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Assessment and optimization of a bulk carrier and a cruise vessel with wind propulsion

MARIN

ANEMOI

FIMC
Flikkema Innovation Management & Consultancy

core|IC

OCEANWINGS

WÄRTSILÄ

RI.SE Research Institutes of Sweden

CHANTIERS DE L'ATLANTIQUE

Università di Genova

EURONAV

Funded by the European Union

Part of content from: Flikkema, 2024, TRA

How to decarbonize shipping

- GHG development in shipping
- Low energy density of e-fuels
- WASP is partly proven, but has more potential



OPTIWISE Objectives

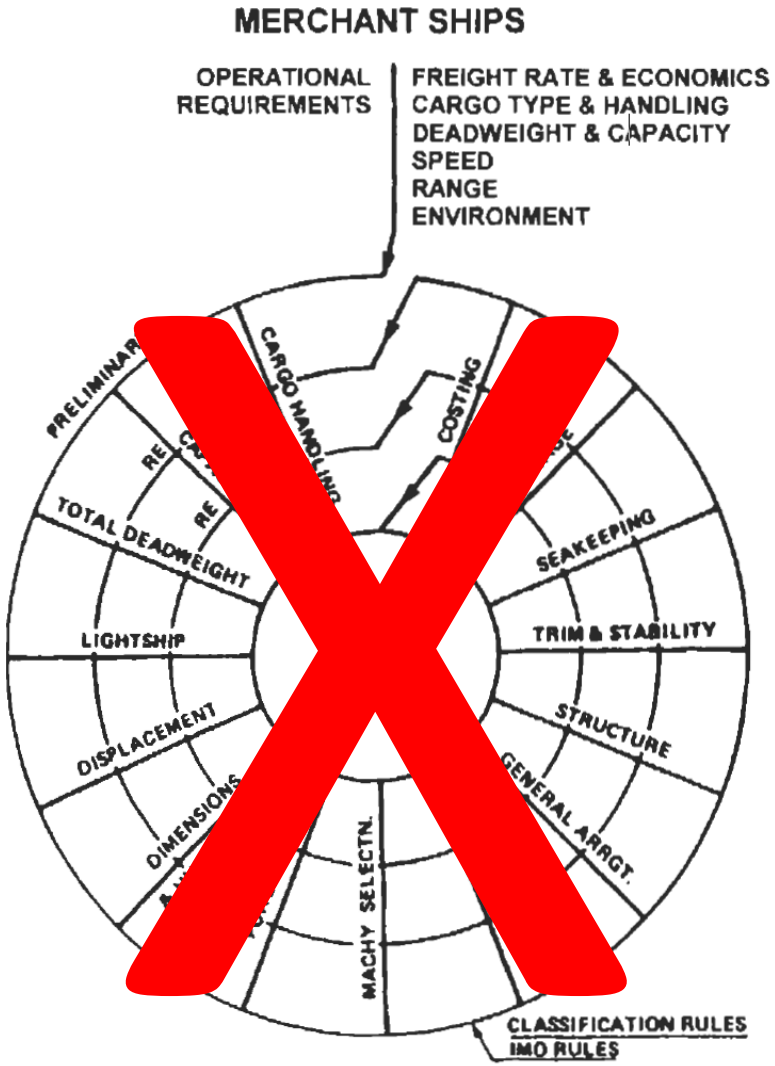
- To develop and demonstrate holistic design and control methods for new-build and retrofit ships with Wind Assisted Ship Propulsion (WASP)
- And demonstrate through 3 design cases the potential energy savings, targeting > 30% improvement

  - Mission based holistic design and assessment methods
  - Improved WASP performance
  - Explore new integrated ship concepts
  - Mission based energy management



Optimization methodology applied to ship design

- Design process



$$\begin{aligned} minimise \quad & f(\boldsymbol{x}) \\ subject\ to \quad & h(\boldsymbol{x}) = 0 \\ & g(\boldsymbol{x}) \leq 0 \end{aligned}$$

Optimization methodology applied to ship design

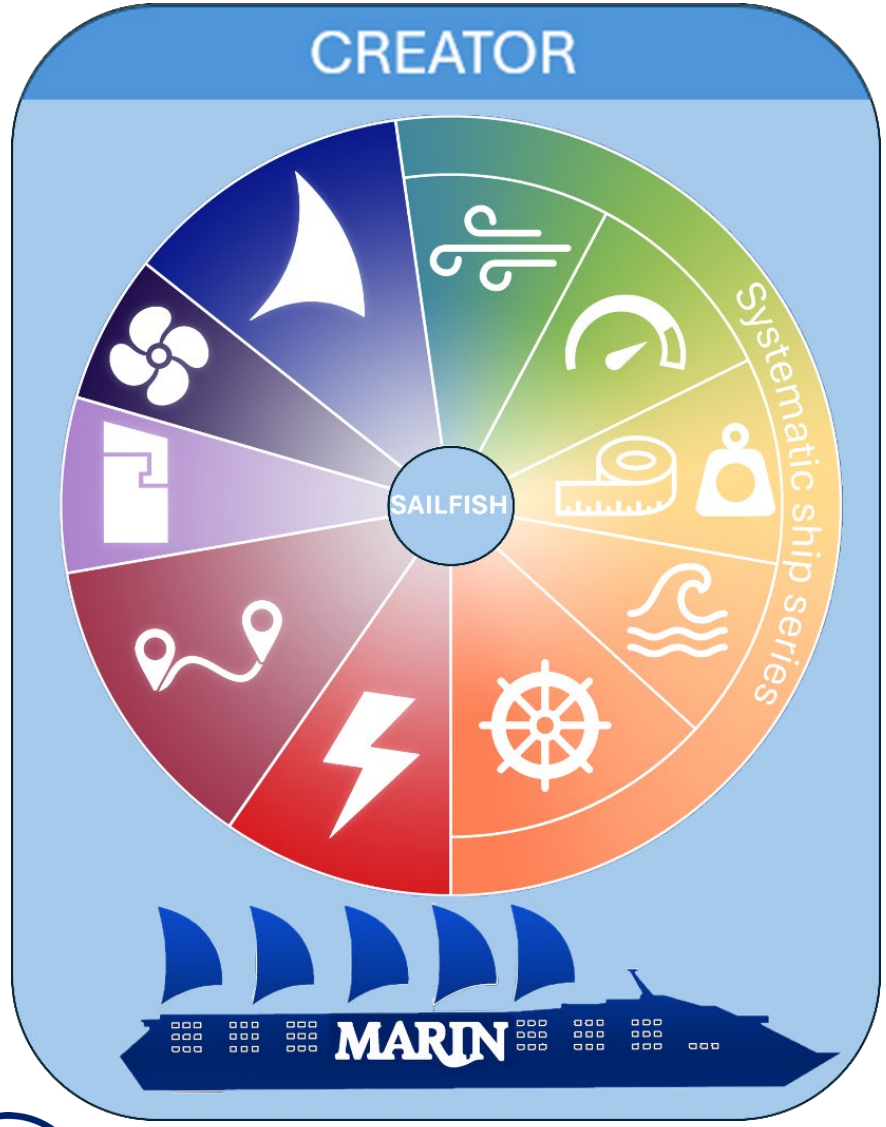
- Design problem defined as optimisation problem

$$\begin{aligned} &minimise && f(\boldsymbol{x}) \\ &subject\ to && h(\boldsymbol{x}) = 0 \\ & && g(\boldsymbol{x}) \leq 0 \end{aligned} \qquad (1)$$

  - **x**: list of design variables
  - f: objective
  - h and g: constraints

- Need to evaluate all relevant aspects using predictive models

CREATOR



- Early assessment tool
- Holistic approach
- Includes:
  - Hull design, Cargo capacity
  - Powering, Manoeuvring, Seakeeping, Aerodynamic
  - Propeller-engine matching
  - Power Propulsion systems
- Performance predictions include:
  - 4-DOF Power Prediction Program (SAILFISH)
  - Voyage simulations with weather routing
  - IMO manoeuvres
- Fast yet accurate predictions
  - User can select the fidelity level
  - Workflow relies on surrogate models based on Machine Learning techniques

Content

- Tanker with Ocean Wings

- Bulk carrier with Anemoi Rotor Sails

- Cruise vessel with Chantiers de l'Atlantique Solid Sails







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Demo Case 1 – Bulk carrier

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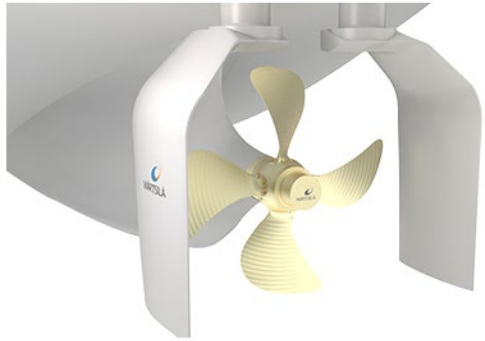
BLUE FORUM

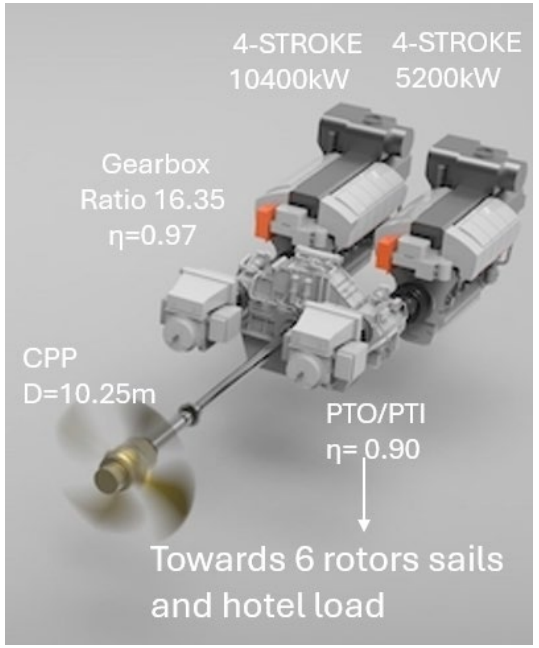
ANEMOI

Overview of the project

- Development Wind Propulsion System
  - Improving aerodynamic, improving mechanical and electrical performance, **design/build/test thrust measurements system**
- Concept design of New vessel
  - General arrangement, new hull form, innovative aft body configuration, PPE systems, early economic assessment
- **Design of new vessel using Holistic optimization**
- **Performance assessments**
  - Energy efficiency, Economic, Logistic, Operations and Regulations
- Control and Energy Management
- Ship Operations and Human Machine Interface



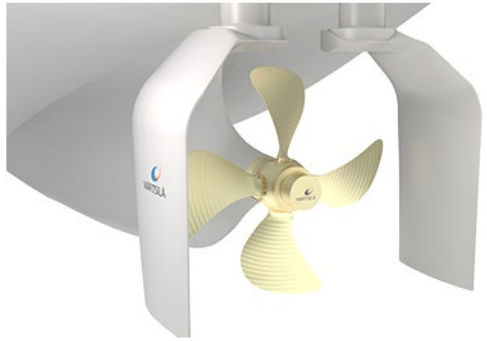


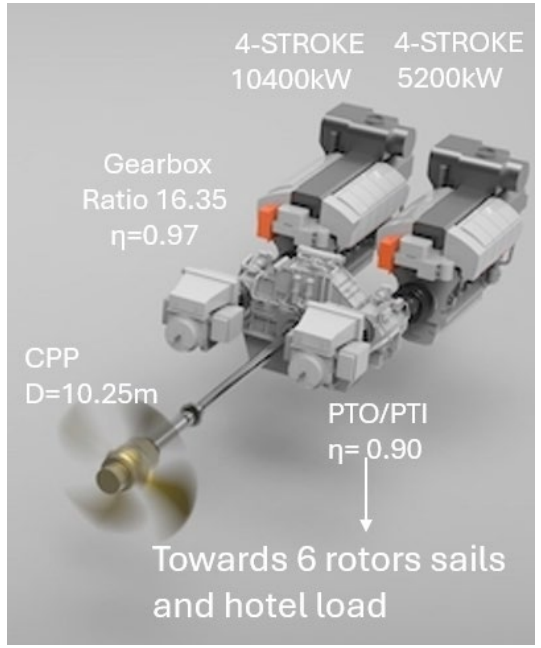


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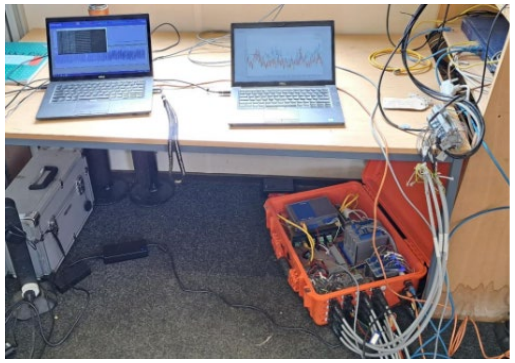


