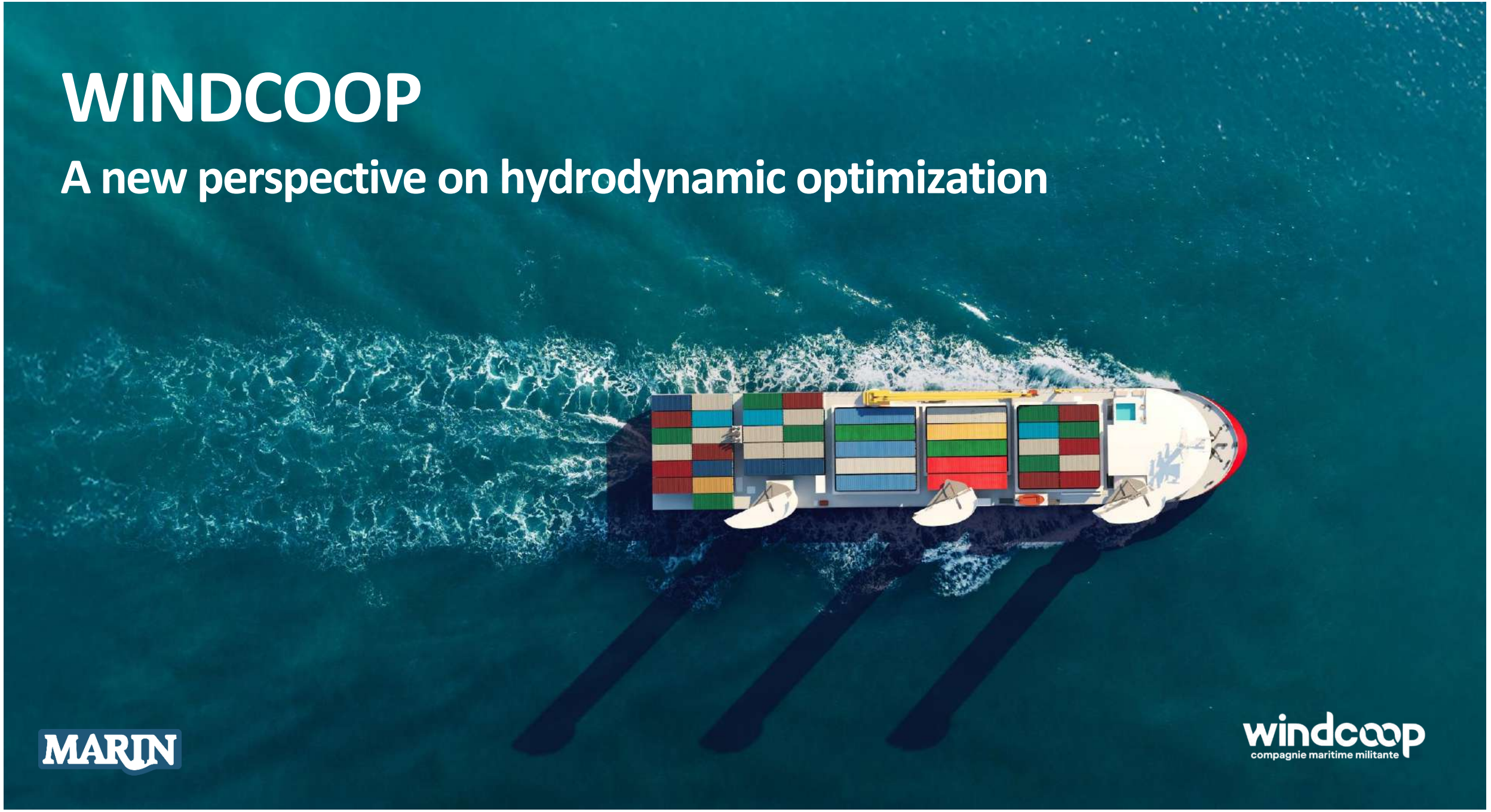
WINDCOOP

A new perspective on hydrodynamic optimization



MARIN

windcoop
compagnie maritime militante

01 Context and project overview

WINDCOOP introduction

A wind-powered shipping initiative

- Founded in 2021 by Zéphyr & Borée, ARCADIE and enercoop
- Low-carbon shipping
- Cooperative business model

Marseille - Madagascar service

- Direct service between Marseille and Madagascar
- Regular liner operations

Strong environmental ambition

- Reduced carbon intensity (g CO_2 / TEU.km)
- Wind propulsion as a primary energy source



02 WINDCOOP vessel

The development of the vessel MIARAKA

An iterative design process, from 67 TEUs to 220 TEUs











2021 Concept 67 TEUs

2023 Scaling up #1 100 TEUs

2024 Scaling up #2 200 TEUs

2025 Rig configuration 220 TEUs

2025 Final design 220 TEUs

Shipbuilding contract
(Main particulars defined)

RMK MARINE

03 Maximizing Wind Propulsion Benefits

A TWO –PHASES OPTIMIZATION PROCESS

I. MAIN PARTICULARS AND OPERATIONAL PROFILE

- CO_2 intensity (g CO_2/TEU.km)
- Transport cost
- Transit time

→ **SHIPBUILDING CONTRACT**

(Main particulars and operational profile defined)

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Pure sailing vessel

II. HULL OPTIMIZATION PROCESS

→ **A new optimization method developed with MARIN …**

- Based on operational profile → variable conditions (Speed, pitch, RPM, …)
- Wind assists conditions (Leeway, Heel angle)
- Including route optimization (routing & speed)

→ **…and respecting contractual constraints**

- Cargo capacity (containers)
- Accommodation
- Bow thruster
- Contract speed (sea trials)
- …



Optimized hybrid vessel

04 The art of hydrodynamic optimisation

The approach for the optimisation of the hull of a wind-powered vessel is different that for a classic motorized vessel

