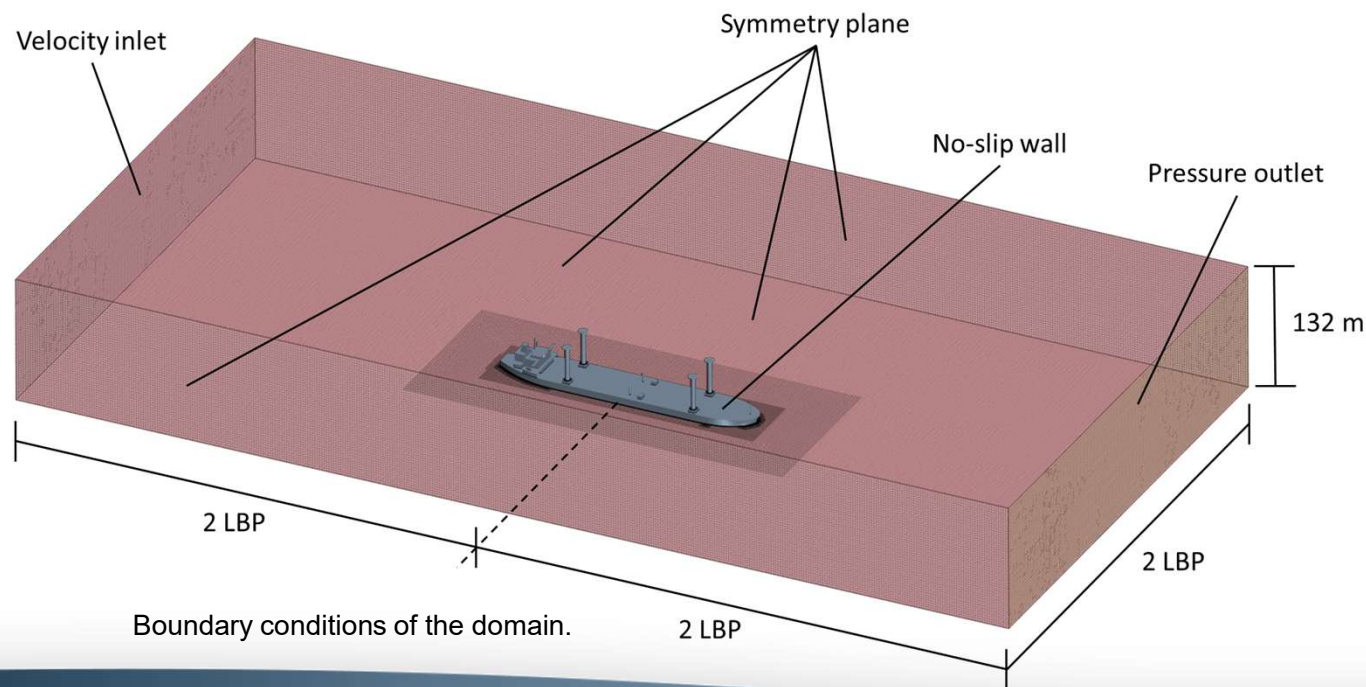


Dimensions



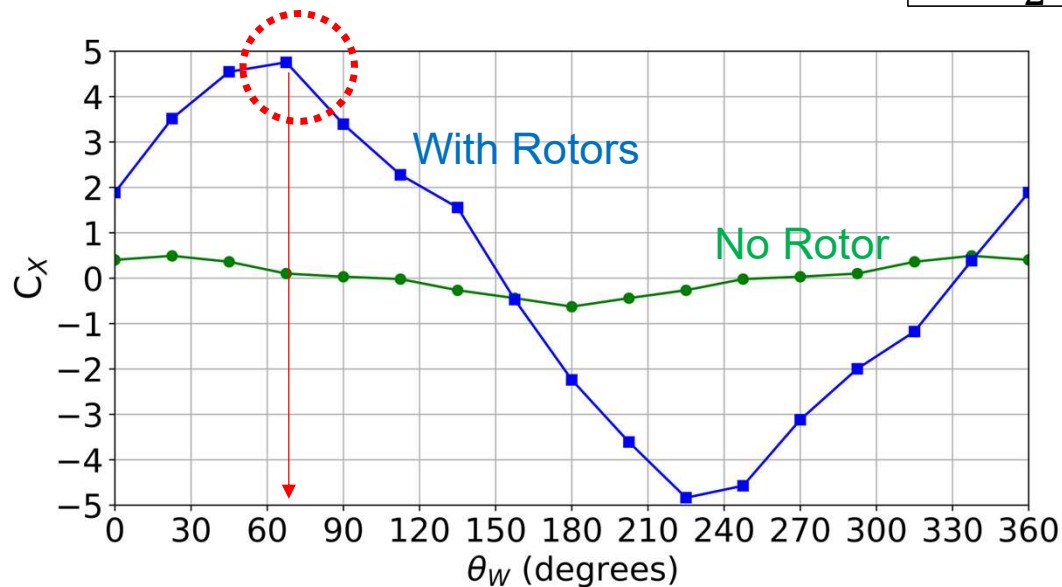
Method

- CFD, finite volume method using the software Star-CCM+;
- Inlet wind is set as uniform;
- To implement the sails rotation, the overset method is applied, using linear interpolation;
- $k-\omega$ SST turbulence model and URANS model with a time step of 0.01 s.