Content: thrust measurements system

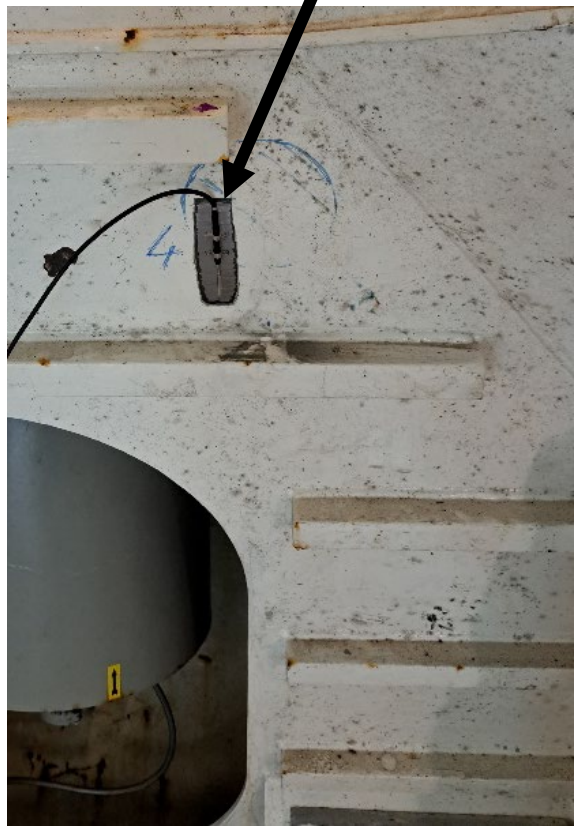
- Instrumentation.
- Test overview.
- Strain gauges (SGs) and Load cells (LCs) results.
- Result comparison.
- Observations and conclusions.

Instrumentation

- Synchronized data acquisition system.
- x6 Strain gauges ⇨ FE analysis
- x4 Load cells.

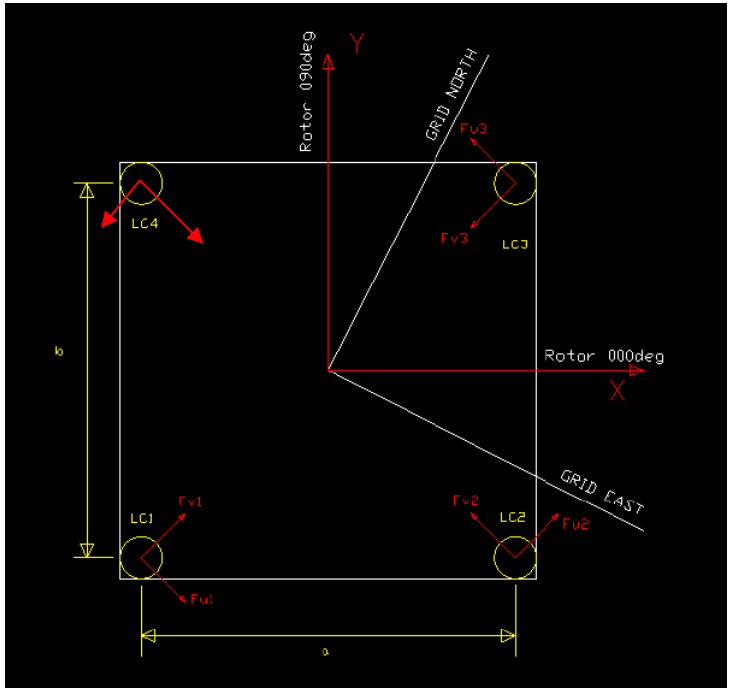


Strain gauge

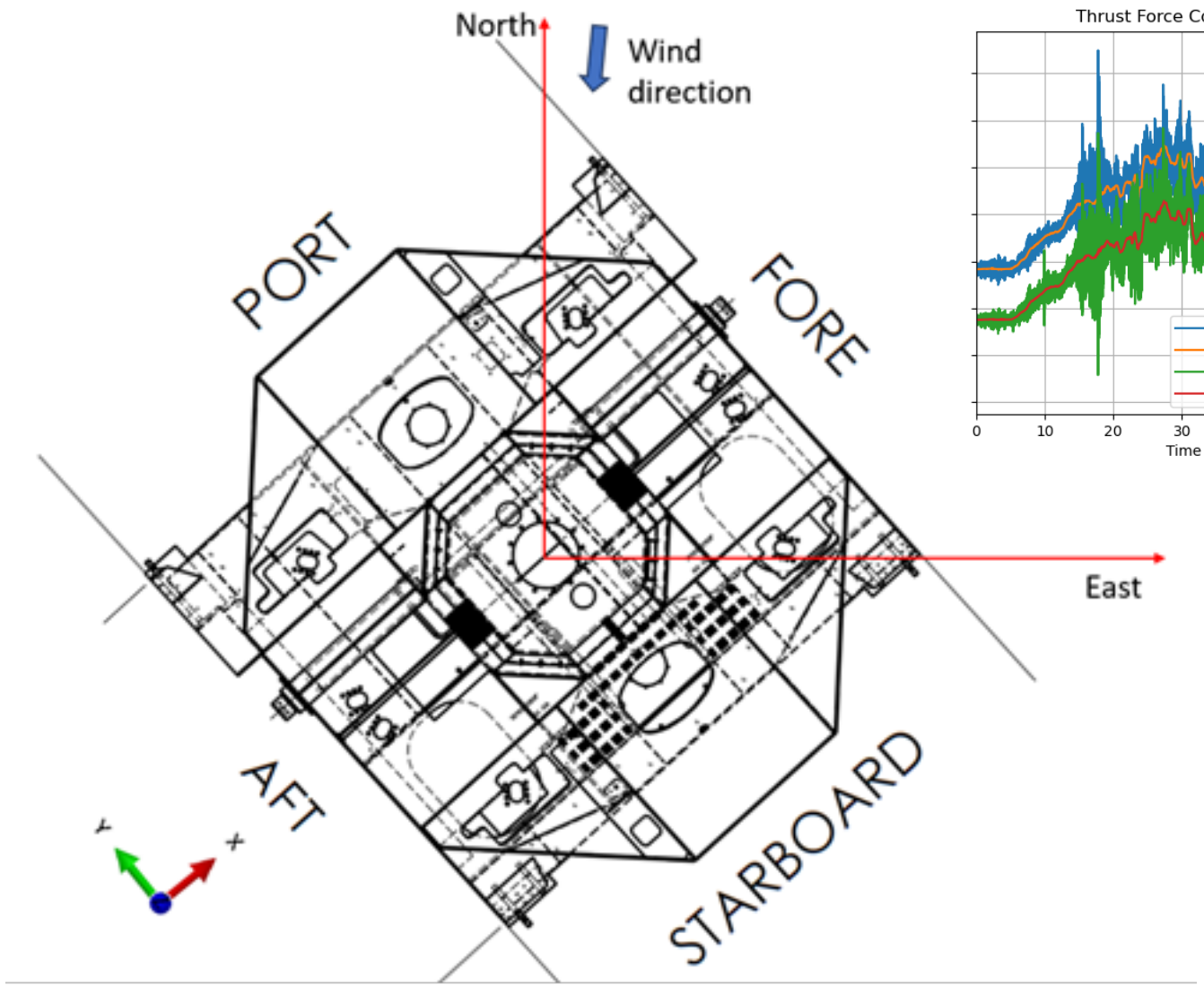


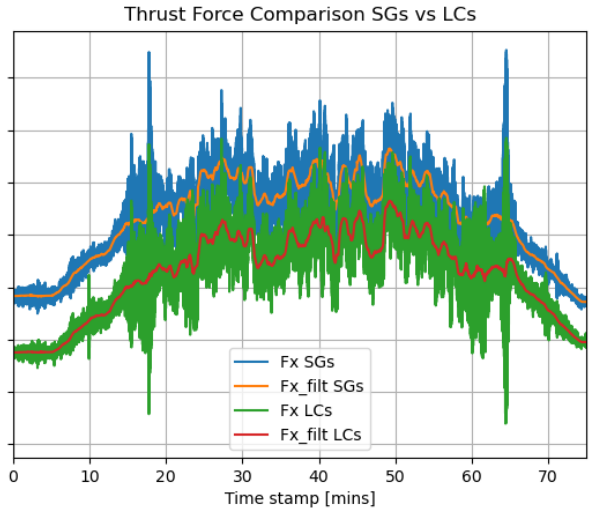


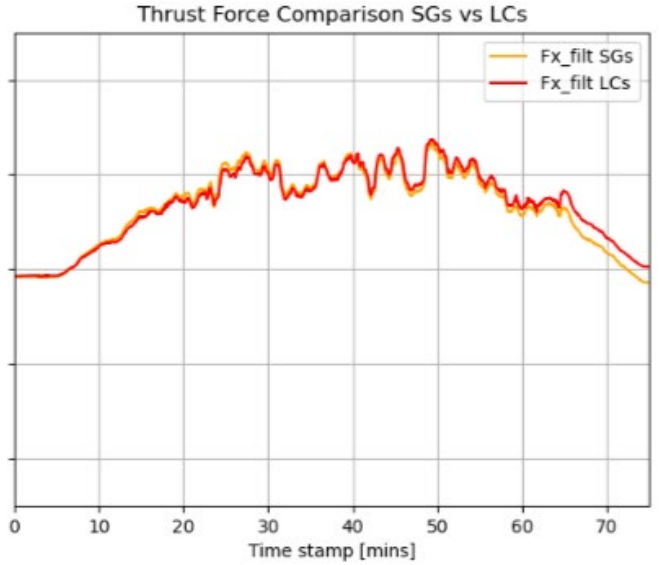
Load cell

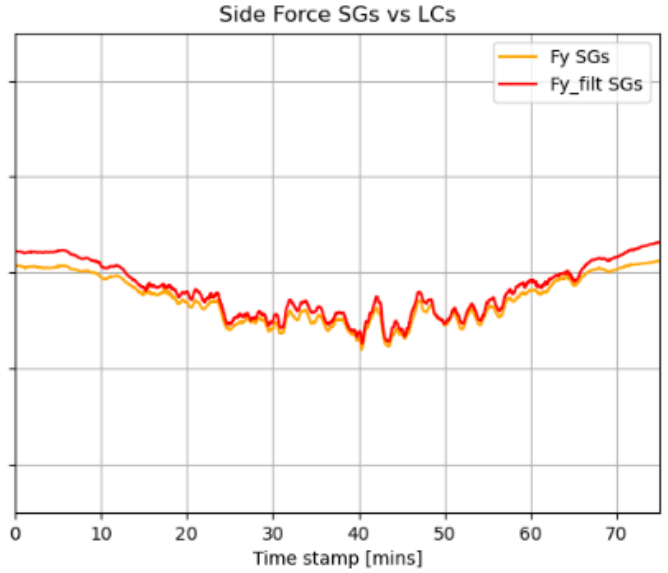


Clockwise rotation, continuous acceleration









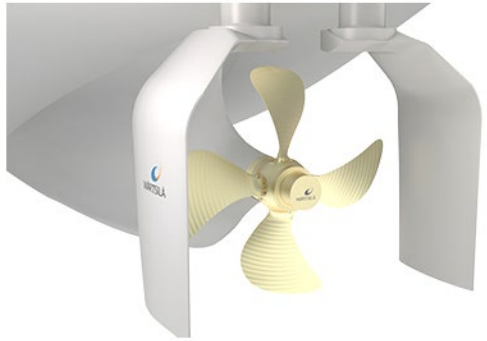
Conclusion

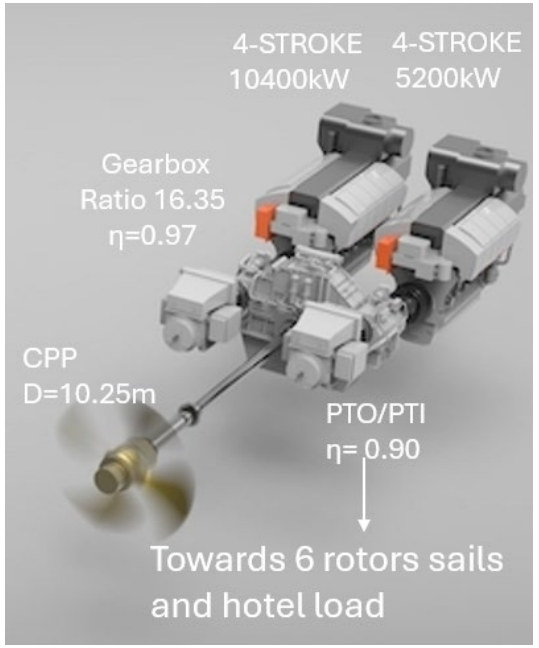
- Positive results, correlation between existing Load cells and the FEM calibration of newly installed Strain Gauges is consistent.
- Recommendation for an actual installation would be to have 2 pairs of strain gauges rather than 1. (2 along the thrust force axis and 2 along the side force axis).
- Possible future step would involve installing such sensors set up on a real case to investigate the effect of the vessel motions on the sensor's readings.