→ The hull optimisation of a classic motorized vessel targets minimal fuel consumption through minimal resistance and maximized propulsive efficiency
- Usually 1 condition (e.g. contractual speed, design draught) or relatively simple operational profile (2D matrix of draughts and speeds)
- Sailing in straight, upright condition
- Hull-propeller interaction, considering a relatively constant propeller loading (KT)

→ However, a wind-powered vessel takes a large part or the entireness of its propulsion from wind.
→ Therefore, the hull form will be determined from the route (and the associated wind conditions) the vessel will be sailing on.
- Objective becomes fuel consumption along the given route
- The operational profile extends to include wind (and wave) conditions (speeds, direction)
- Sailing in straight and upright condition, but also under drift and heel
- Large variations in propeller loading
- Trade-off between optimal resistance and sufficient course-stability

05 The art of hull form optimisation

The different steps in the optimisation

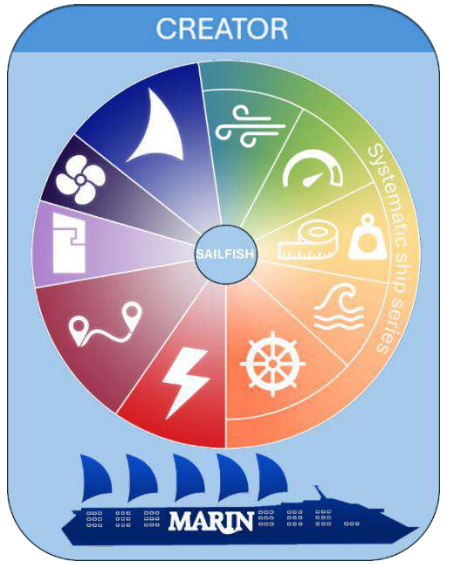
- Determination of the environmental conditions
  - BlueRoute (wind conditions)

- Determination of the sailing profile (initial PPP)
  - Using initial numerical models (hydro, aerodynamics, propulsion, etc…)

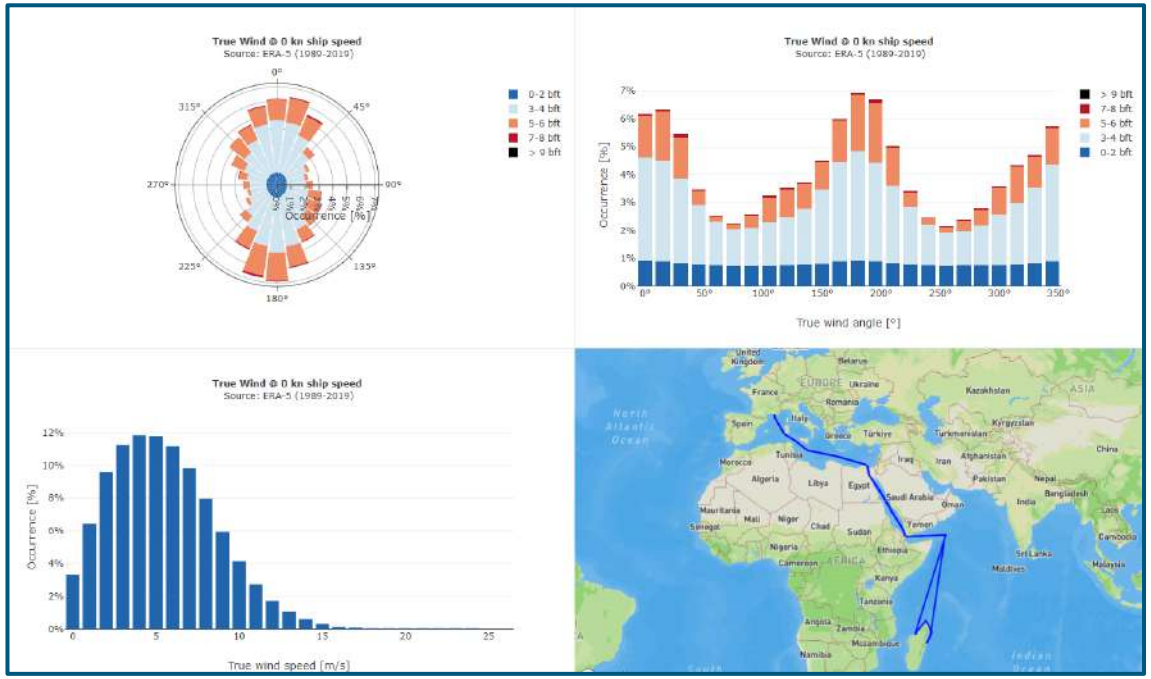
- Identification of the optimisation constraints (design restrictions due to cargo capacity, etc…) and operational constraints (heel angle, rudder angle, leeway angle)