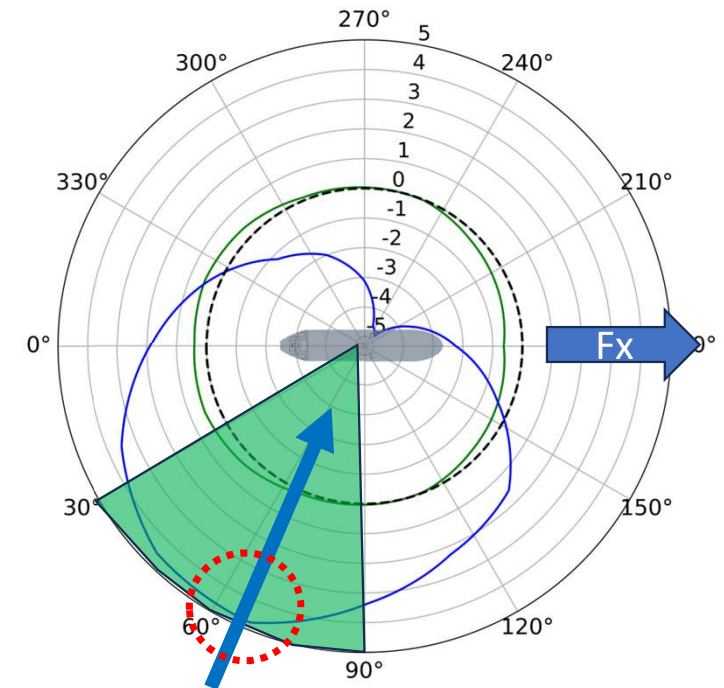


Results – Ahead Force

$$C_X = \frac{F_X}{\frac{1}{2} \rho V_W^2 A_T}$$

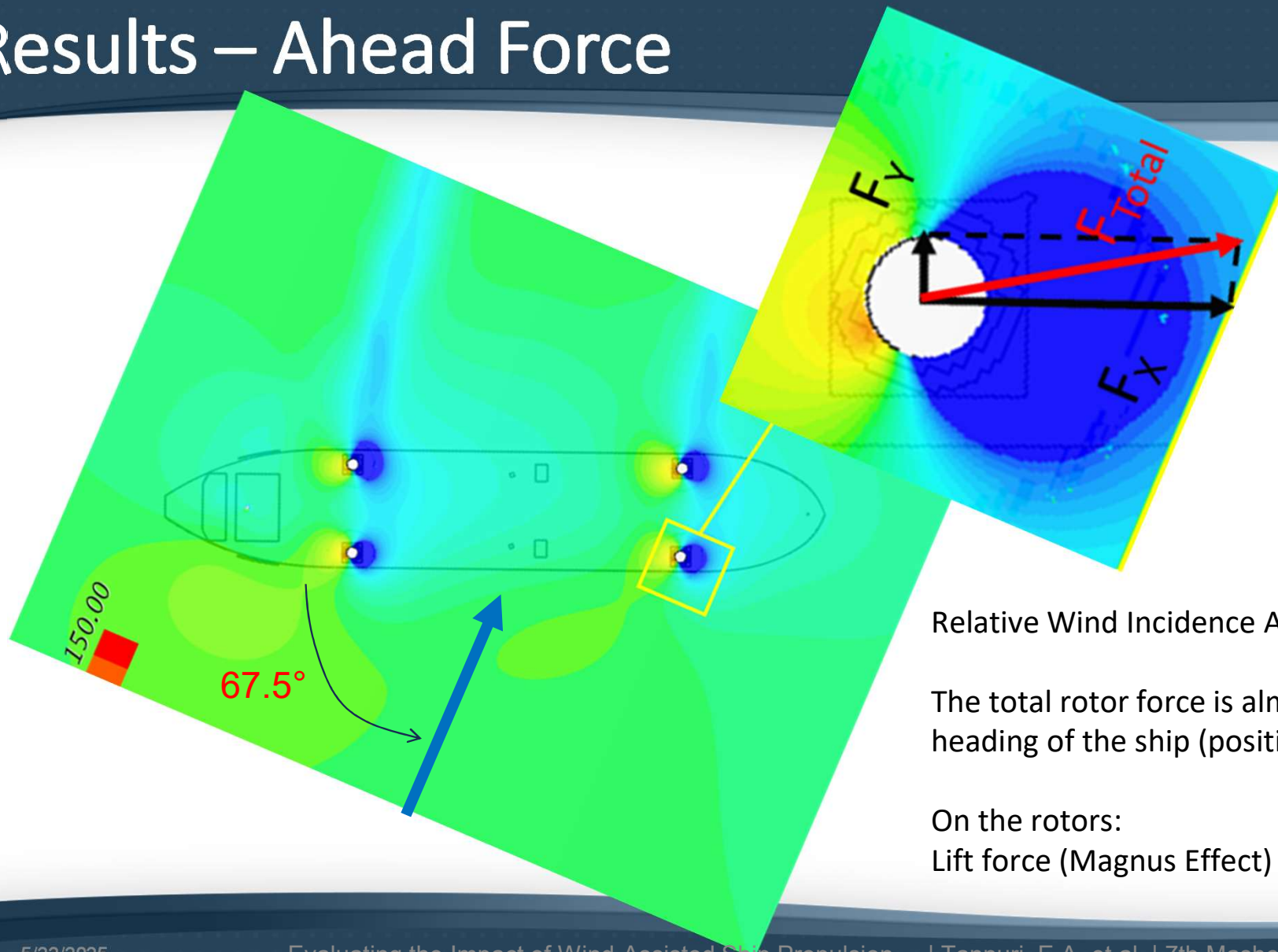


Maximum ahead thrust (X axis)
Relative Wind Direction



From 30° to 90° significant ahead wind force

Results – Ahead Force

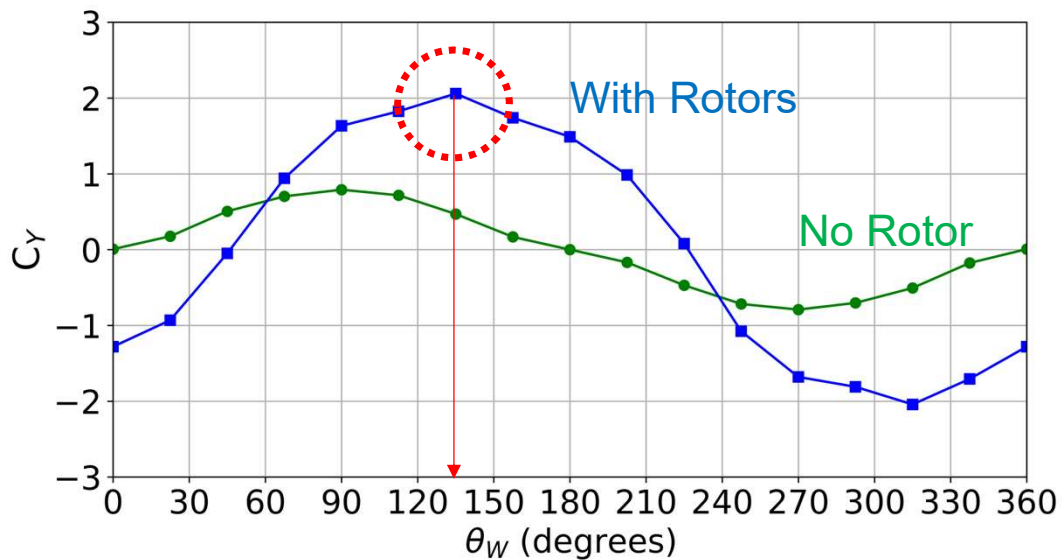


Relative Wind Incidence Angle 67.5°

The total rotor force is almost aligned with the heading of the ship (positive X axis).

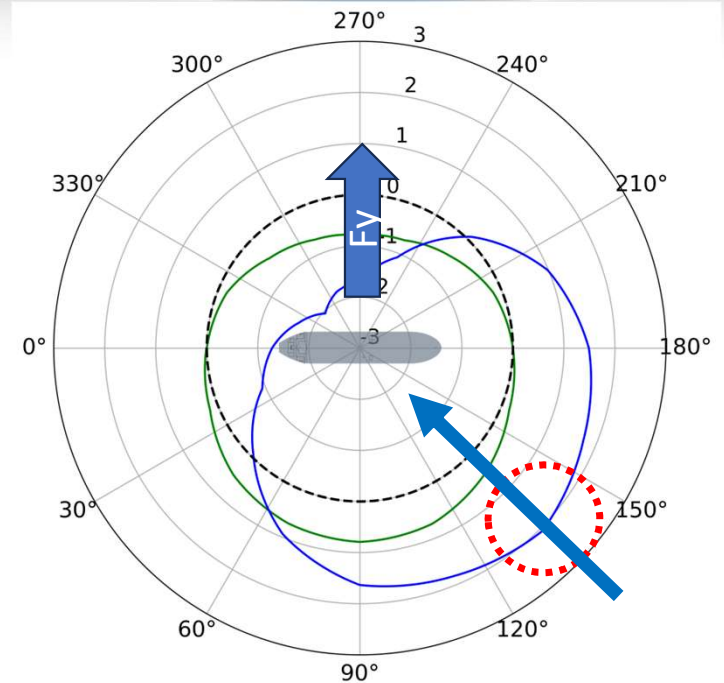
On the rotors:
Lift force (Magnus Effect) $\gg$ Drag Force