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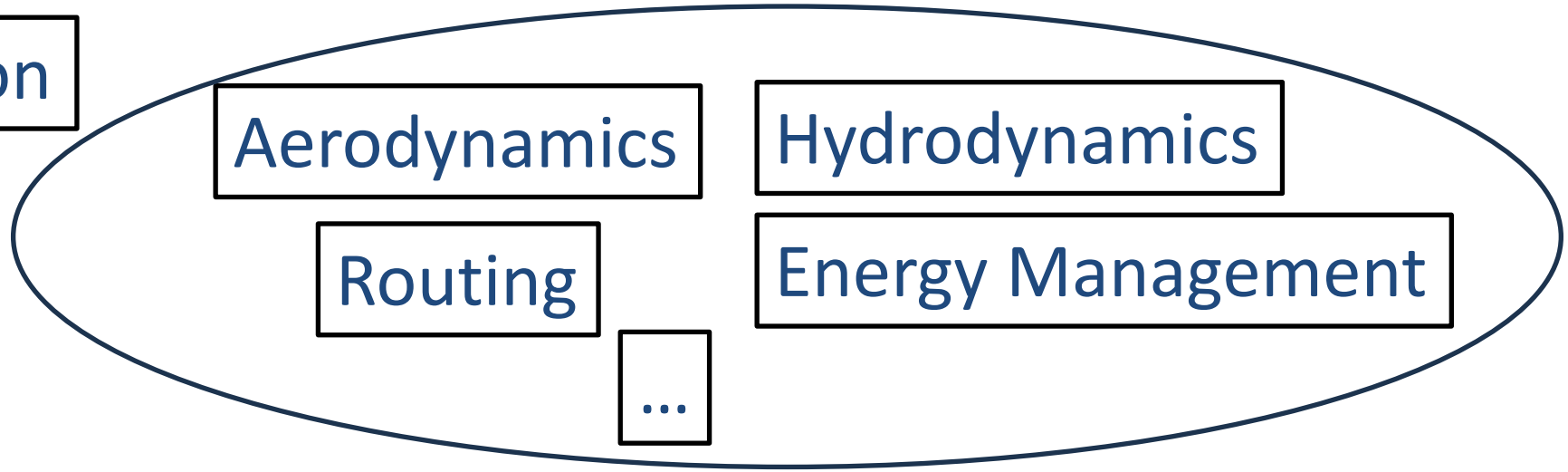




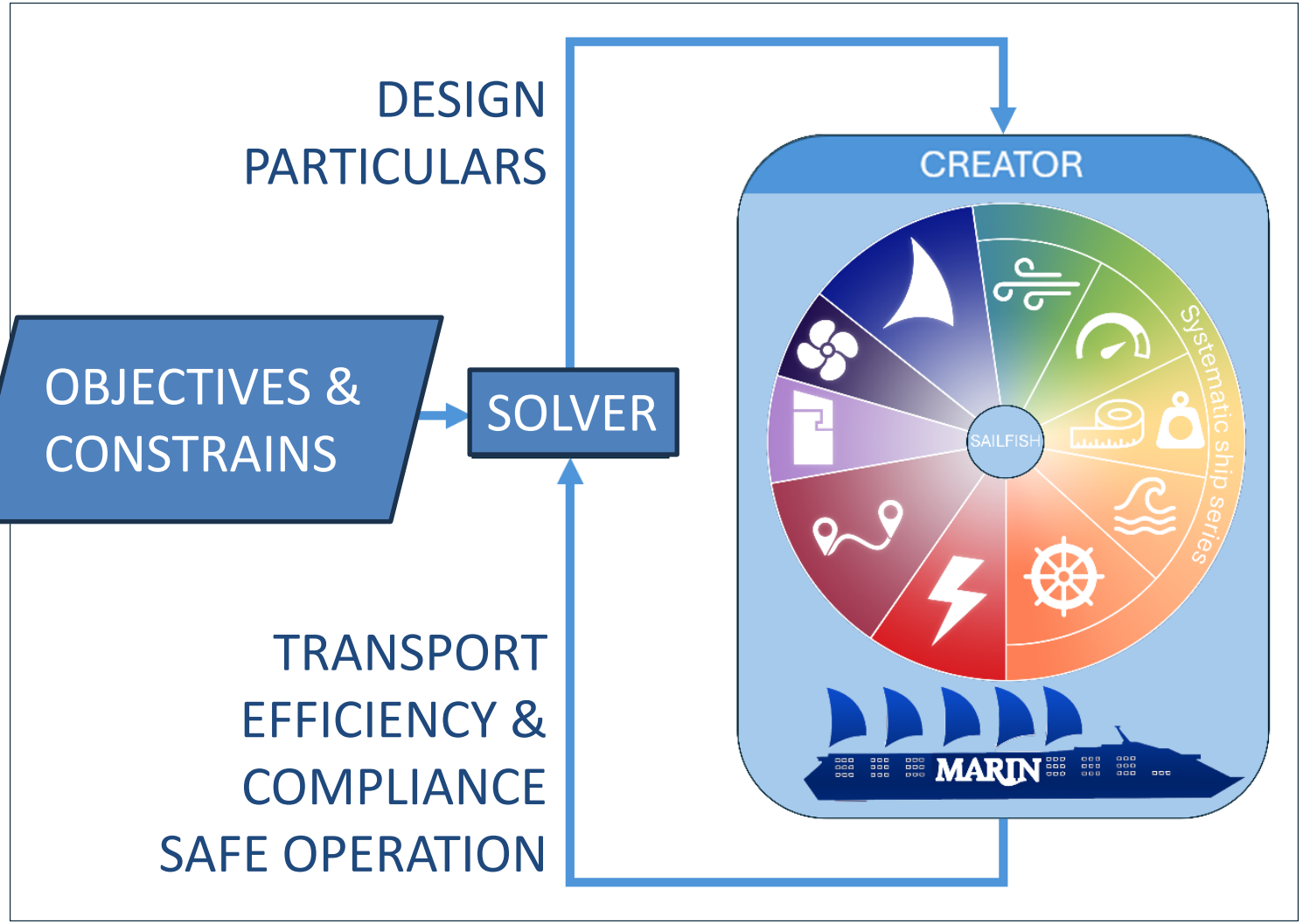
Problem statement

How can we design and optimise ships with wind propulsion and demonstrate the energy savings?

Holistic optimisation



CREATOR optimization workflow

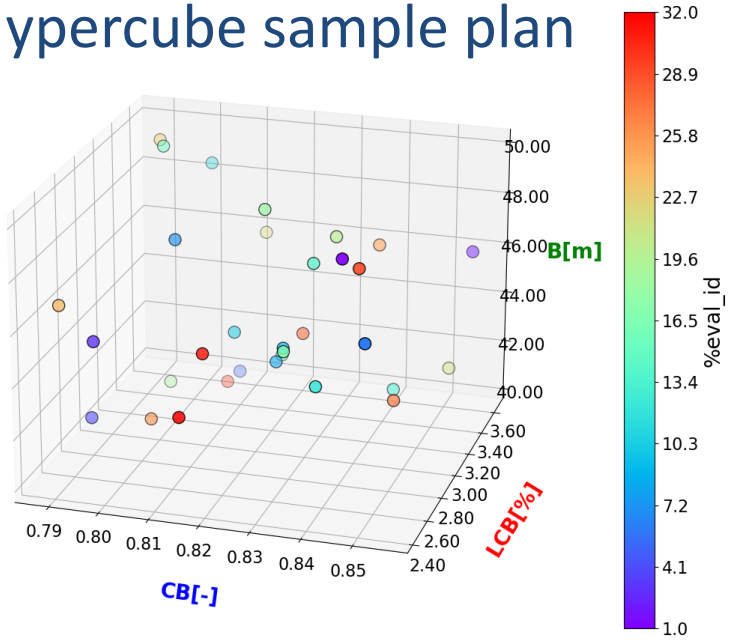


- Loop around CREATOR:
  - Evaluate prescribed design of experiments
  - Surrogate-based optimization
- Objectives:
  - Required transport efficiency in kW/(tons cargo x miles)
  - Fuel consumption
  - CO_2 emissions
  - …
- Constraints:
  - Ship motions
  - Cargo capacity
  - …

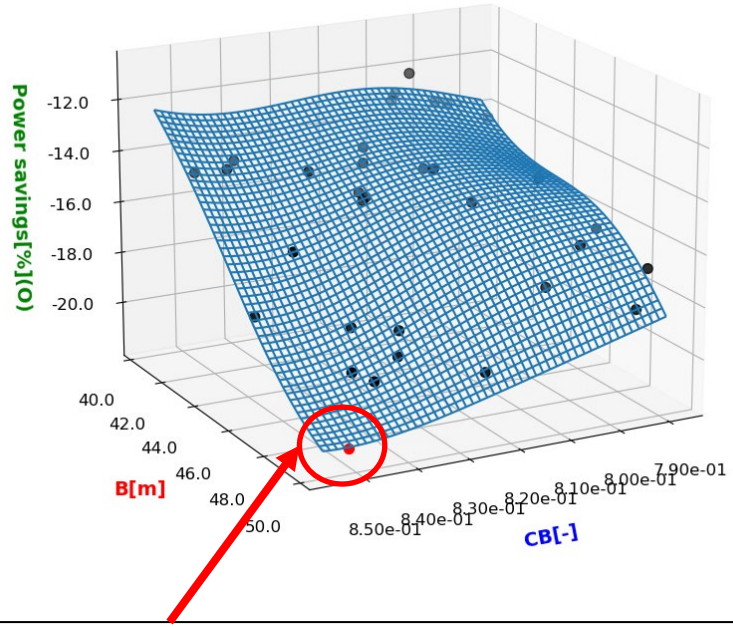
Optimize Hull form

	Symbol	Reference vessel	Range	Unit
Block coefficient	Cb	0.856	0.786 to 0.856	[-]
Relative centre of longitudinal buoyancy[1]	LCB	3.69	2.4 to 3.69	[%]
Beam	B	50	40 to 50	[m]