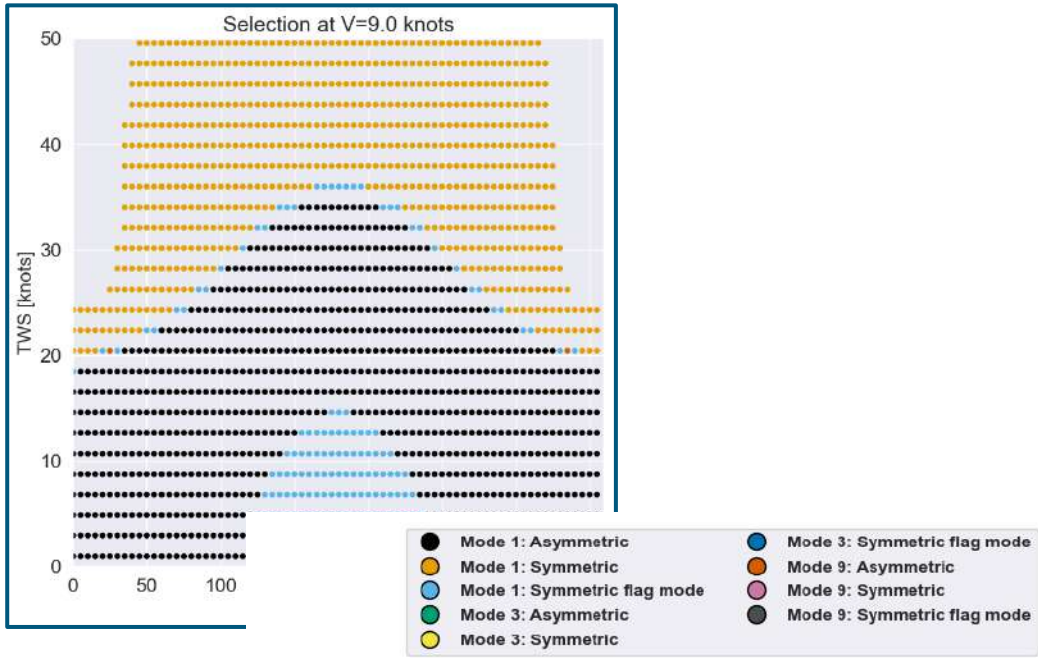
- Initial hull form analysis, including wake field

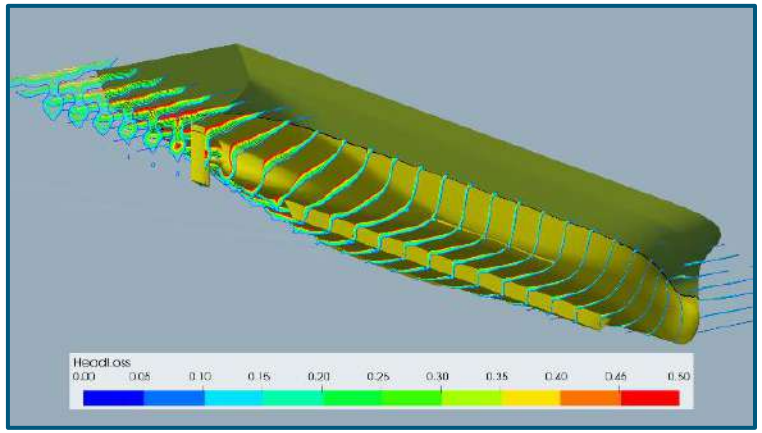
- Hull form optimisation
  - Manual form exploration, search for improvements in most typically encountered sailing configurations
  - Innovative approach where:
    - every single variation is evaluated through CFD (sailing straight and under leeway) and a (simplified) PPP
    - The results from the weighted PPP simulations (based on the voyage simulations) are fed to an optimiser to optimise the fuel savings and CLR under 3 deg leeway

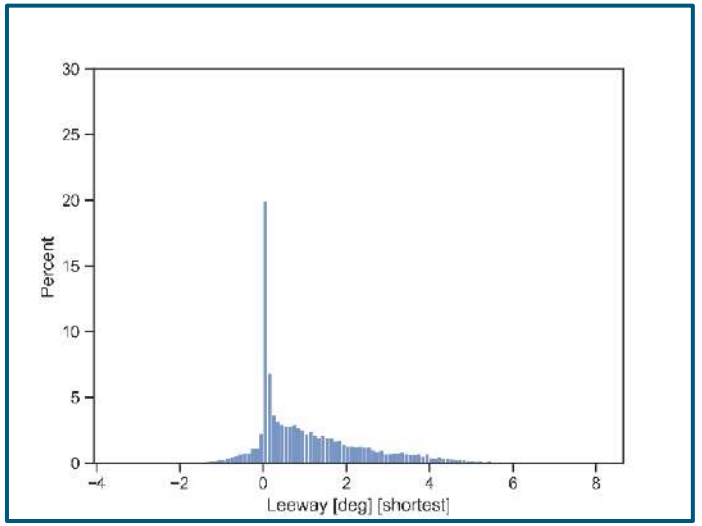


06 Initial conditions







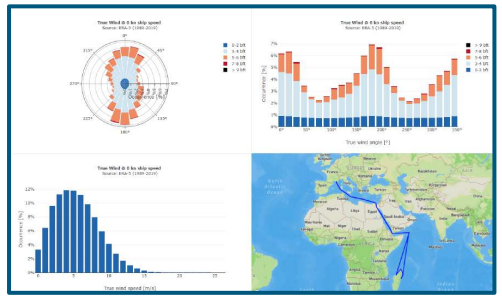


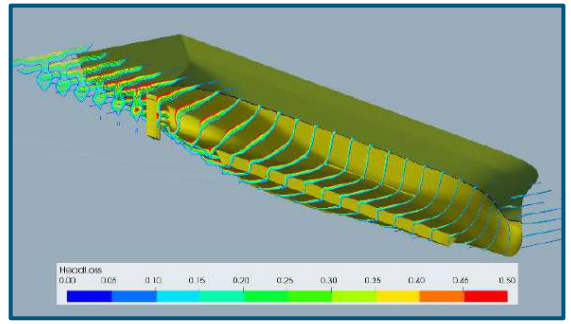
07 Initial conditions

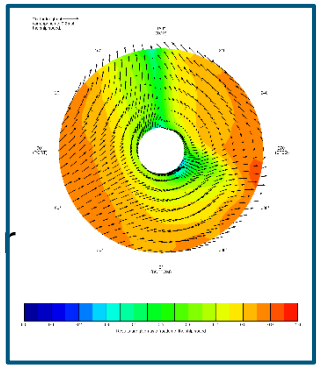
- Initial analysis of hull form and effective wave field
  - RANS-BEM calculations using MARIN's codes REFRESCO (RANS) and panel code PROCAL
  - Evaluation of wave systems, viscous losses and areas of reversed flow
  - Effective wake field → input for propeller design
  - Effective wake field → effect of skeg at drift angles 0°, 3°, 6° and 9°