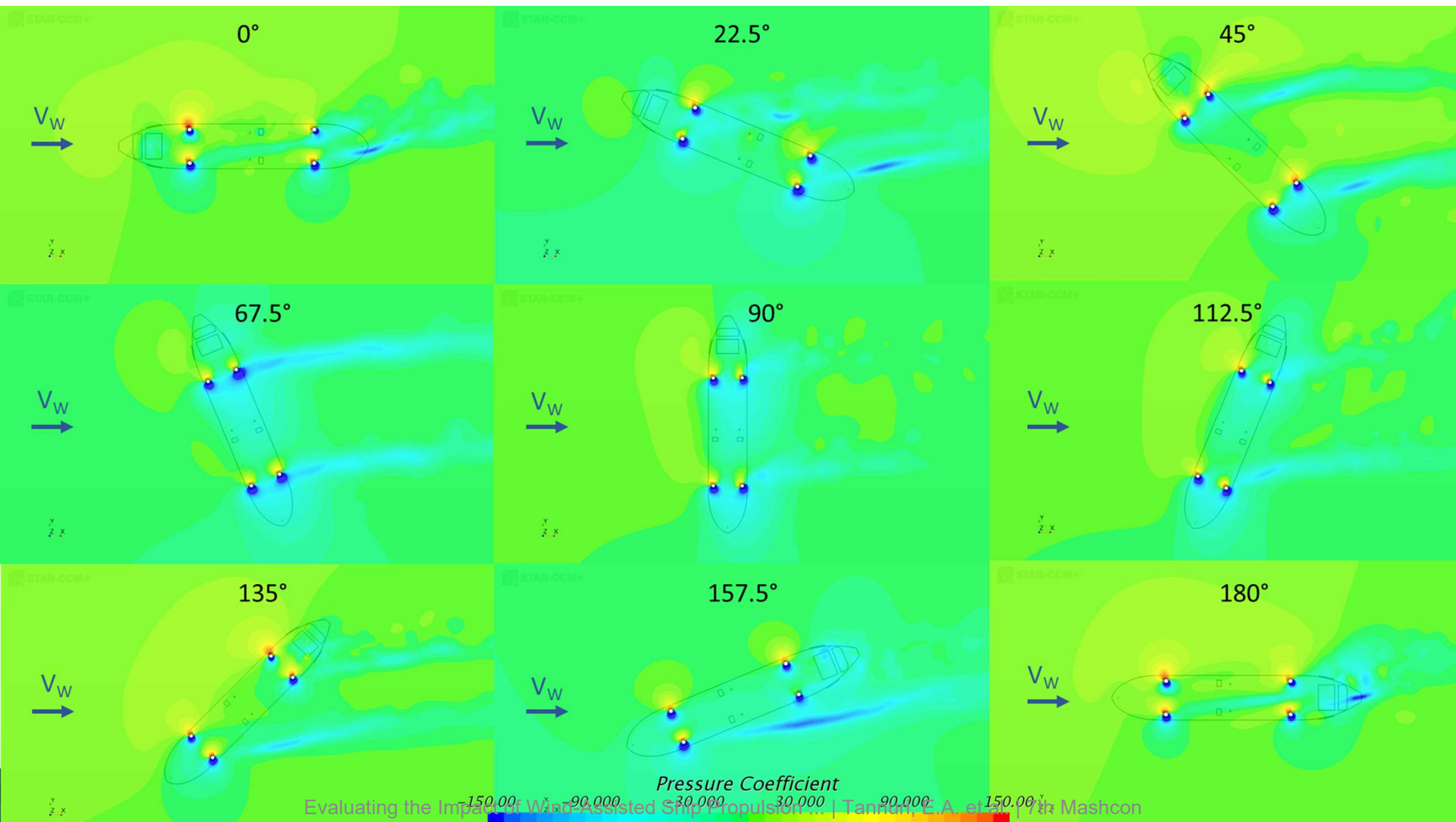
Results - Lateral Force

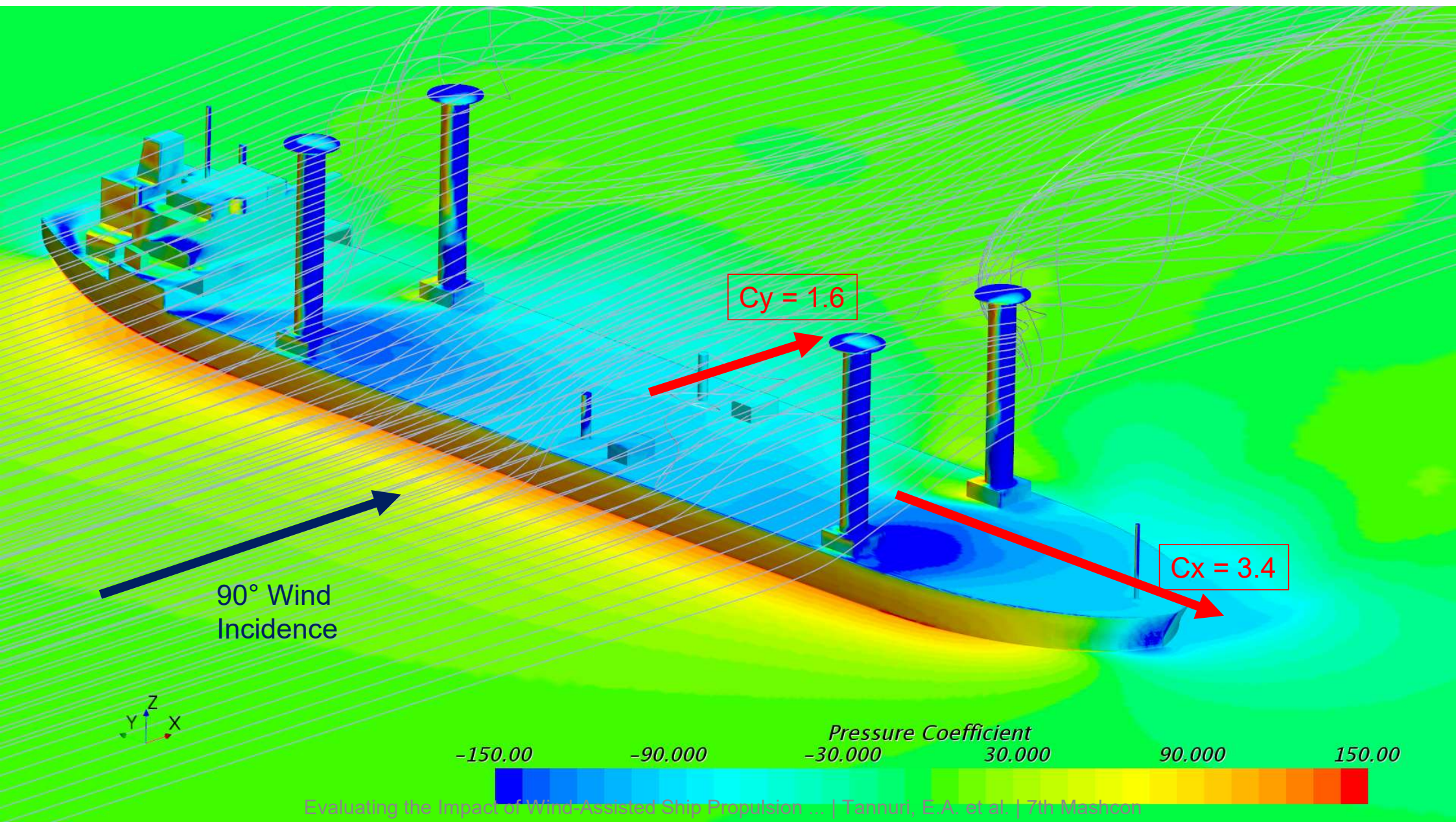


$$C_Y = \frac{F_Y}{\frac{1}{2} \rho V_W^2 A_L}$$

The peak lateral force coefficient (Y axis) is reached at 135° when rotors are present;

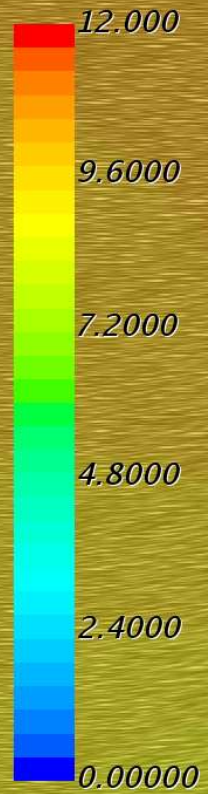






We can see the interaction between the two rotors.
This is the reason to consider non-symmetrical layouts

Velocity (m/s)



V_w
→
→
→
90° Wind Incidence



Ship maneuvering simulator



- Marine simulators:
 - Predicting the vessel's trajectory in maneuvers;
 - Training naval officers;
 - Navigability in restricted areas.
 - Port /Channel design
- Realistic graphical interface;
- Mathematical model:
 - Hydrodynamic model;
 - Aerodynamic model.