Latin Hypercube sample plan

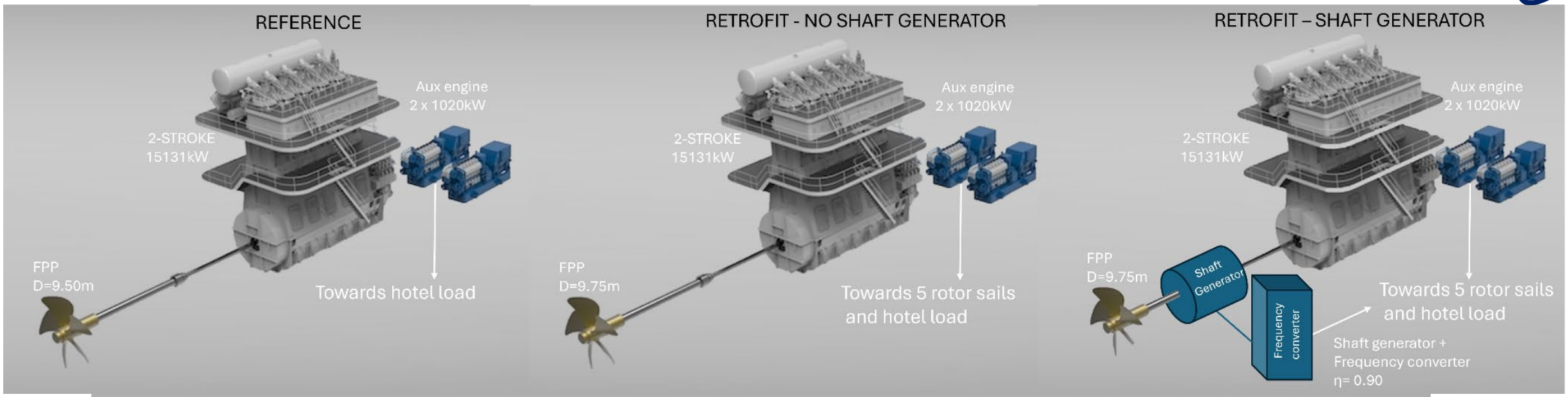


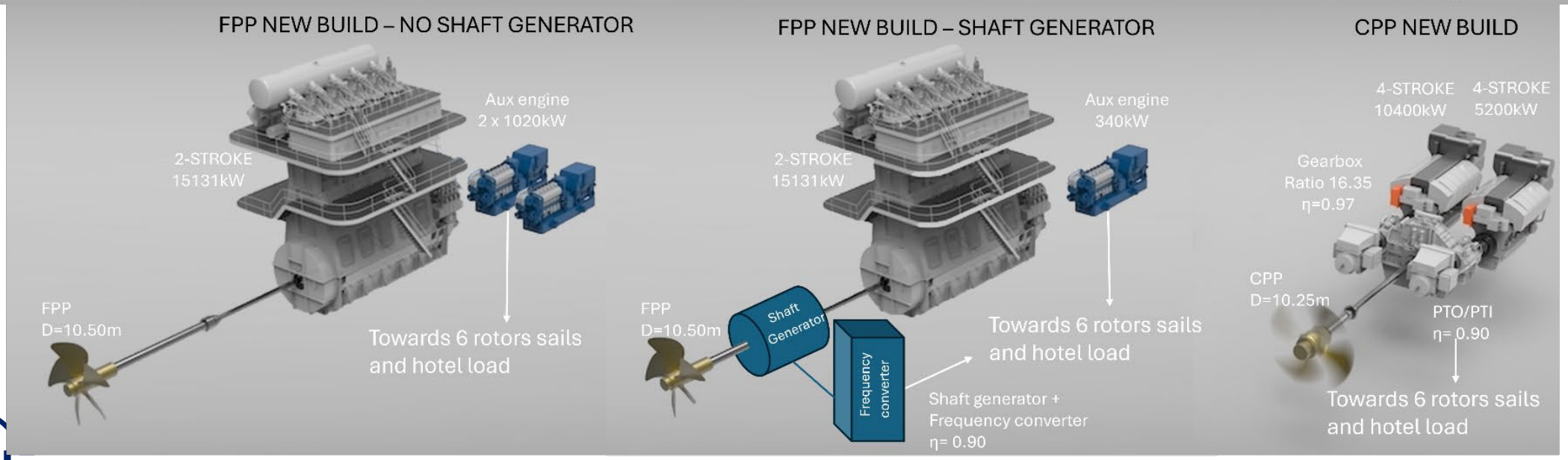
Surrogate power savings per tons cargo x miles



Optimum is current design of Newcastlemax -> good news!

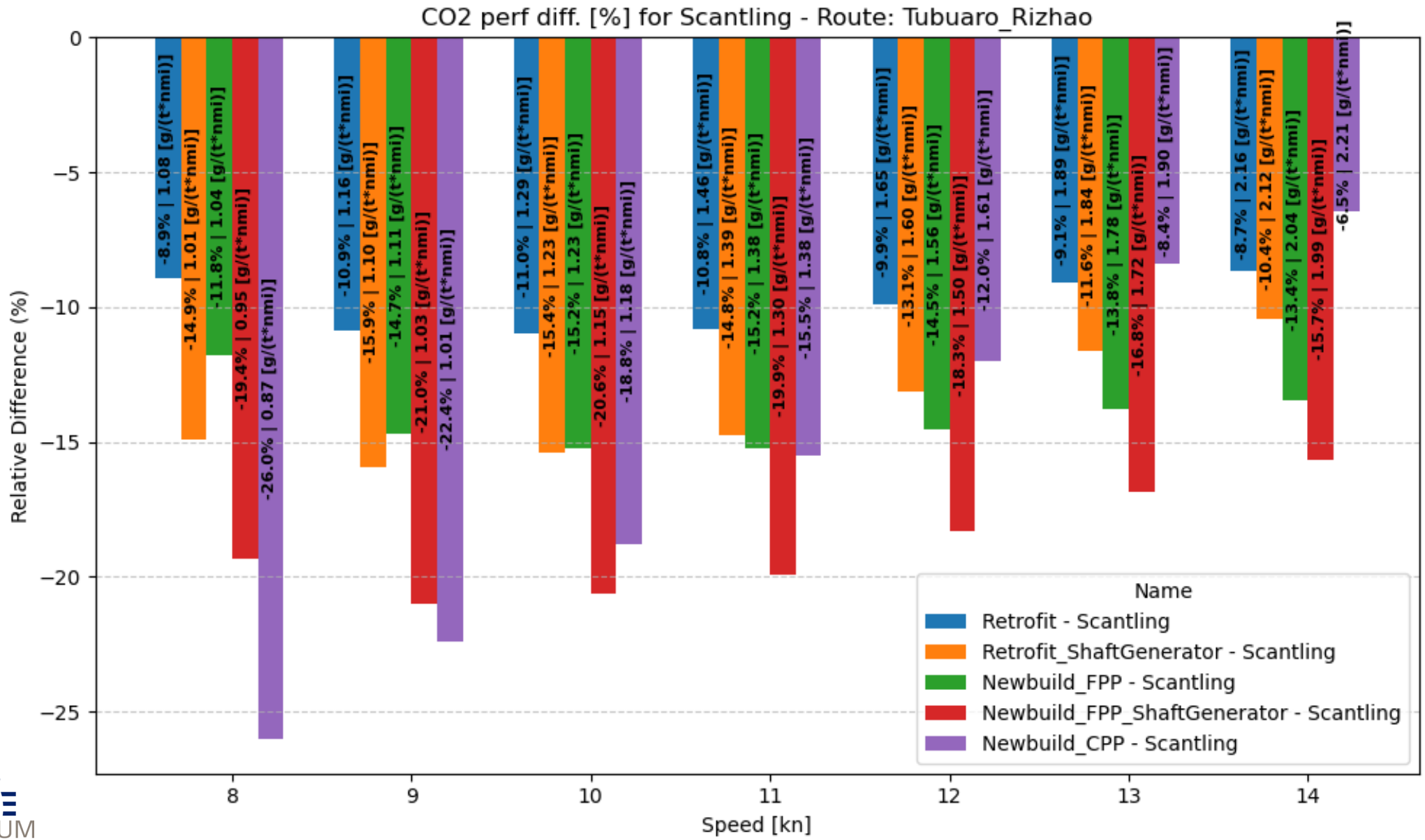
Different Propulsion and Energy configurations



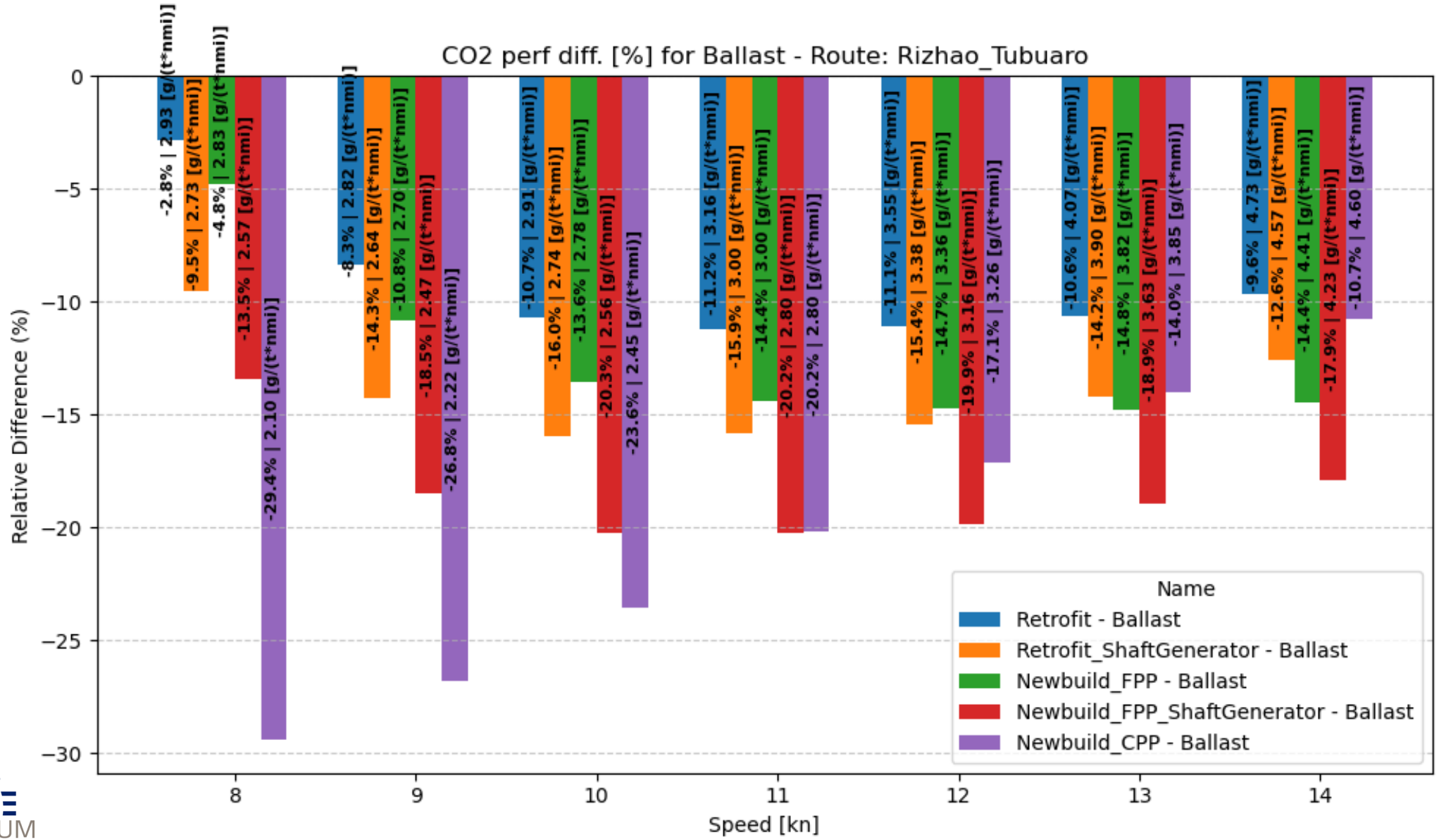


Initial drawings: courtesy Wartsila. Configurations on slides: initial drawings adapted by MARIN

Final Performance assessment : Scantling



Final Performance assessment : Ballast



Outcomes

- Optiwise has been fundamental to develop CREATOR. Tool can/is now be used in an early design phase to assess and optimise ships wind propulsion in a holistic manner.
- CREATOR is demonstrated for the bulk carrier and for Cruise line vessel of Optiwise. Key findings for the bulk carrier are:
  - The existing hull form of a Newcasltemax is found optimal in terms of power savings per tons cargo x miles
  - Trade off FPP and CPP configurations is speed and to a lesser extent route dependent.
    - At current operating speed, i.e. 12 knots in ballast, 11 knots in scantling, the FPP yields higher fuel/CO2 savings.
    - If operating speed further decreases, a CPP is becoming advantageous

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Cruise Vessel



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Reference design by Chantiers ‘d Atlantique



Length	L_{PP}	~ 200	m
Breadth moulded WL	B	~ 25	m
Draught	T	~ 5.4	m
Number of sails	-	3	-
Air draft	-	~ 100	m
Total sail area	A_{ref}	~4500	m^2