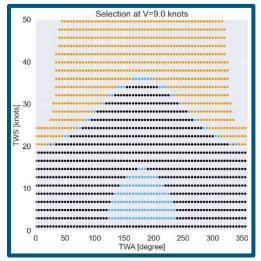
- Performance prediction program (PPP)
  - Sailing on fixed route (see above) at a fixed speed (9, 10, 11 and 12 knots)
  - Preferred propulsion modes as function of speed
  - Wind conditions (TWS, TWA)
  - Influence of sail protection curve (asymmetric, symmetric, symmetric feathered)

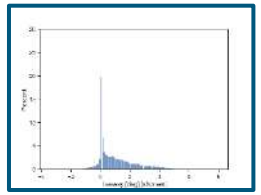
- Voyage simulations
  - Sailing on fixed route or sailing on route including weather routing
  - Prediction of CO2 emissions along the route
  - Insight in the operational profile of the vessel (speed, leeway, heel, rudder angle, propeller rotation rate (including 'smart' combinator curve)







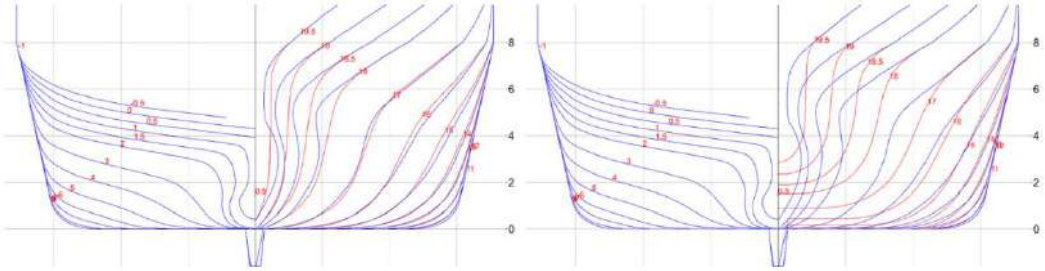


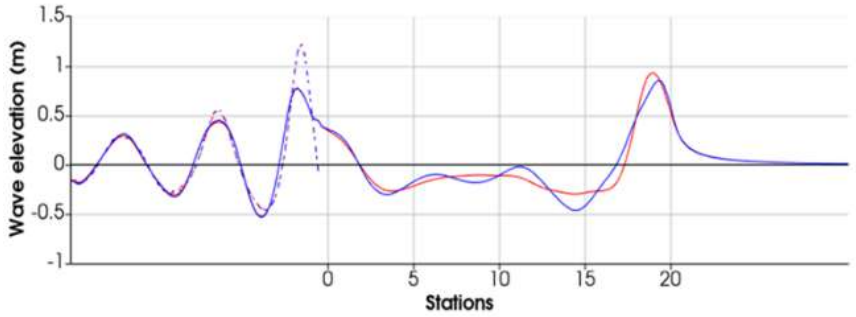


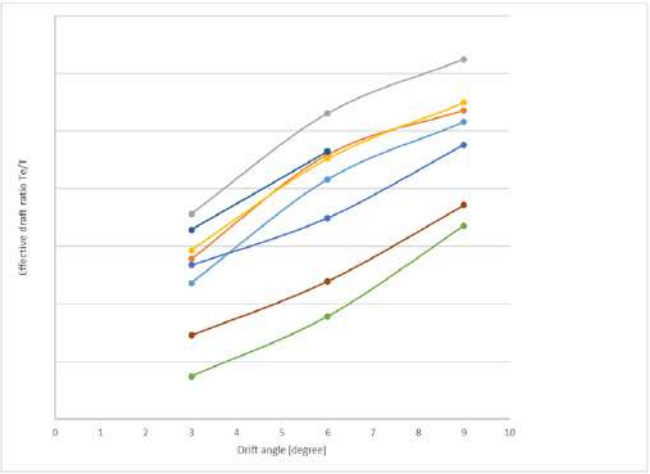
08 Hull form optimisation

- **First phase: manual hull form exploration (potential flow, RANS)**
  - Obtain a relatively good hull form for the second phase
  - Explore the effect of major changes in hull design
    - Removal of the bulb
    - Larger bulb
    - Fore shoulder variation
    - Lifted bow without bulb, inspired by classical sailing
    - Raising transom
    - Adding deadrise
    - Etc…
  - Drift keel kept unchanged

→ Benefit observed from raising transom
→ Variation with bow up valuable for the second phase (parametric optimization) due to performance under drift







09 Hull form optimisation

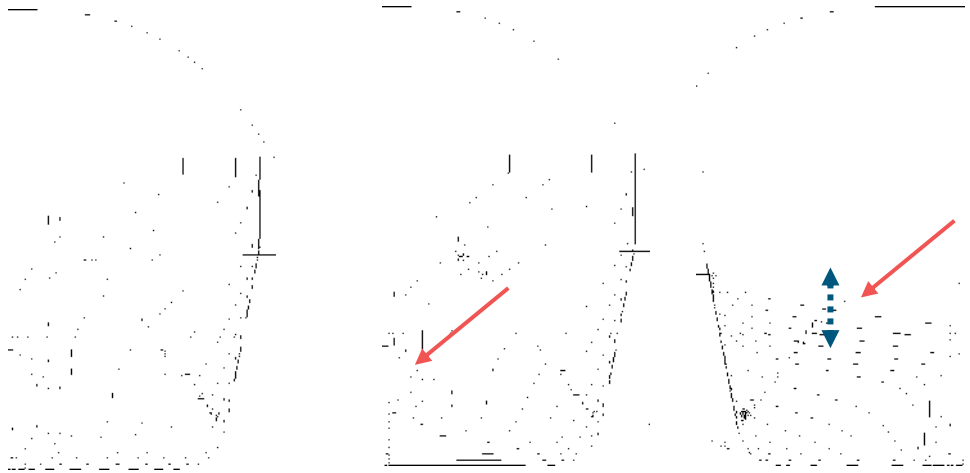
- **Second phase: parametric hull form variation (RANS, PPP)**
  - Use of the knowledge from previous phase
  - Intermediate hull form used as reference
  - Hull form variations
  - Drift keel (skeg) variations
    - Length
    - Position
    - Slope