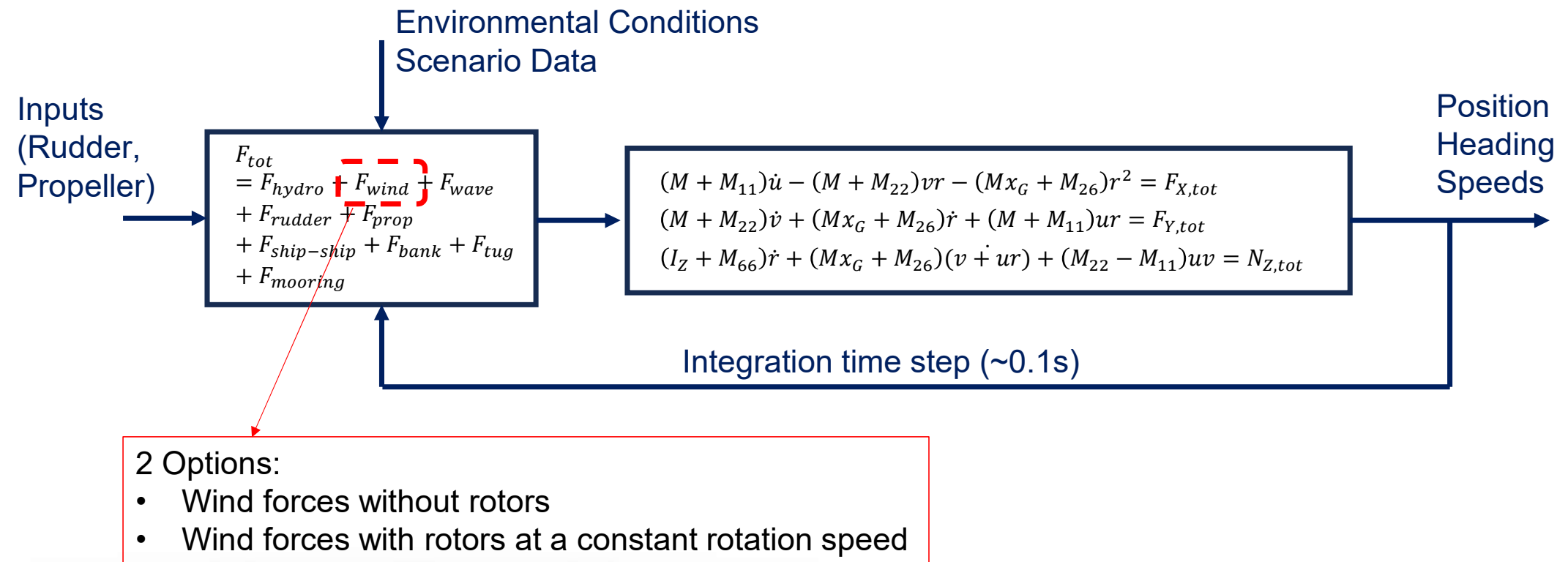
Technical cooperation:



TPN ship maneuvering simulation center.

Maneuvering Simulations

Ship Maneuvering Model (simplified 2D)



Maneuvering Simulations



Ship Maneuvering Model (simplified 2D)

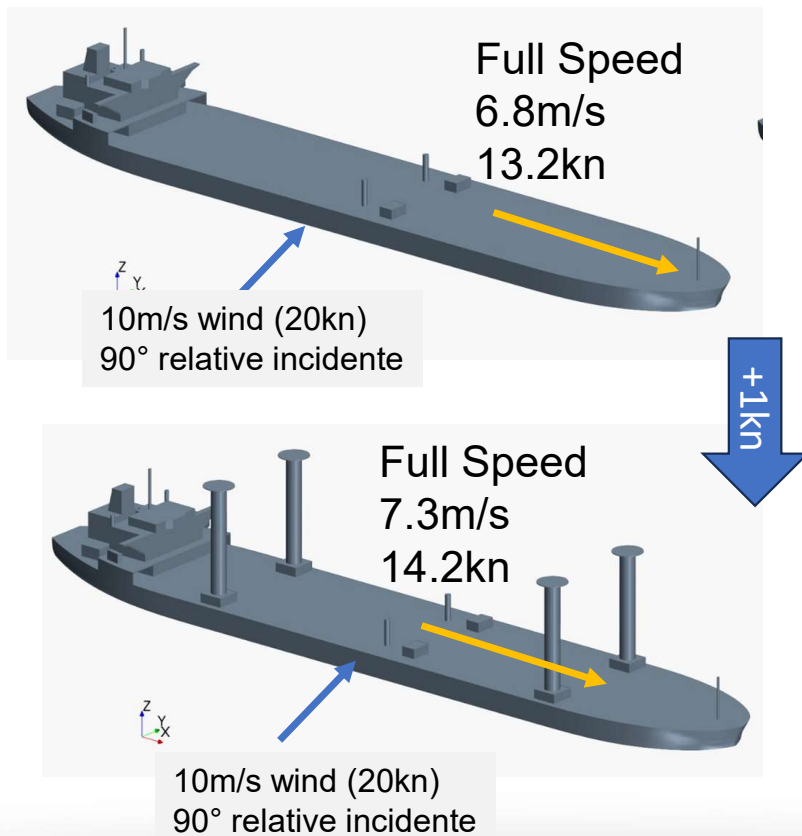
We executed standard maneuvers with the Suezmax

- Turning circle, zig-zag and crash stop tests
- With and Without Rotors
- 10m/s and 20m/s wind
- Rotors with constant RPM
- Shallow and Deep Water

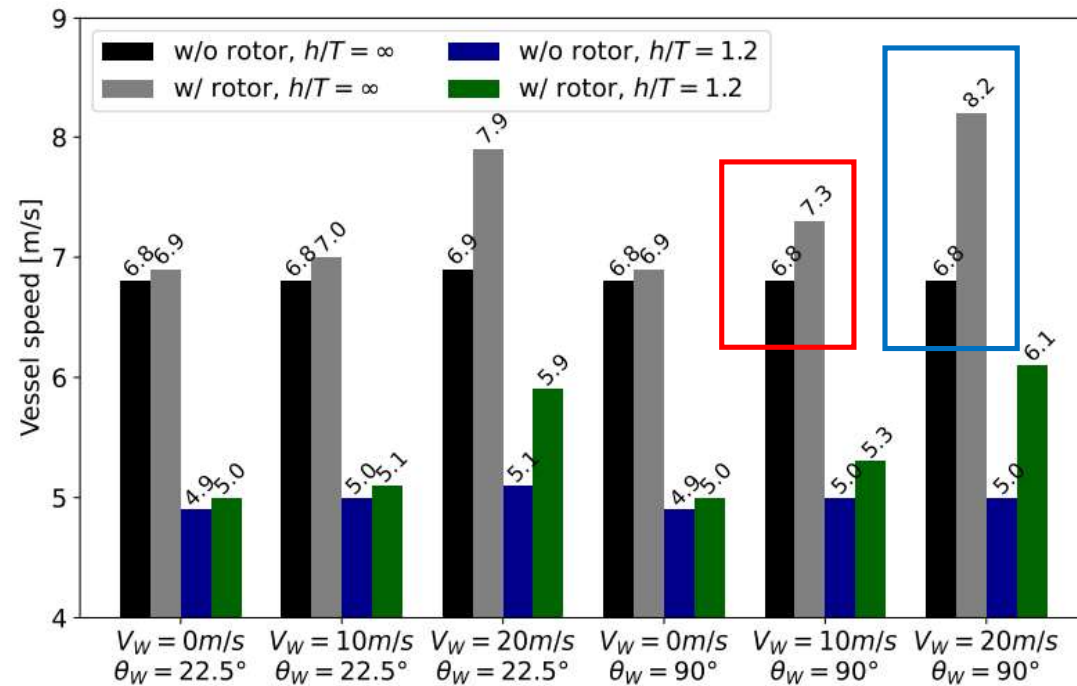


Results - straight-ahead velocity

Typical scenario → +1kn with rotor



Vessel speed under varying V_W , θ_W and h/T

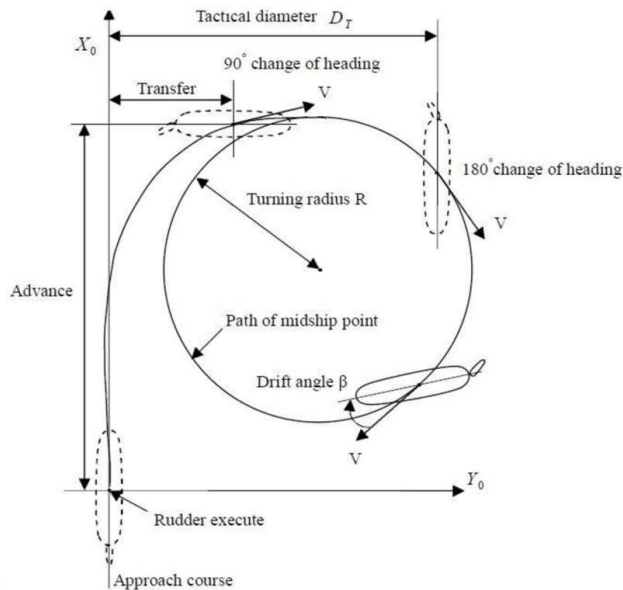


With stronger winds, rotors may increase speed up to 1,4m/s (2.7kn)

Results – turning circle

Turning-Circle Summary (First Turn)

- Metrics: Advance (AD), Tactical Diameter (TD), non-dimensional turn rate (r/c), steady-turn speed ratio (V_C / V_0), and drift angle (β_C).