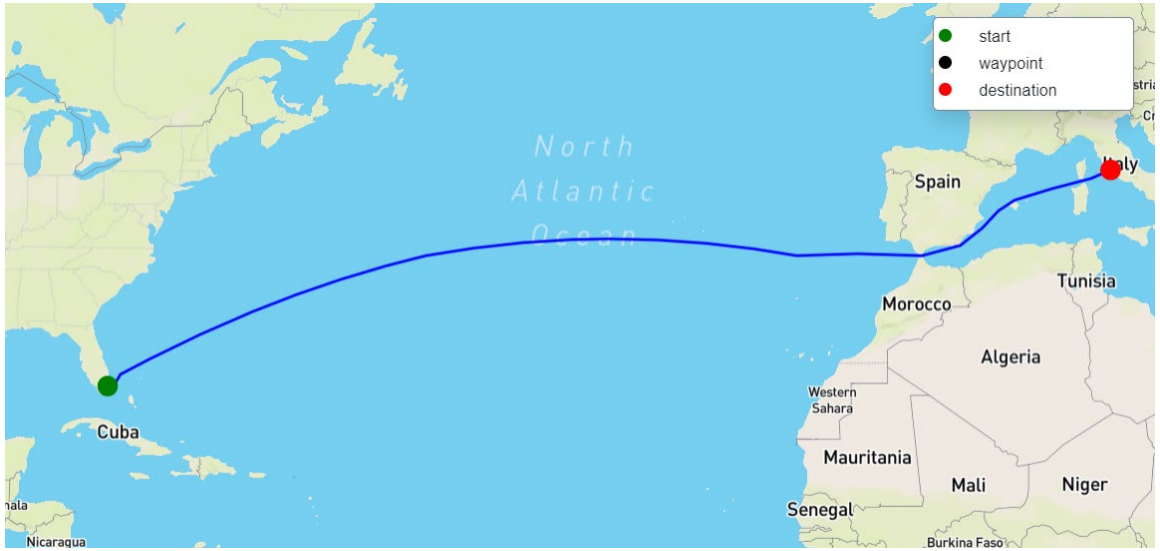
- Twin fixed pitch propellers on fixed shafts
- Twin spade rudders
- A single “anti-drift” fin
- One pair of roll stabilization fins

Reference routes









- Speed about 12 kn
- Hotel load 1600kW
- Adapted schedule compared to common cruise liners

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Cruise Vessel Seakeeping & Manoeuvring Tests



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Part of content from: Eggers&Kisjes, 2024, RINA Wind Propulsion Conference

Background

- Secondary forces may affect manoeuvring & seakeeping
- Ship still needs to comply with regulations and comfort expectations

- Assessment methods for manoeuvring & seakeeping with wind propulsion not well established



Objectives

- Development of test set-up and methods
- Direct validation of ship design
- Validation material for fast time or bridge simulations

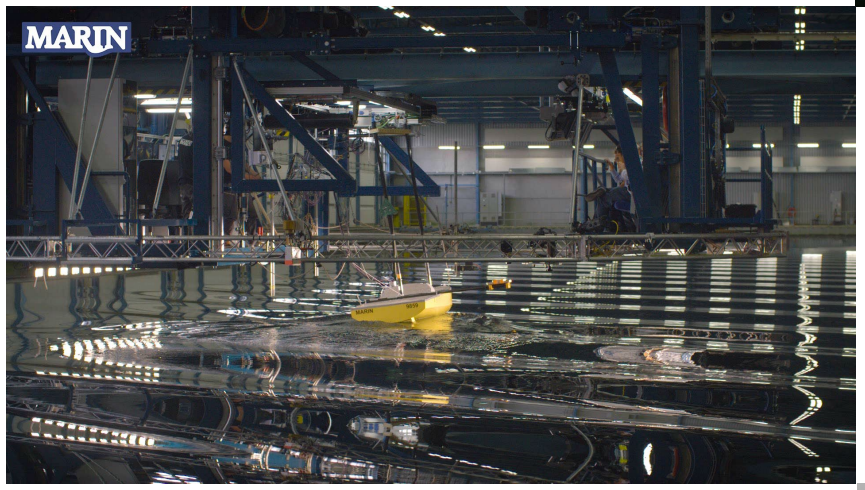


Past projects to model wind propulsion

‘Real wind’ (Eggers & Kisjes 2019)

- Complete experiment
- Quite complex
- Sub optimal wind quality



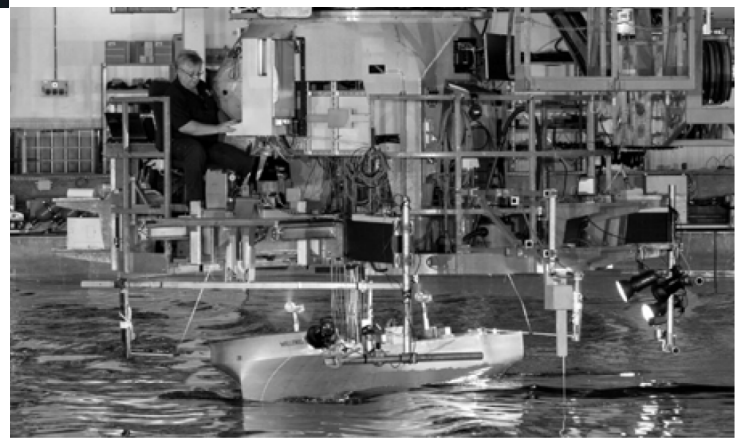


Lines & winches (Eggers 2018)

- Powerful
- Yaw moment not variable
- Not turning circles

Fans (Gerhardt 2021)

- Turning circles
- 3 DoF forces



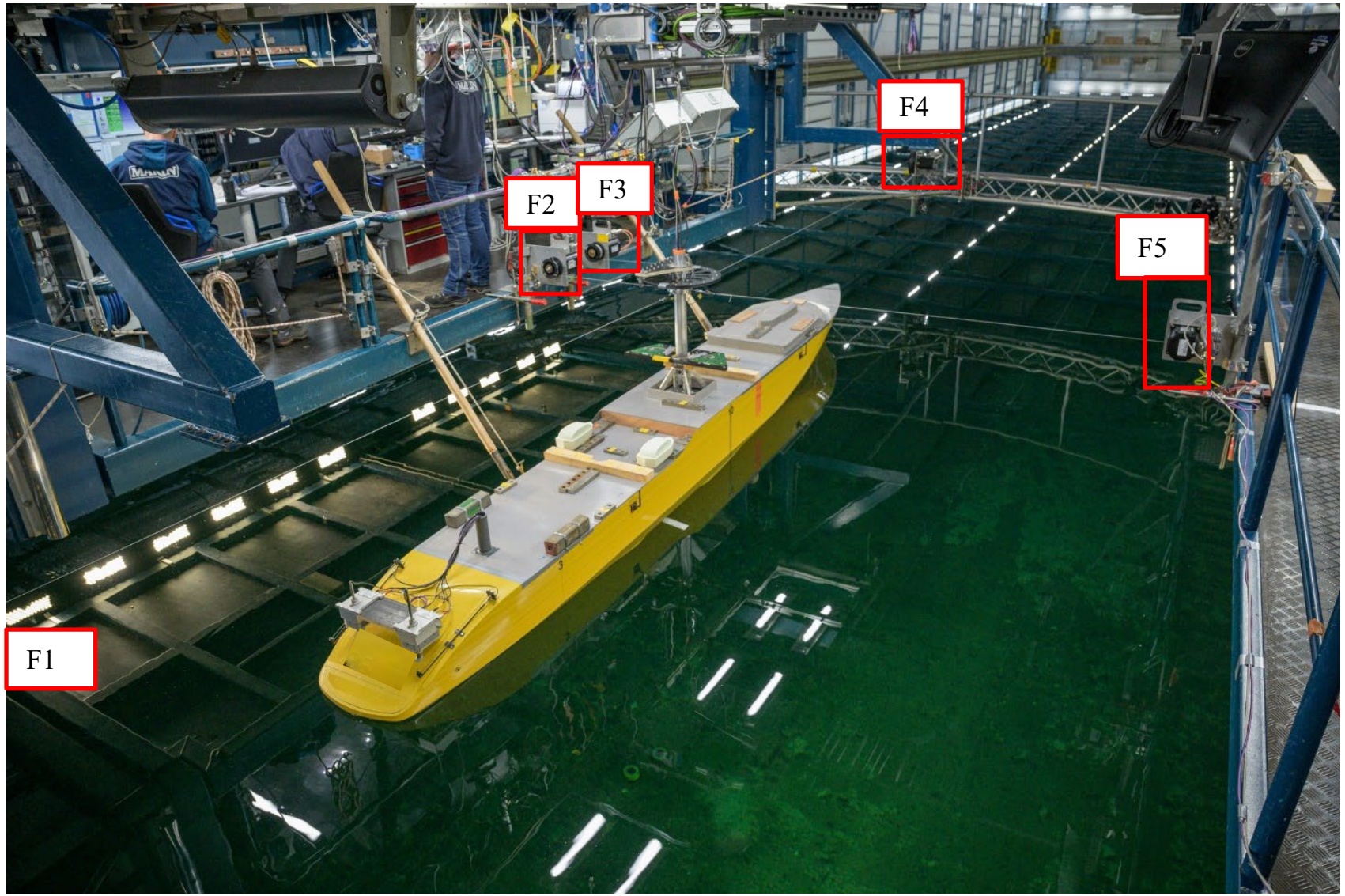
Requirements and method selection

Our requirements

- Powerful (test the largest systems)
- Possibility to model Fx, Fy, Mz independently and dynamically
- Fast (allow to model e.g. roll damping)
- No large (power) cables to the model
- Acceptable noise for basin crew

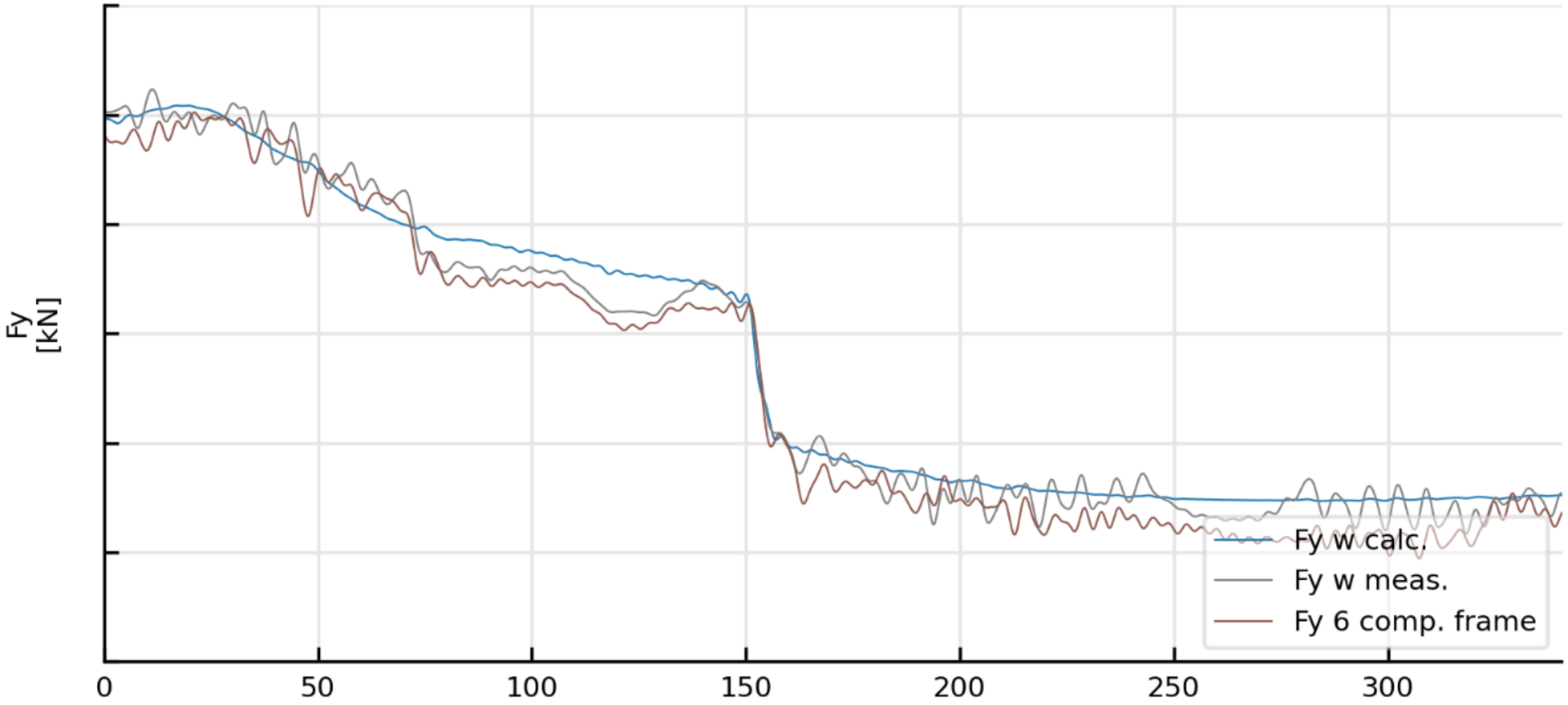
➢ This led us to an improved set-up with lines and winches