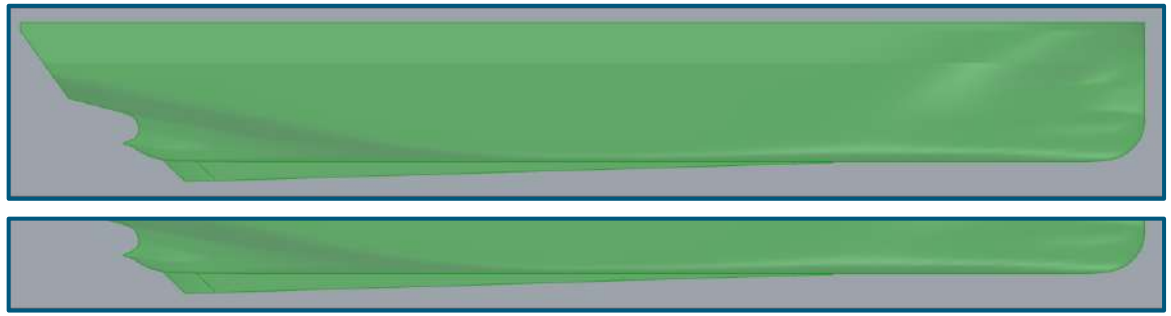
  → <u>64 different combinations of hull form and drift keel</u>
    - DoE realized by a Latin Hypercube sample plan

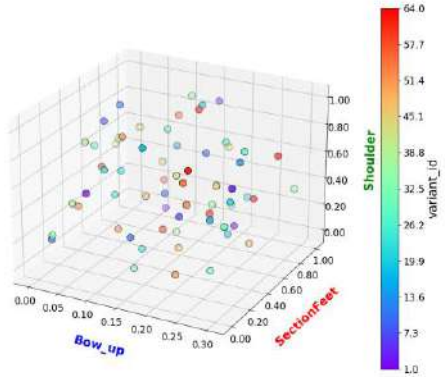
  - One propulsion mode
    (engine for propulsion, generator set for hotel loads)

  - One sail mode (asymmetric)

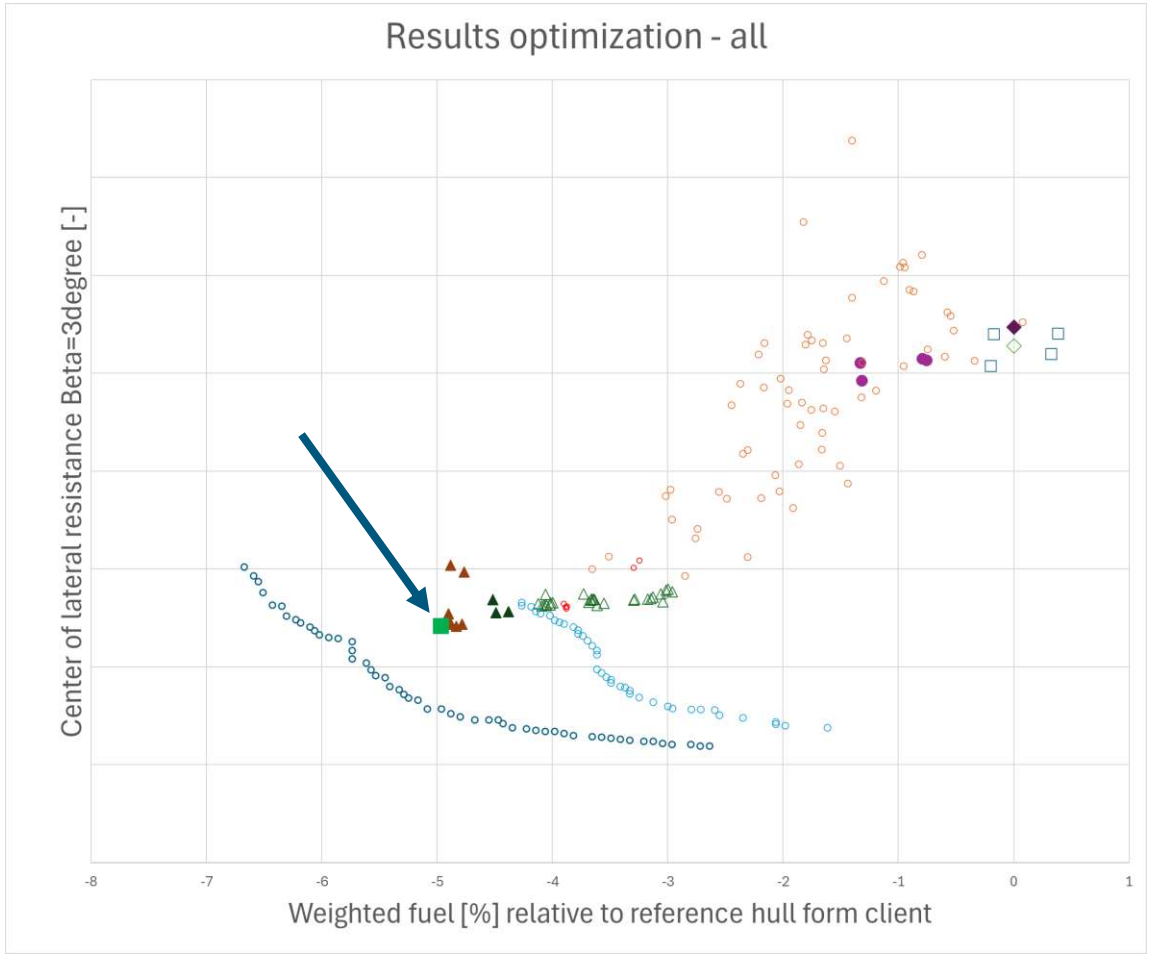
  - 4 speeds, covering the expected speed range