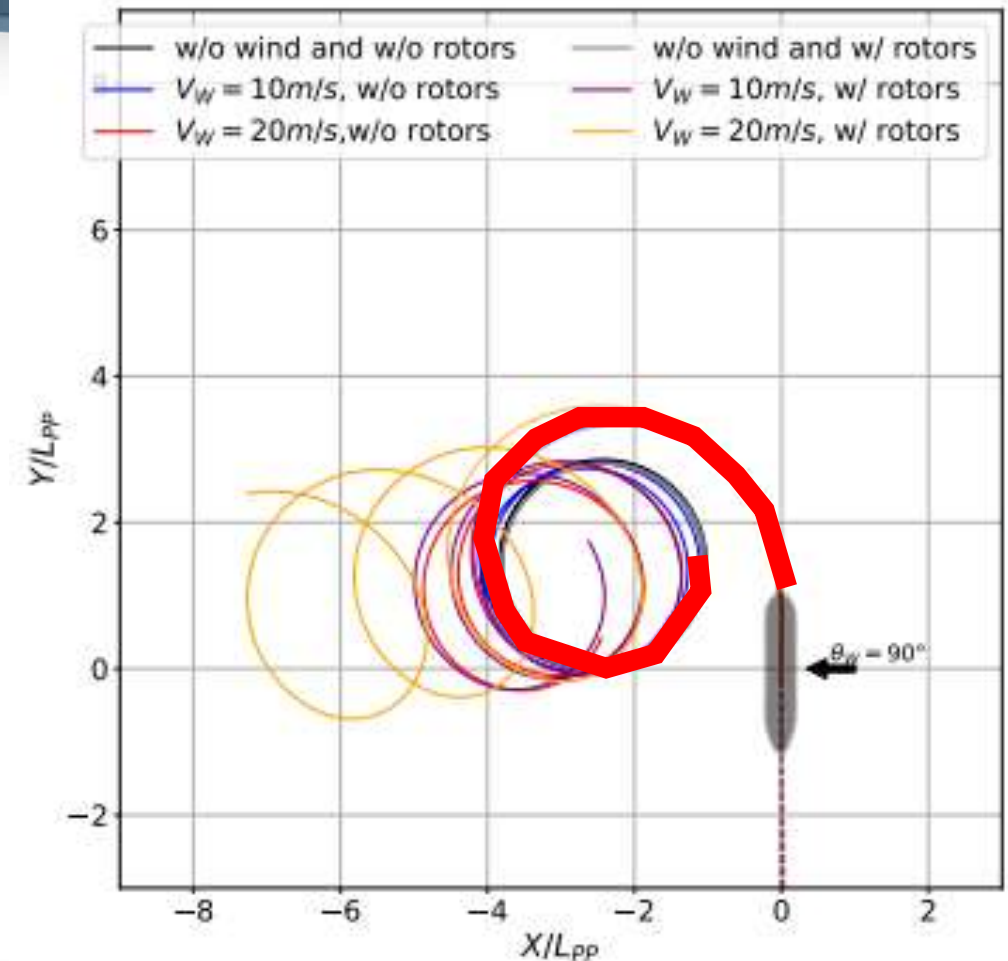


IA generated figure

Results – turning circle

Turning-Circle Summary (First Turn)

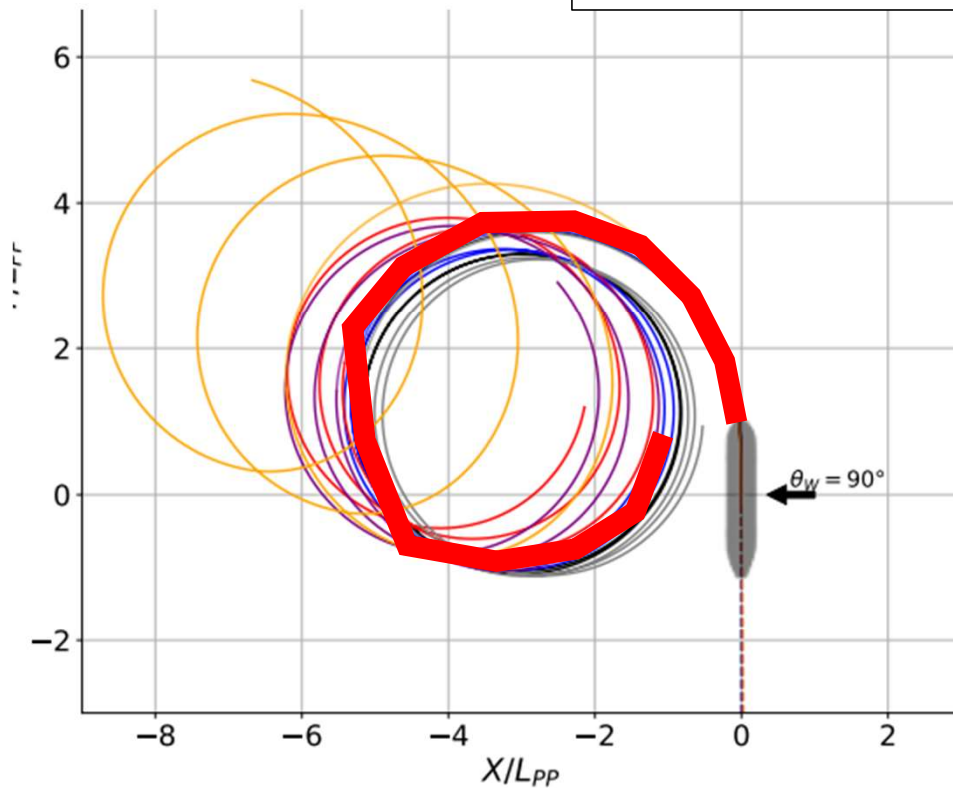
- Impact of Rotor Installation
 - At 10 m/s wind: $\approx 5\%$ average change across all metrics.
 - At 20 m/s wind: average change increases to $\approx 17\%$



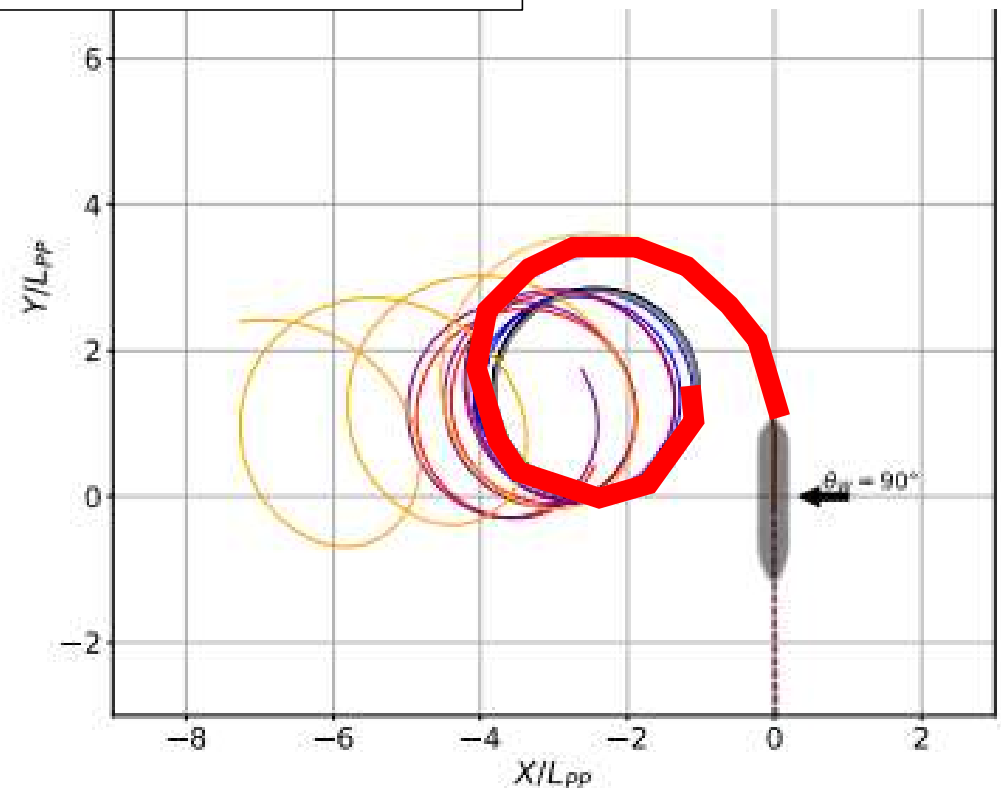
(b) Deep water and portside.