Experimental set up with winches



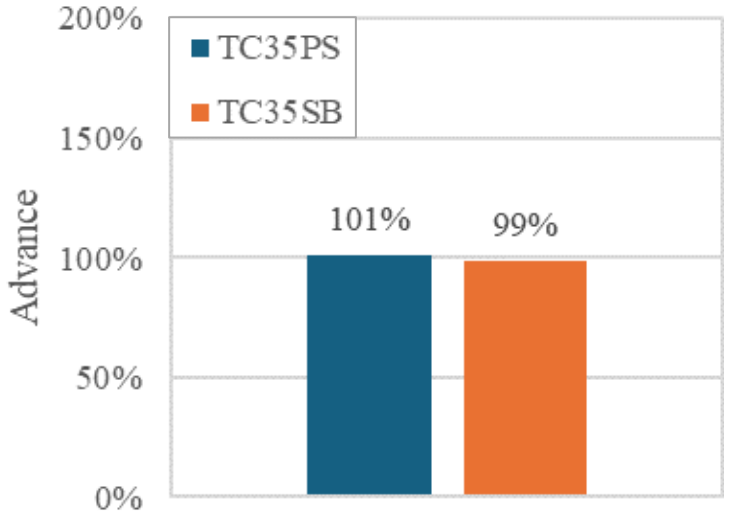
- Externally desired forces applied by lines and winches
- Forces are measured in every line
- ‘Windmast’ mounted on a force measurement frame (as second check to measure winch loads)

Experimental setup - test setup performance

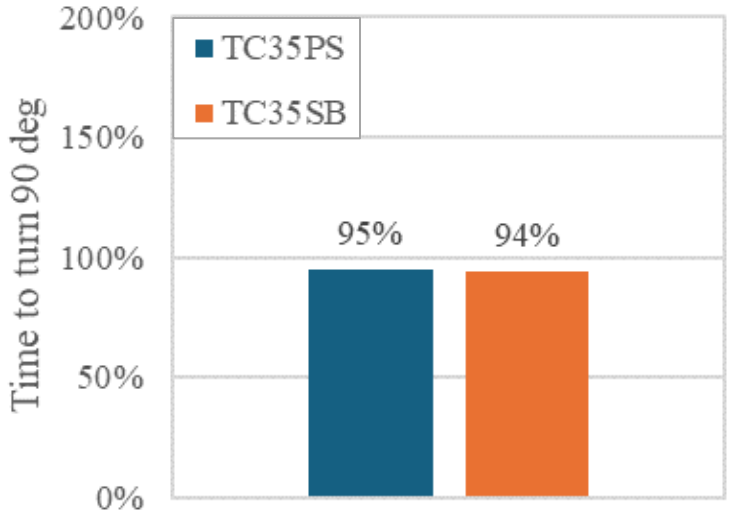


Experimental setup – test set up performance performance

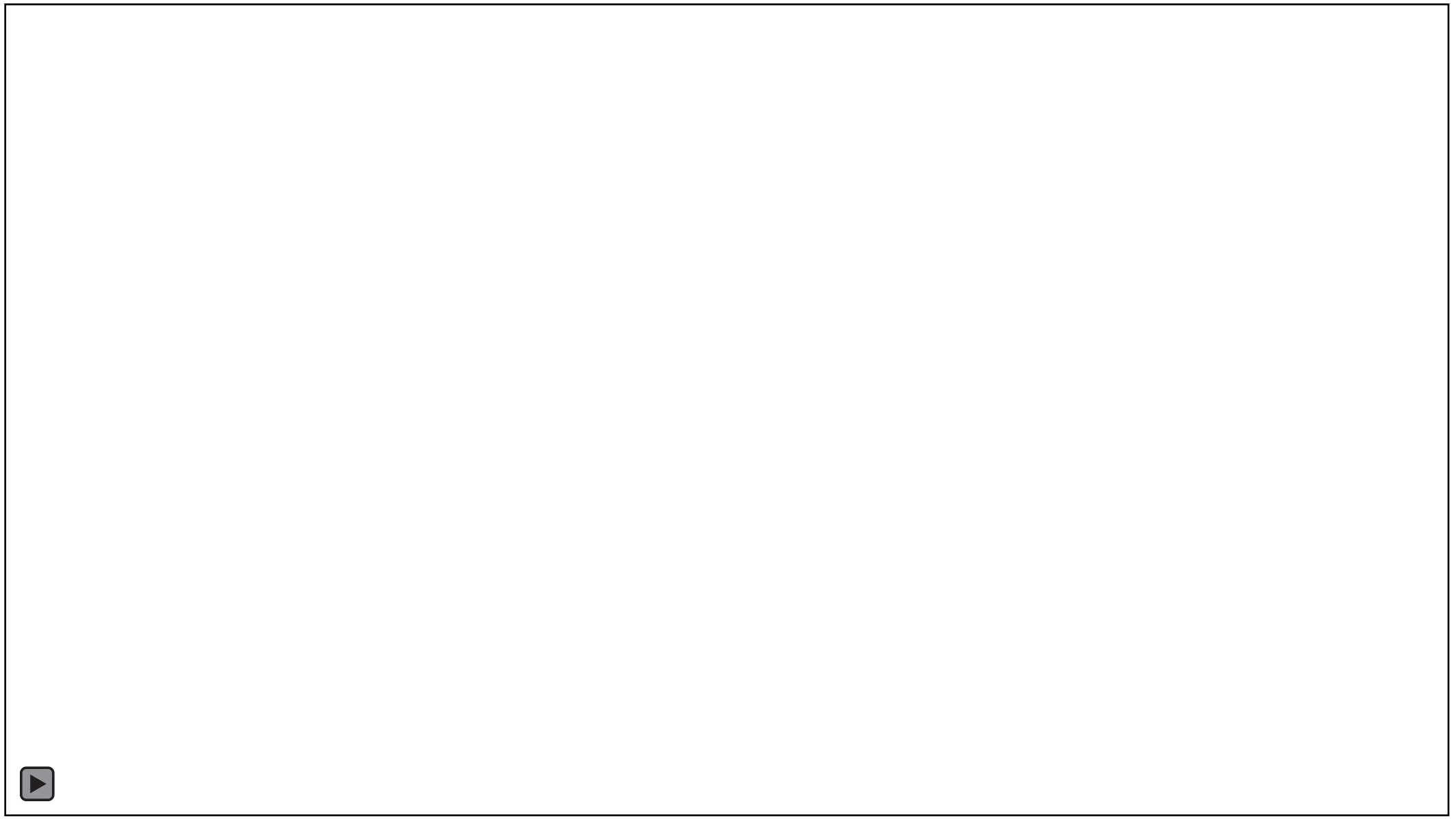
Manoeuvring characteristics with pre-tension compared to free running tests without winch lines attached (100%).





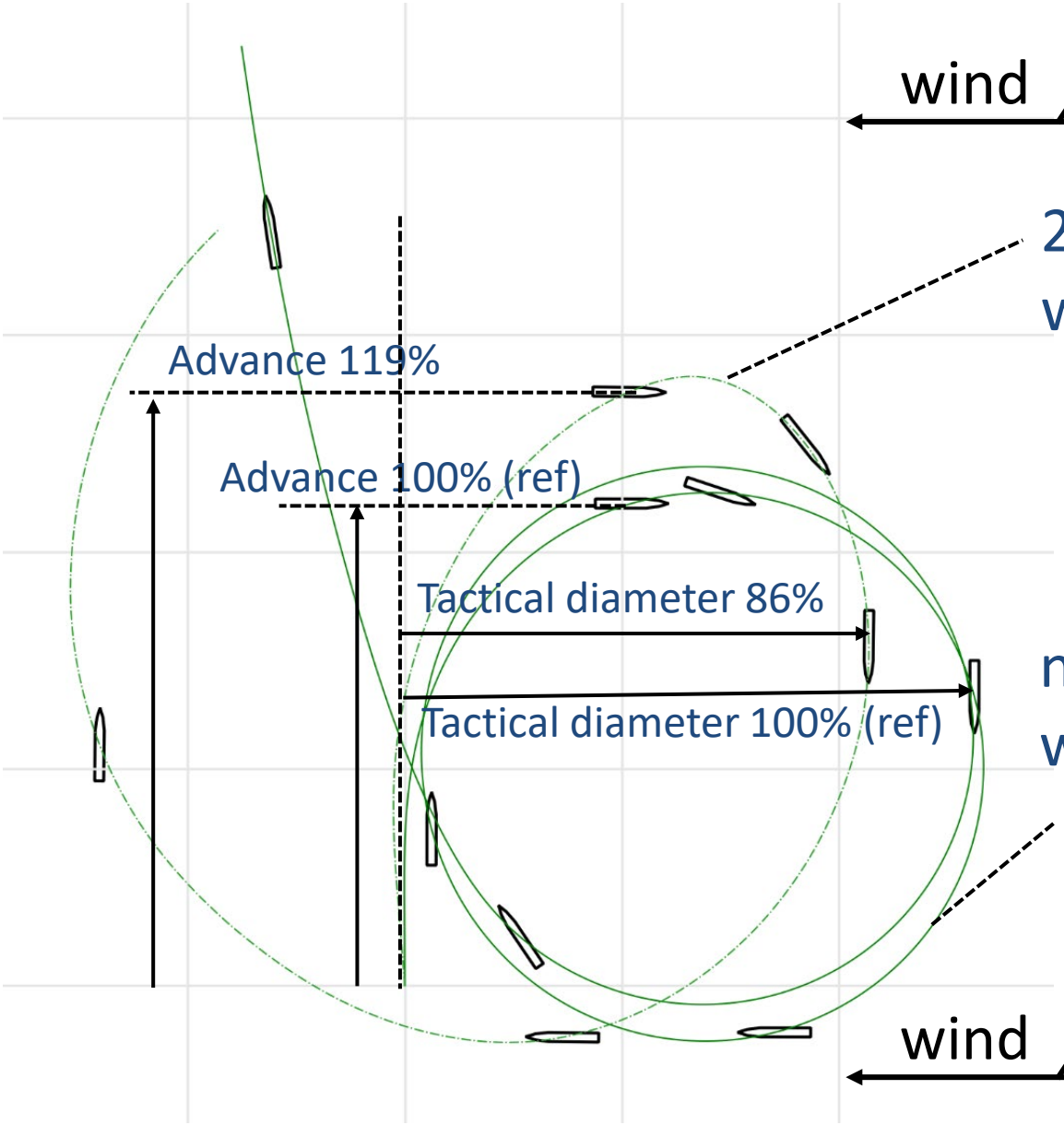


Experimental setup – video



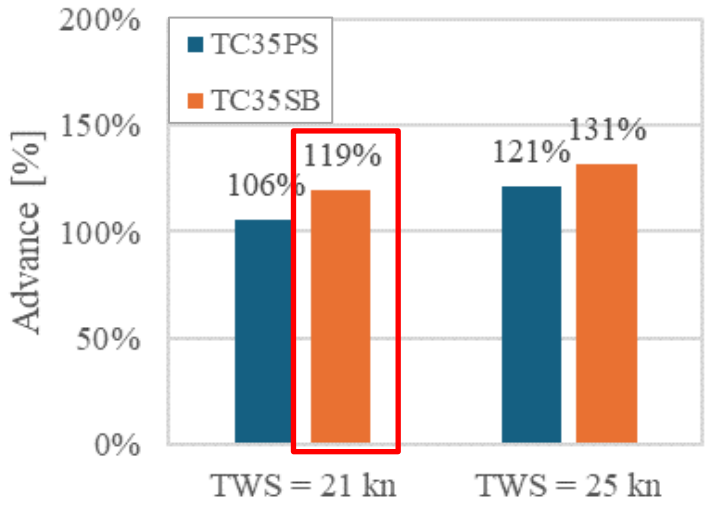
https://vimeo.com/890323546/c52e0685a0?share=copy