10 Results



- Reference hull client
- Reference hull client [fine]
- Corners points [hull form]
- Corners points [hull form- Fine grid]
- DOE [64 samples]
- Estimated pareto
- Evaluated pareto
- Estimated pareto iteration 1
- Evaluated pareto iteration 1
- Evaluated pareto [fine]
- Evaluated pareto [fine - No Bow up]
- Winning hull form [fine]

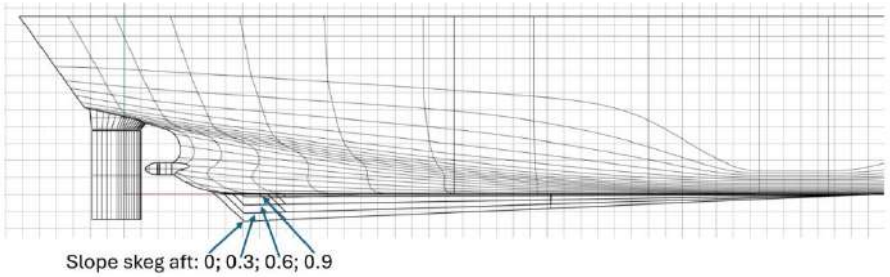
11 Further appendage refinement

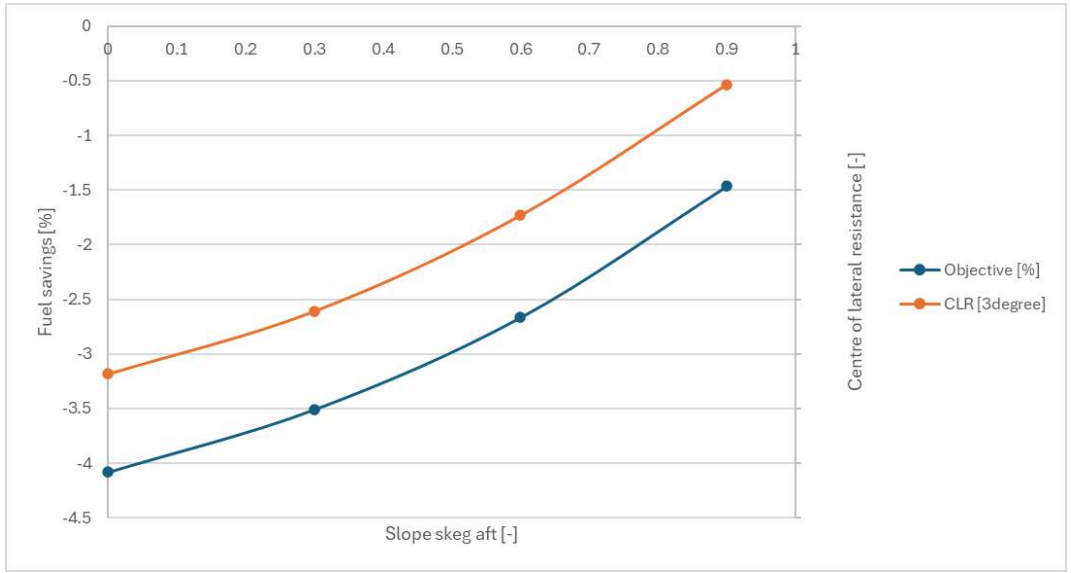
- **Third phase: a smaller parametric variation of appendages (RANS, PPP)**
  - Variation on drift keel height, width and shape
  - Variation on bilge keel position
  - Variation on rudder size

→ reducing the drift keel height is beneficial for resistance but **detrimental** for fuel savings

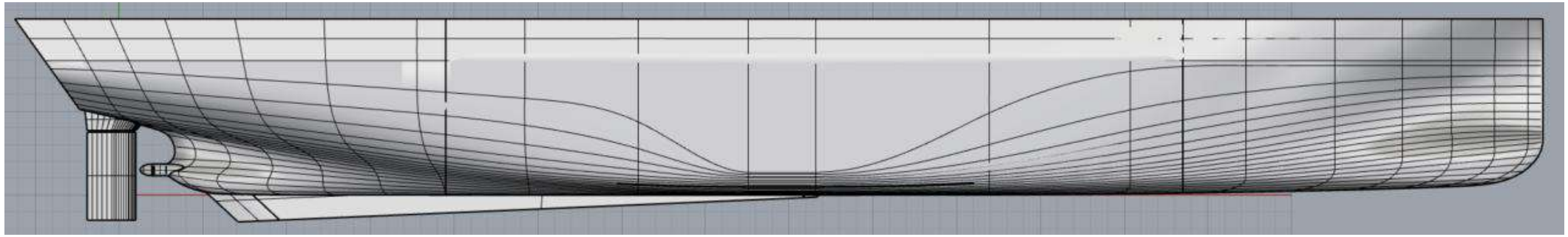
→ increasing the keel height moves the centre of lateral resistance backwards and reduces the drift angle