Results – turning circle

- Larger turning diameters in shallow water versus deep water



(d) Shallow water ($h/T = 1.2$) and portside.



(b) Deep water and portside.

Results – turning circle

Wind-Induced “Drift-Away” Effects

Reference pattern:

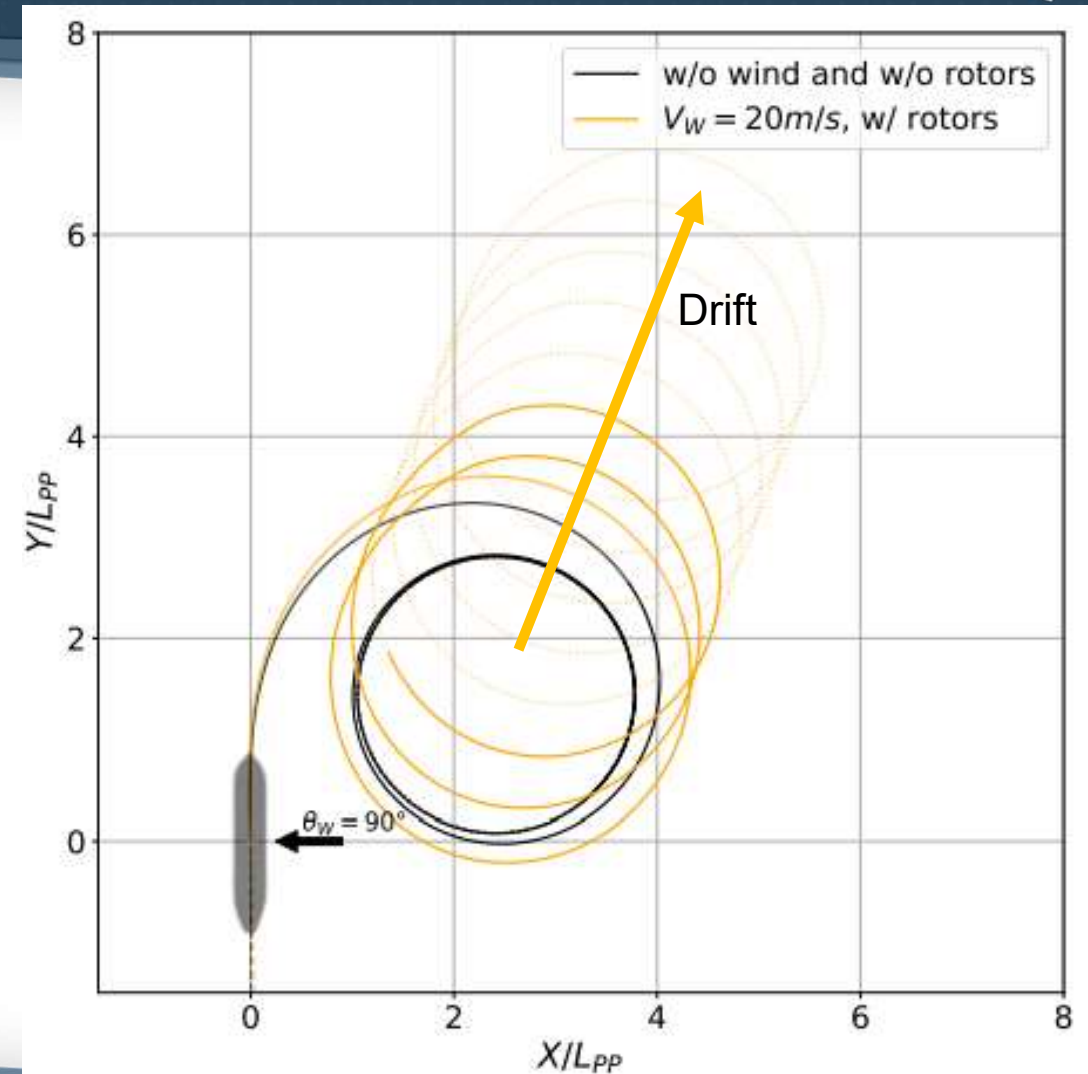
- No wind / no rotors → turns remain almost *concentric*.

With wind + rotors (20 m/s, 90°):

- Trajectory departs sharply from reference path
- Exhibits both angular displacement and lateral offset.

Quantification:

- Deviations captured by the two *drift-away characteristics* defined in Simman



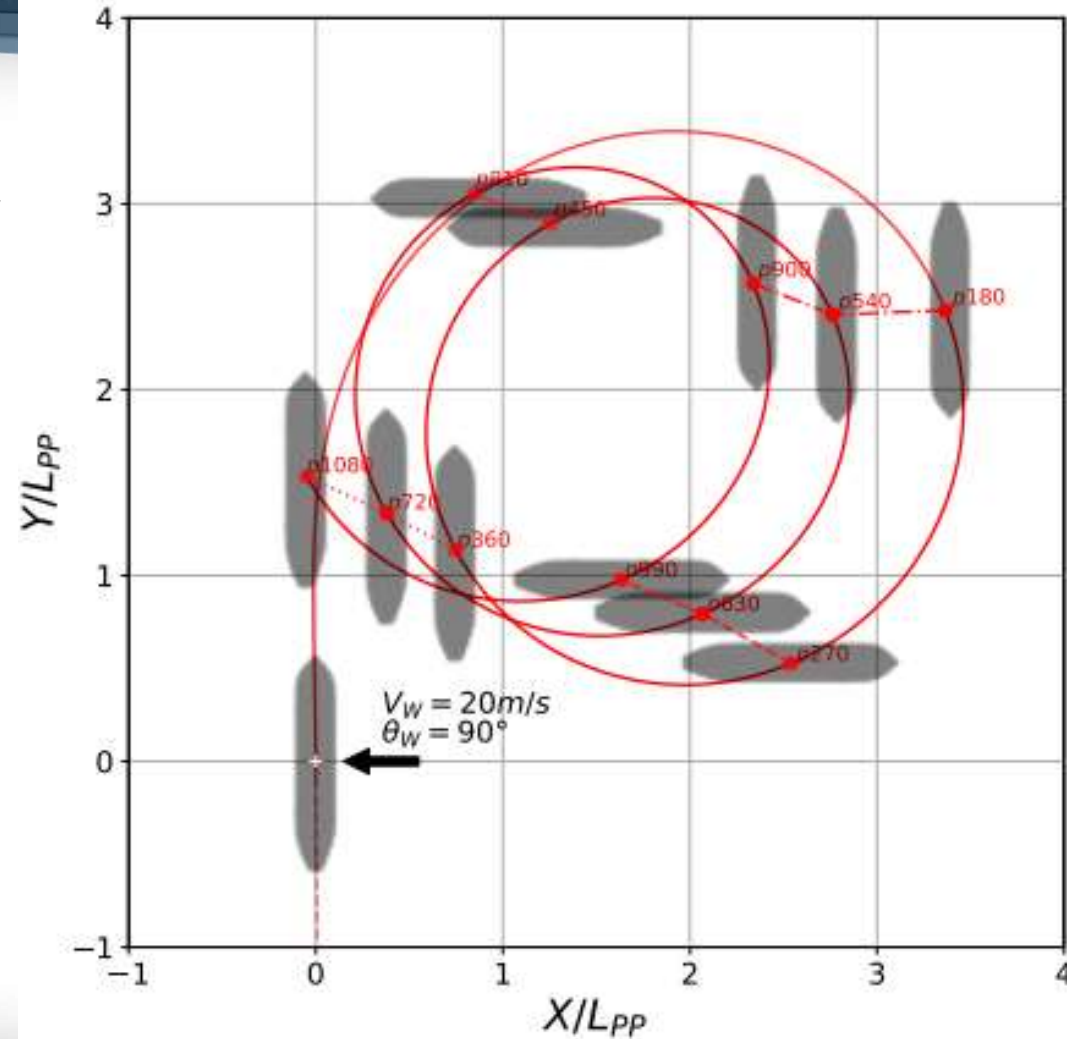
Results – turning circle

- The approach introduced in the SIMMAN conference for turning circle in waves is employed
- Eleven points used to evaluate the drift-away behavior
- Both distance and angle between these points are computed to obtain the drift distance (H_D) and drift angle (μ_D):

$$H_{D(\theta+360^\circ)-\theta} = \sqrt{(x_{\theta+360^\circ} - x_\theta)^2 + (y_{\theta+360^\circ} - y_\theta)^2}$$

$$\mu_{D(\theta+360^\circ)-\theta} = \arctan(x_{\theta+360^\circ} - x_\theta, y_{\theta+360^\circ} - y_\theta)$$

Drift-away analysis.