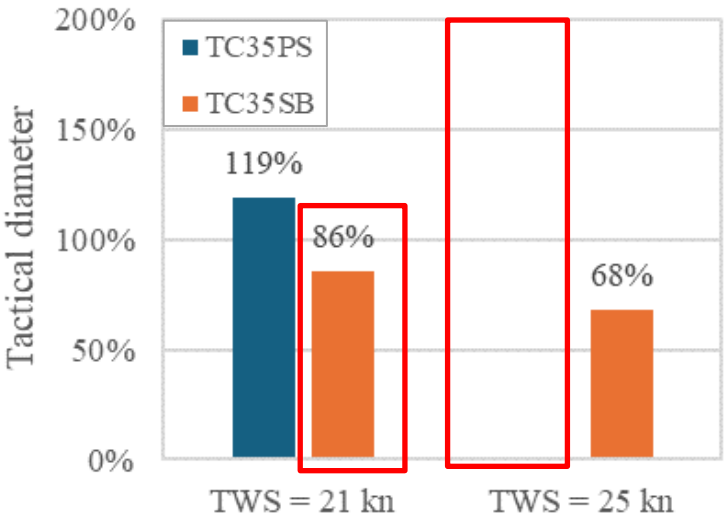
Manoeuvring results



21 kn wind,
with anti-drift fin

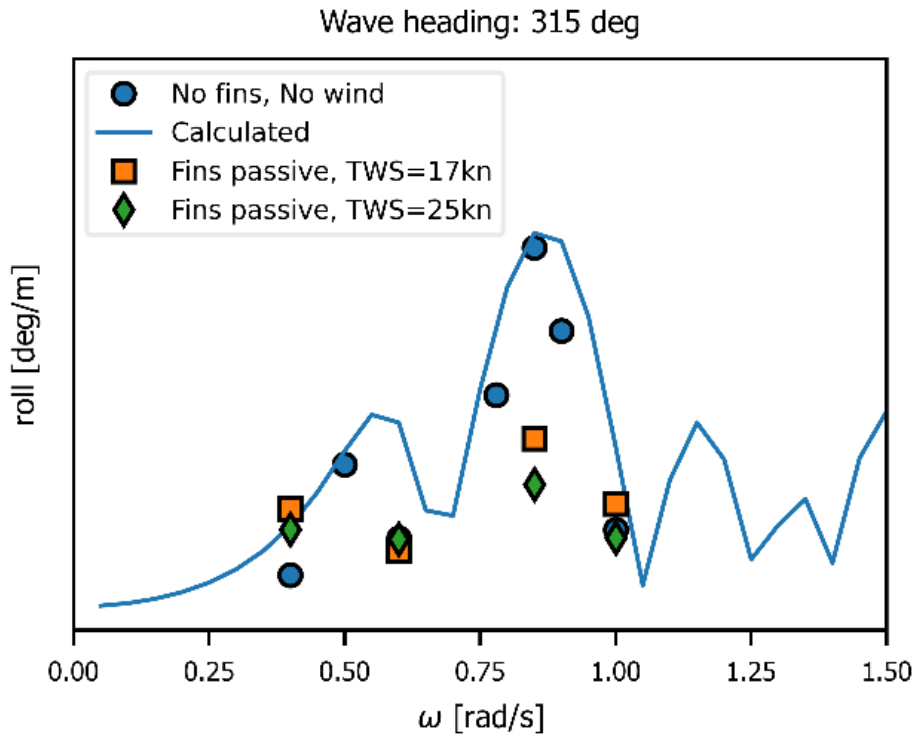
no wind,
without anti-drift fin

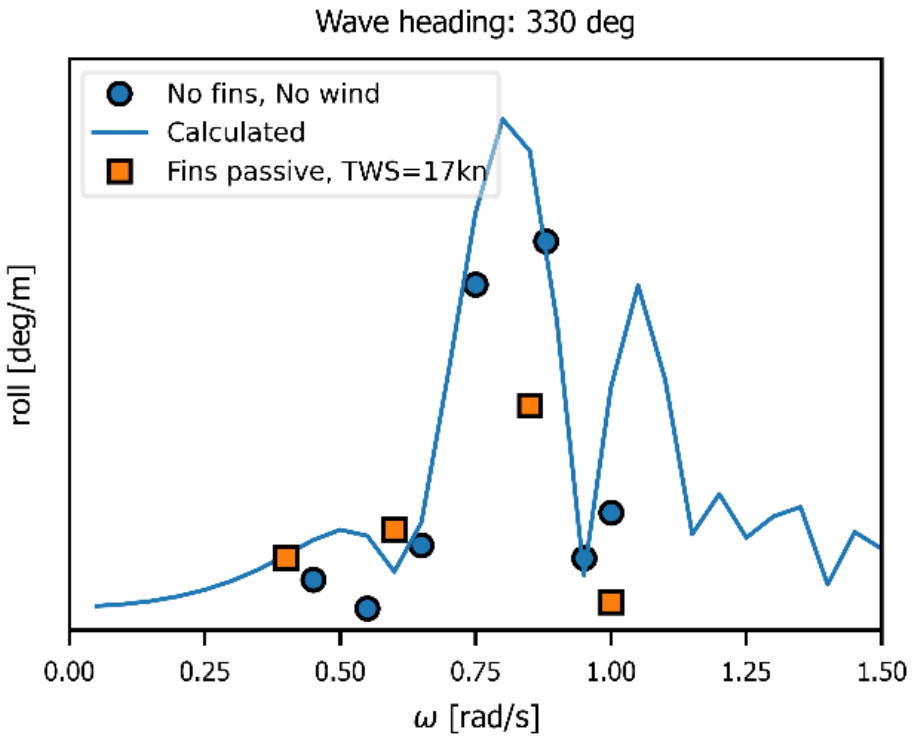




Seakeeping results - roll response

- General observation is that roll motions are reduced for stern quartering waves





Conclusions & Recommendations

Test setup:

- Test setup proved to be suitable to tests ships with wind propulsion
- Plausible dynamic response

Ship response:

- Manoeuvrability can be affected by wind propulsion. Power boosting can likely improve the turning ability for the case vessel
- In seakeeping, the sails provided addition roll damping, differences in yaw oscillation are relatively small

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Cruise Vessel Optimization results



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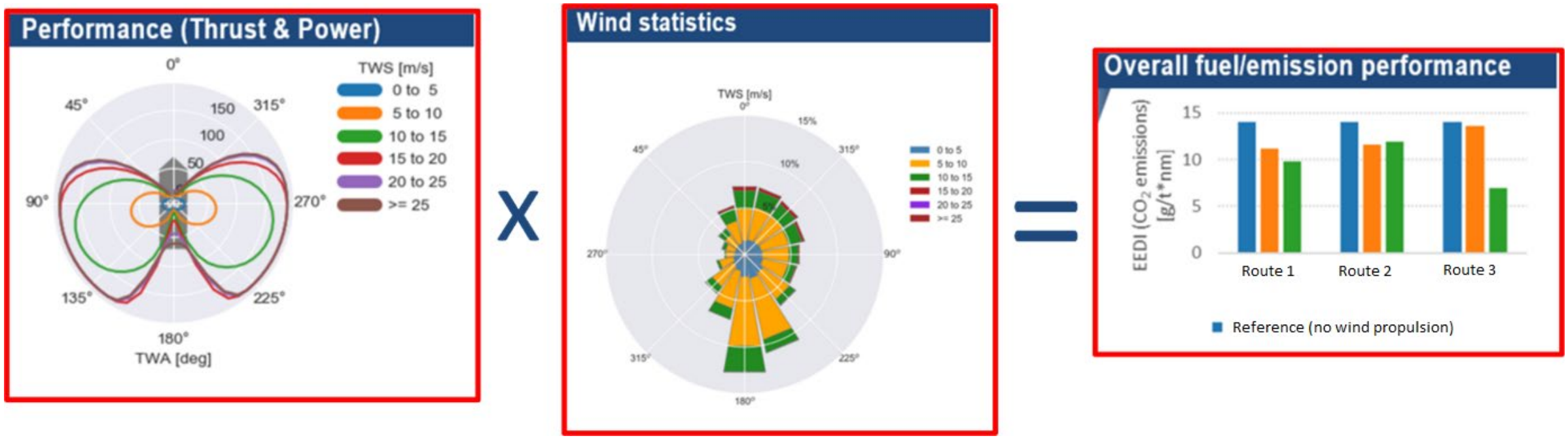
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Main dimension variation

Design variable		Range	Unit
Slenderness	$\frac{L_{OS}}{\nabla^{\frac{1}{3}}}$	6.0 - 10.0	-
Block coefficient	C_B	0.50 - 0.70	-
Relative LCB	$\frac{LCB}{L_{OS}}$	-5% - 3%	-
Beam to draught ratio	$\frac{B}{T}$	2.4 - 6.0	-
Displacement	Δ	15,000 – 30,000	t

Objective

- Average shaft power <u>including</u> wind propulsion
- Shaft power at operational speed in trial condition (excl. wind propulsion)

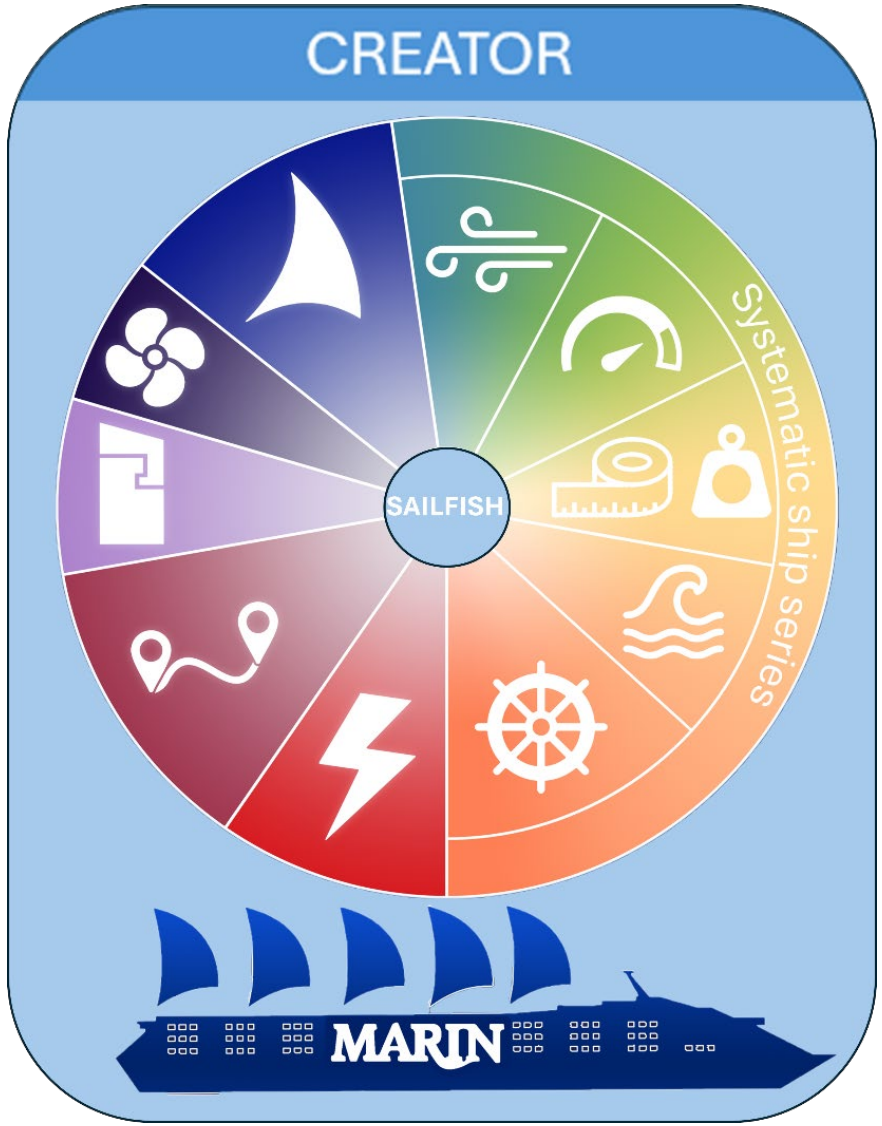


Constraints

Parameter	Change / range
Displacement change	< 0.5 % of weight
LCB change	< 2.5 % of LCB from App
Metacentric height	3 m < GM < 5 m
Length overall	< 294m
Moulded Beam	< 32.23m
Draft	< 9.5m
~~Air Draft~~	~~< 57.91m~~
Number of passengers	Equal to reference ship