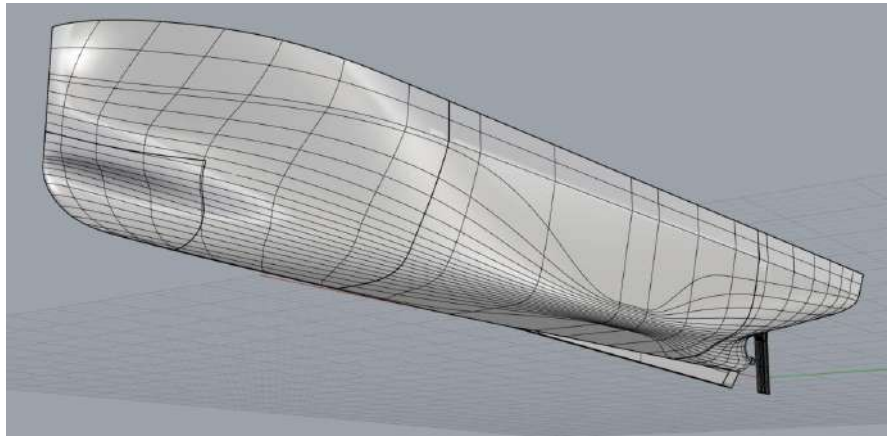
→ **highlights the fact that such ships need to be optimized in a broader range of conditions than pure straight sailing.**

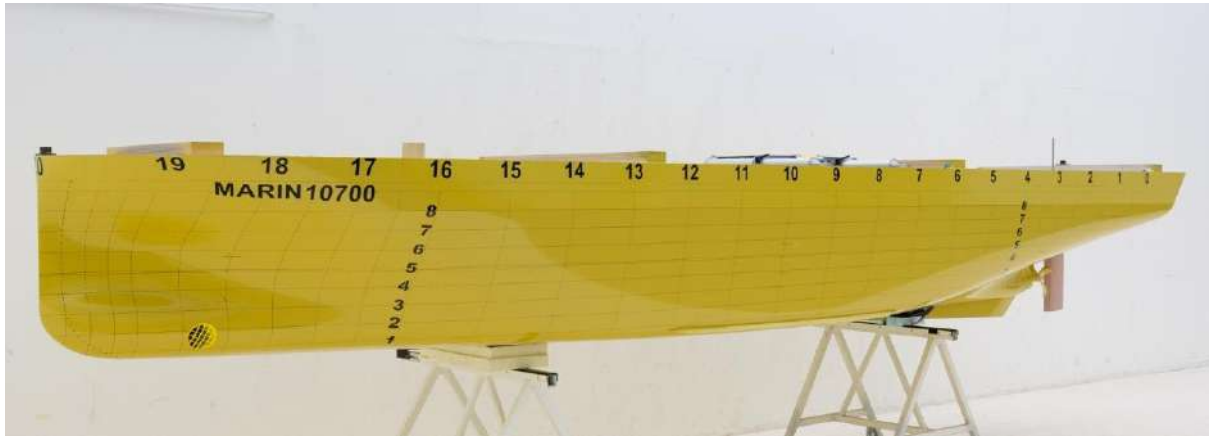




Results: optimal hull form and appendages

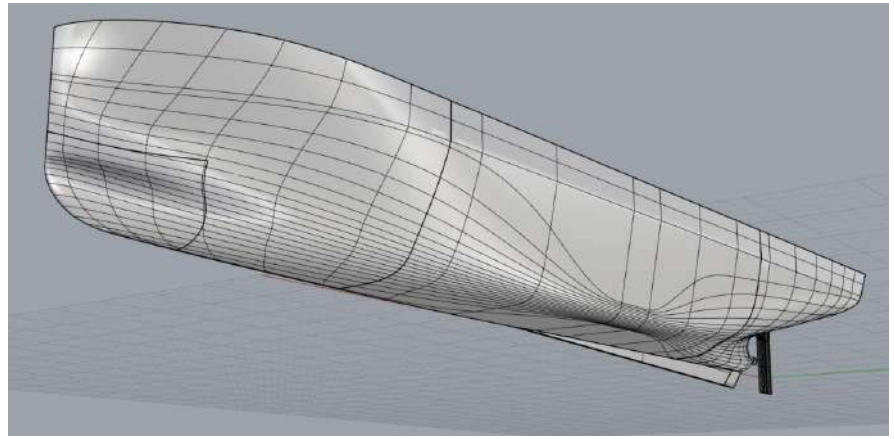




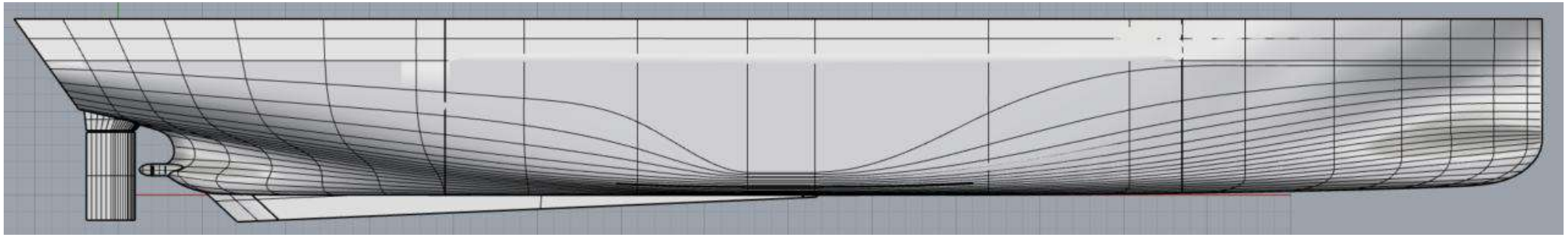


13 Assessment with final hull form

- **The selected optimum hull form features**
  - a sloped skeg moved aft of moderate length
  - a bow raised to the maximum allowable vertical position to accommodate the bow thruster
  - a raised transom.
  - the fore and aft sections are more rounded than those of the original hull form.
  - the skeg has a rounded leading edge and unchanged width compared to that of the original design.
  - the rudder remains identical to that of the reference hull form
  - the bilge keels are centred around midship