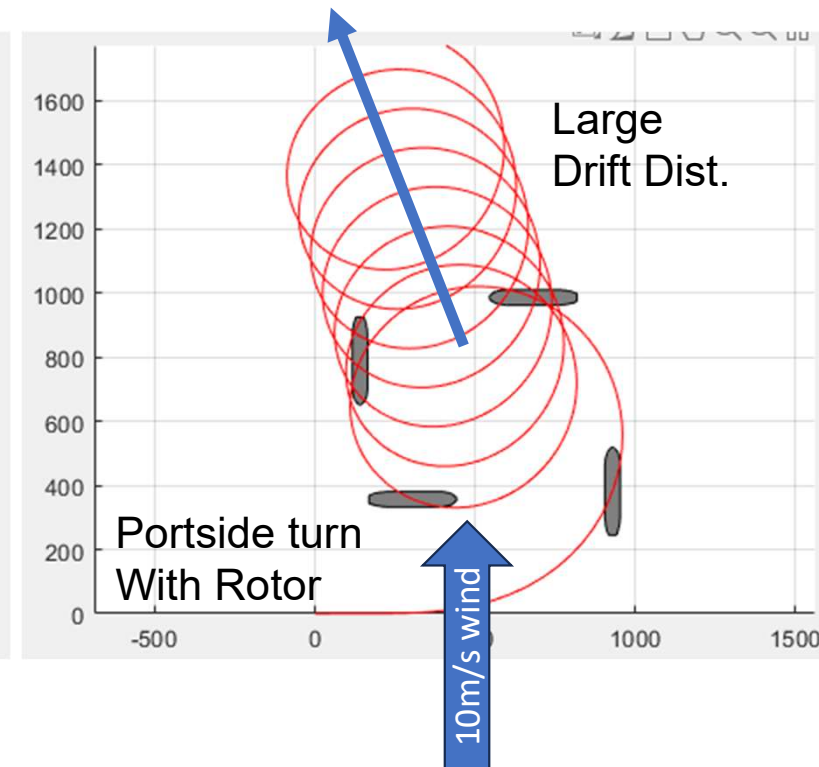
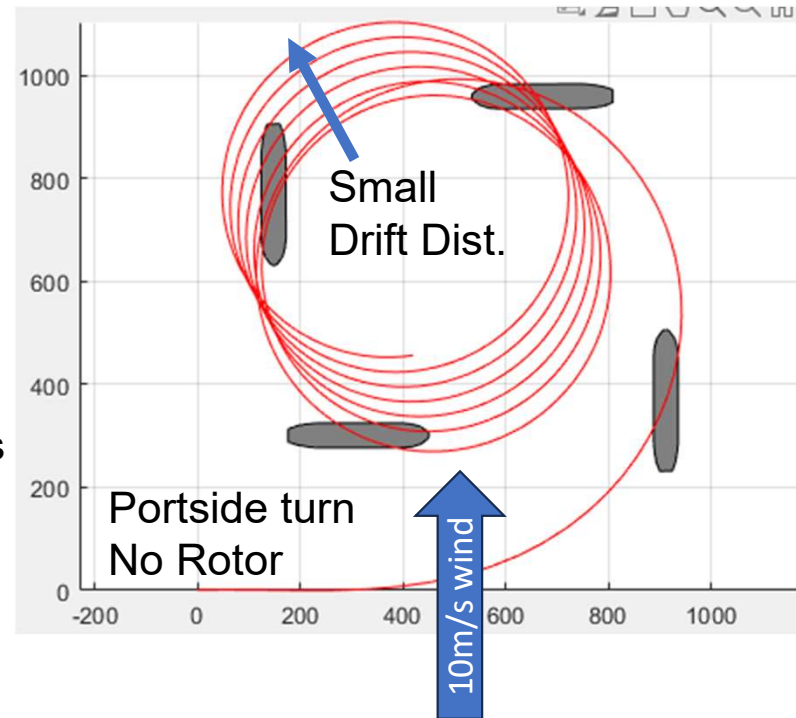


Results – turning circle

Drift-Away

Rotor-sail impact:

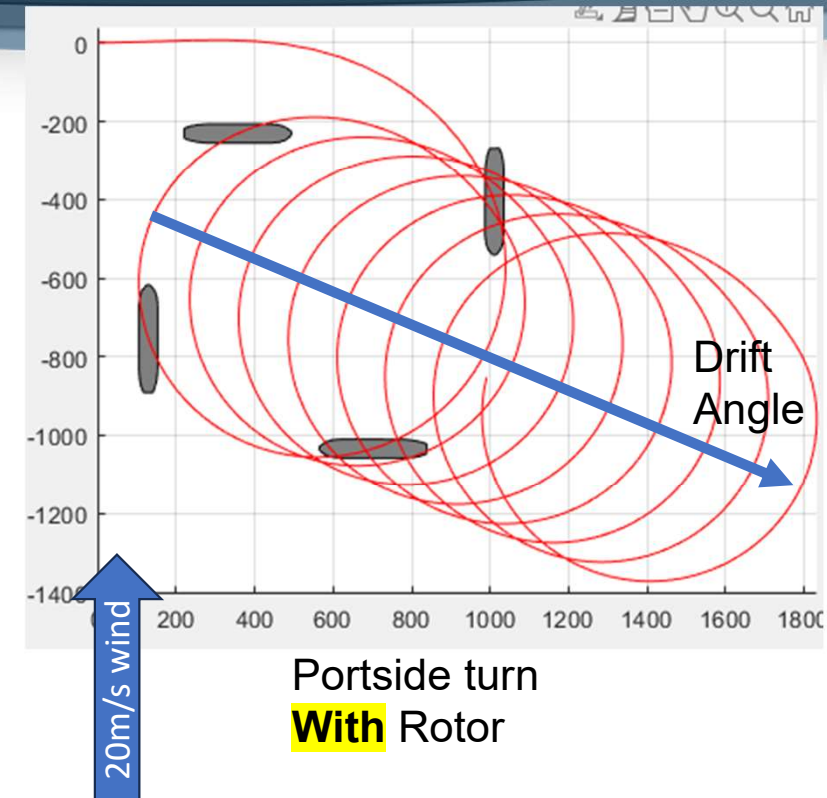
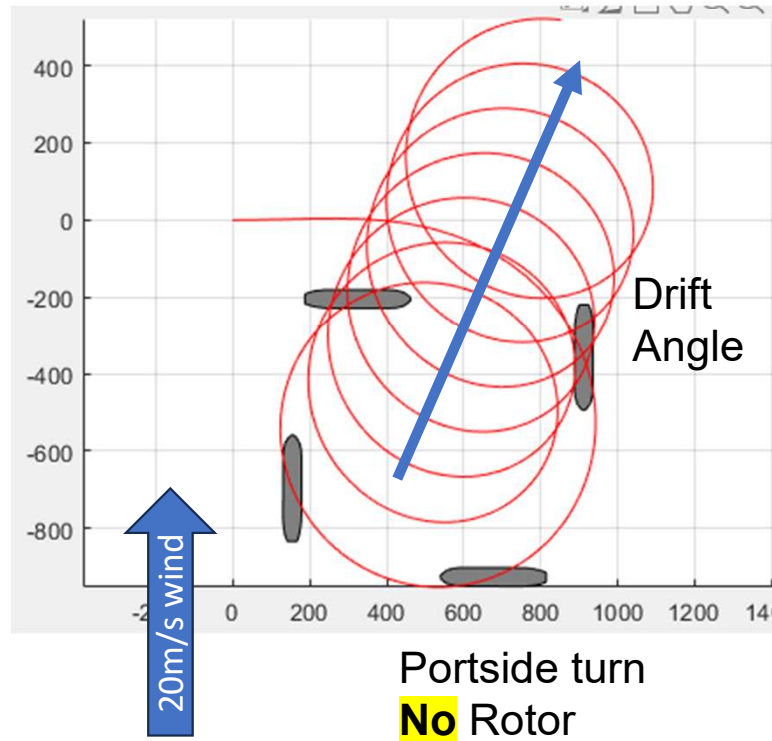
- Drift-away parameters show **much larger deviations** with rotors than without.
- **Drift Distance(HD)** increases by **> 0.87 LPP**;