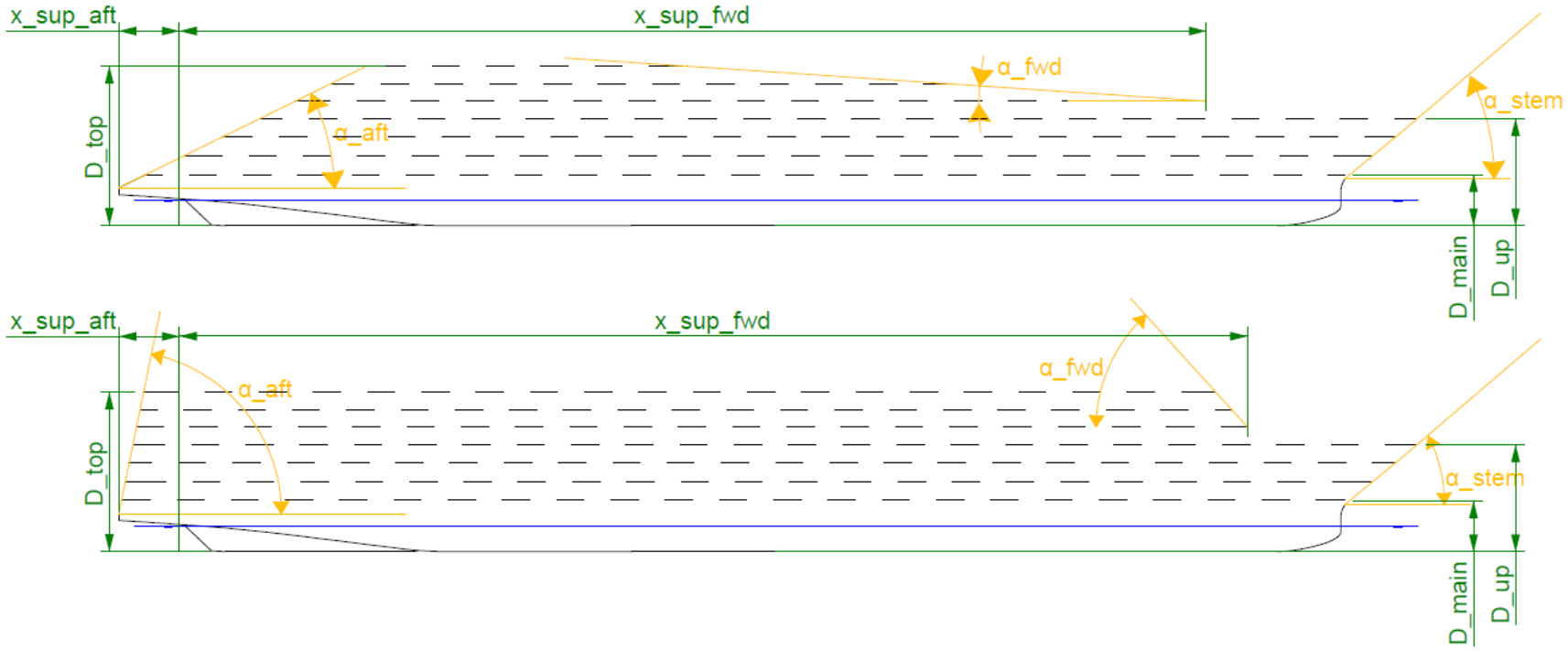
Predictive models

- General arrangement and weight
- Hull form geometry and hydrostatics
- Resistance and propulsion
- Hull and rudder forces
- Seakeeping
- Aerodynamics and wind propulsors
- Performance prediction (PPP)



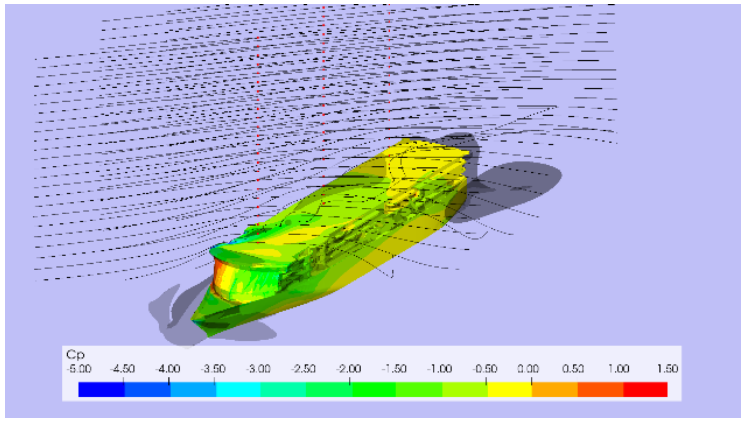
General arrangement and weight

- Parameterised model of superstructure
- Parameters based on regressions of existing vessels
- Closest match of weight, LCG and GM range for each design



Aerodynamics and wind propulsors

- Windage
  - CFD of the superstructure of the parent design
  - Coefficient used with design particulars



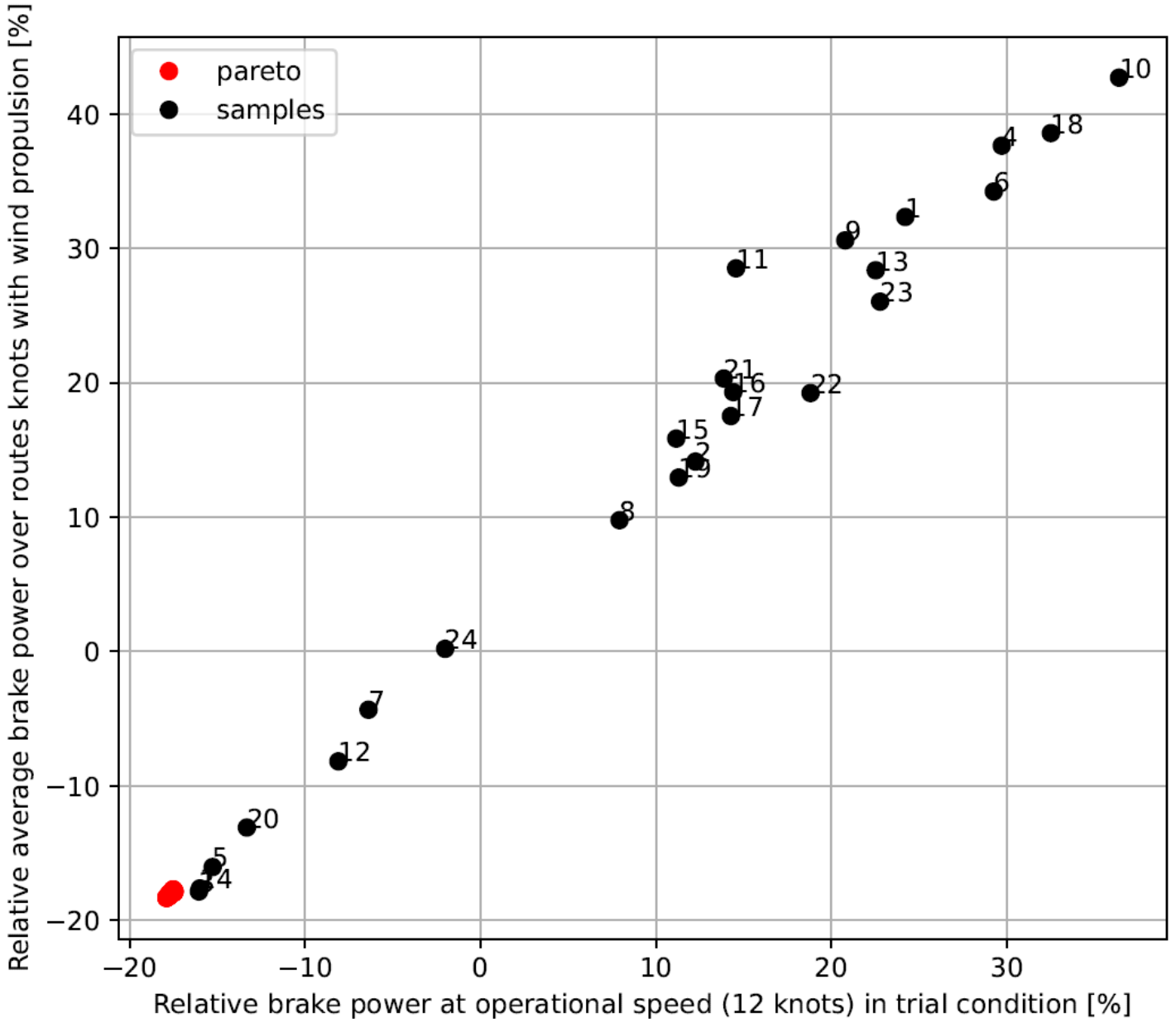
- Wind propulsion
  - 3 solid sails
  - Placed at most forward feasible positions
  - Aerodynamic interaction neglected

Height	74.0	m
Tilted height	31.5	m
Lateral area	1430	m^2



Resulting pareto front

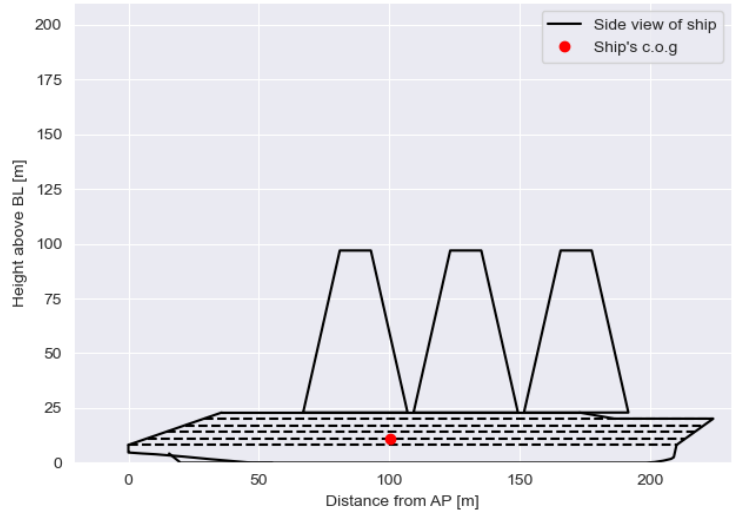
- Evaluated designs (black)
- Pareto “front” from optimization algorithm (red)
- Strong correlation (no trade-off) between wind propelled (vertical) and conventional (horizontal)!
- Appendages and character of lines ensures proper sailing performance

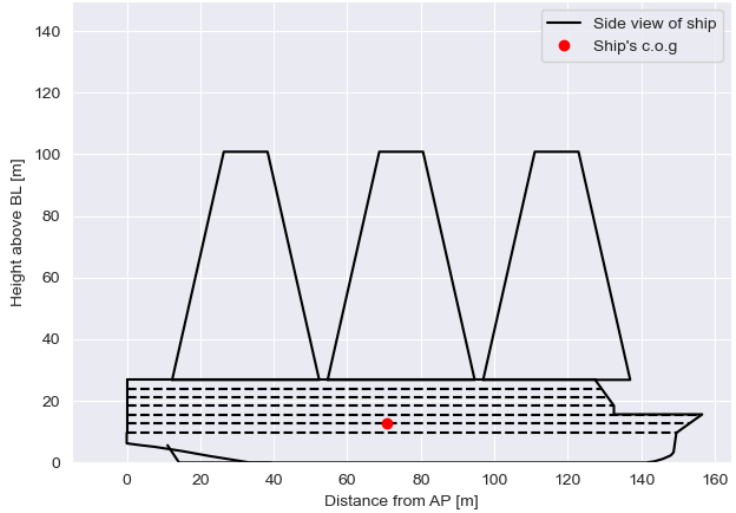


Optimized Design

- Relatively short, wide and beamy design
- Wetted surface is a main driving factor
- Aesthetics may be important in confirming this design

		Reference	Optimized
Length overall	L_{OS}	~210 m	149.5 m
Beam	B	~25 m	28.6 m
Draught	T	~5.40 m	7.21 m
Block coefficient	C_B	Not disclosed	0.50





Power savings and conclusions

- Shaft power reduction of 17% from optimizing main dimensions
- Shaft power reduction of 24% from wind propulsion
- Optimal hull very similar when optimizing with or without wind propulsion

- Importance of shaft power savings diminish when including harbor time and hotel load
- Large part of savings form operational speed
- Combined saving in CO_2 emissions up to 65%

- What about aesthetics and will it all fit?
  - Still traditional design work needed
  - But interesting insights at an early design space

Questions?