Results – turning circle

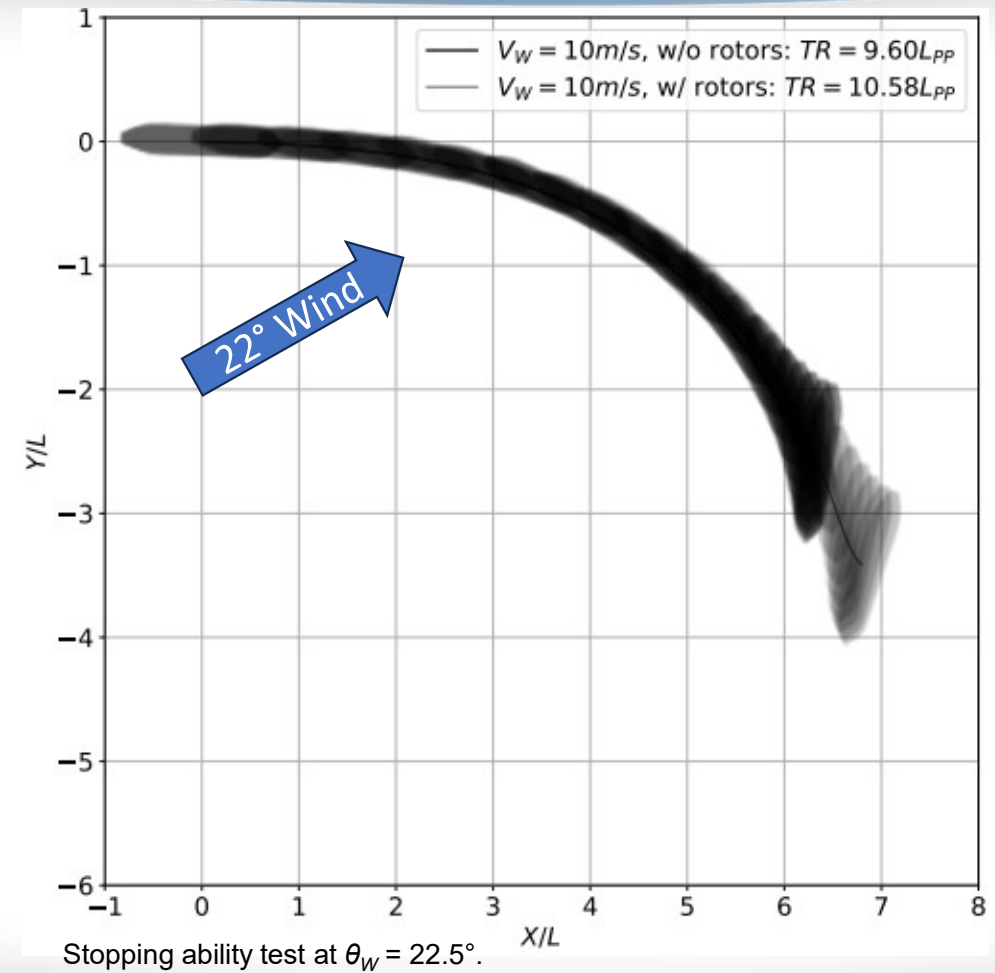
Drift-Away

drift angle (μD) may change up to 74°



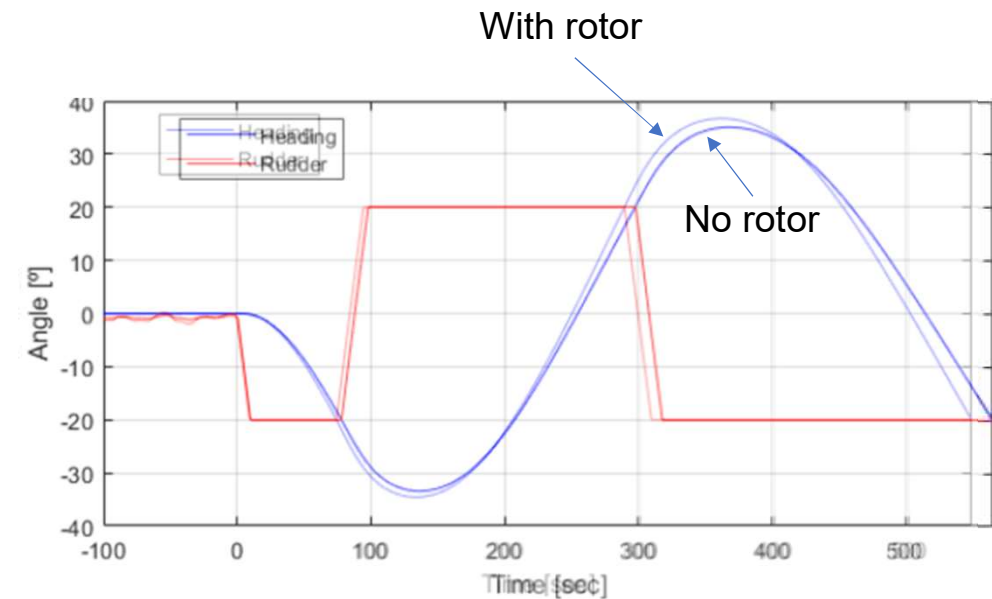
Results – Crash Stop Test

- The case **with** rotors exhibits a track reach approximately $1 L_{BP}$ longer than the **no** rotor.
- Lateral deviation and head reach are also more pronounced when rotors are present;
- Obs: initial speed is higher With Rotor



Results – 20/20 ZigZag Test

- The variations observed for 20/20 ZZ parameters were around 10%;
- The second overshoot was larger (12%) for the rotor case, meaning a less efficient yaw-checking ability.



Zig-zag test with 20° of rudder angle at $V_w = 20$ m/s and $\theta_w = 22.5^\circ$

Conclusions



CFD-Based Maneuverability Study – Suezmax Tanker with Rotor Sails

CFD setup: Calculated aerodynamic wind-force coefficients for baseline hull and rotor-sail retrofit; imported into a 6-DOF maneuvering simulator.

Benchmark maneuvers executed: turning circle, zig-zag, and crash-stop tests (IMO standards).

Turning circle impact: mean variation of $\approx 5\%$ at 10 m/s wind; $\approx 17\%$ at 20 m/s.

Drift-away analysis (SIMMAN-style): rotors raise drift distance **HD** $\rightarrow$ **0.87 LPP** and drift angle **μD** $\rightarrow$ **74°**; at 20 m/s.

Crash-stop: rotor sails **increases stopping track** ($<1LOA$).

Zig-zag result: **$\sim 10\%$ reduction** in yaw-checking effectiveness with rotors installed.

Future works

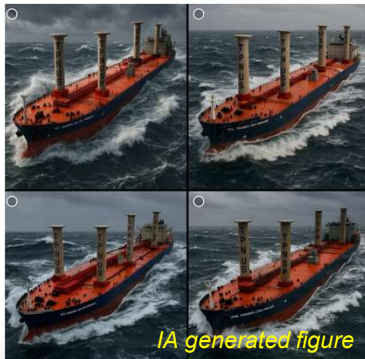


- This study provides a preliminary investigation into the influence of WASP ships on maneuverability.
- Future research will address several key areas. These include the impact of varying the following parameters:

- Rotor operation
 - Rotation speed;
 - Arrangement;
 - Size.

- Environmental conditions
 - Currents and waves.

- Vessel load
 - Ballast;
 - Partially loaded.



Acknowledgments