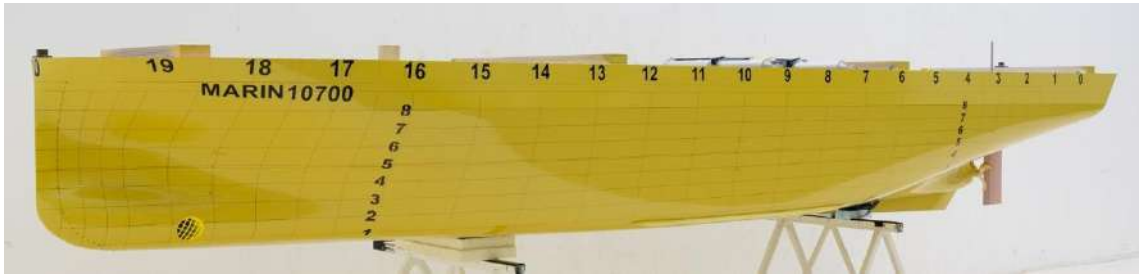


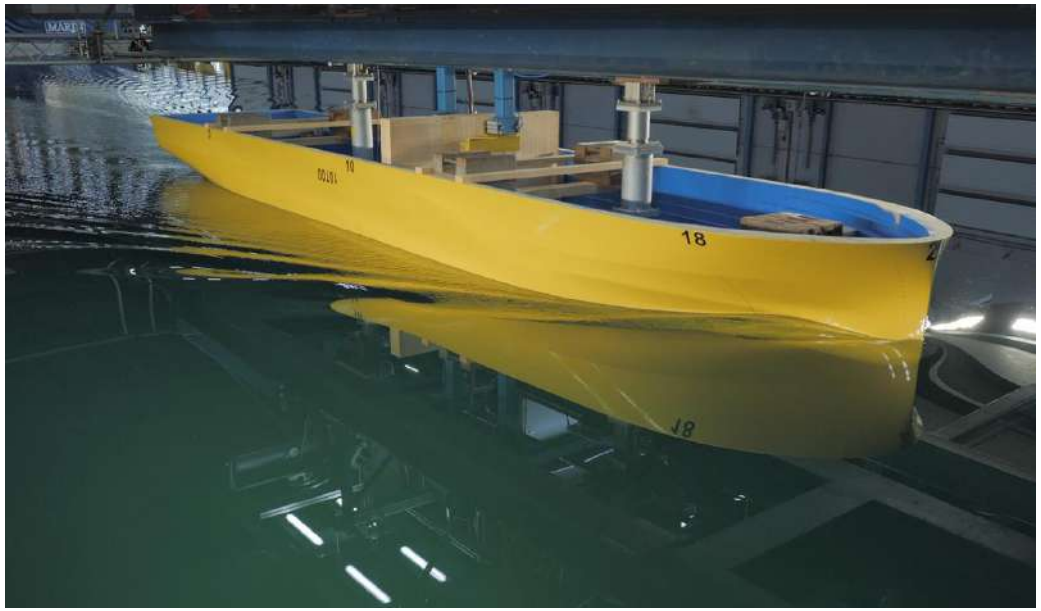
- The selected hull form is expected to deliver about 5 % fuel savings compared with the initial hull form



Model tests

- **Model tests performed with a semi-captive model**
  - Model scale 1:13.5, model length approx. 6.5 m
  - Objective: develop a hydrodynamic force database
    - Ship drag and lift forces and moment around vertical axis
    - Variation in drift angle, heel angle, speed, propeller thrust contribution



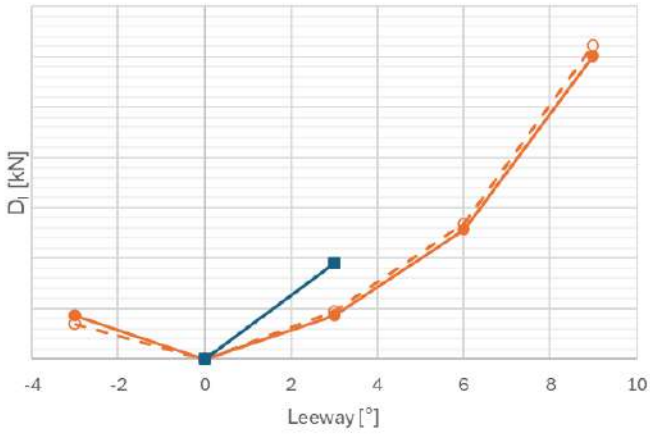


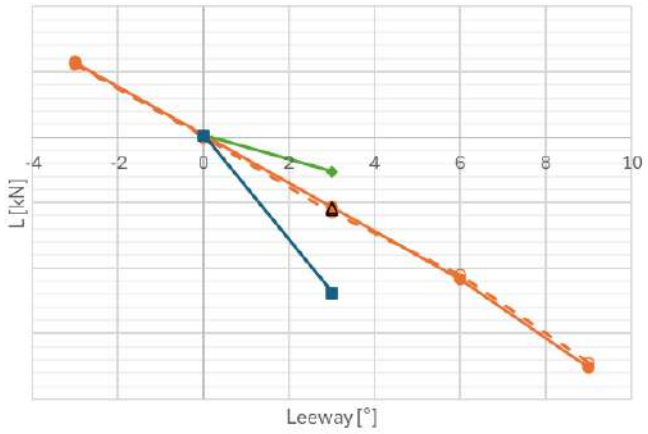


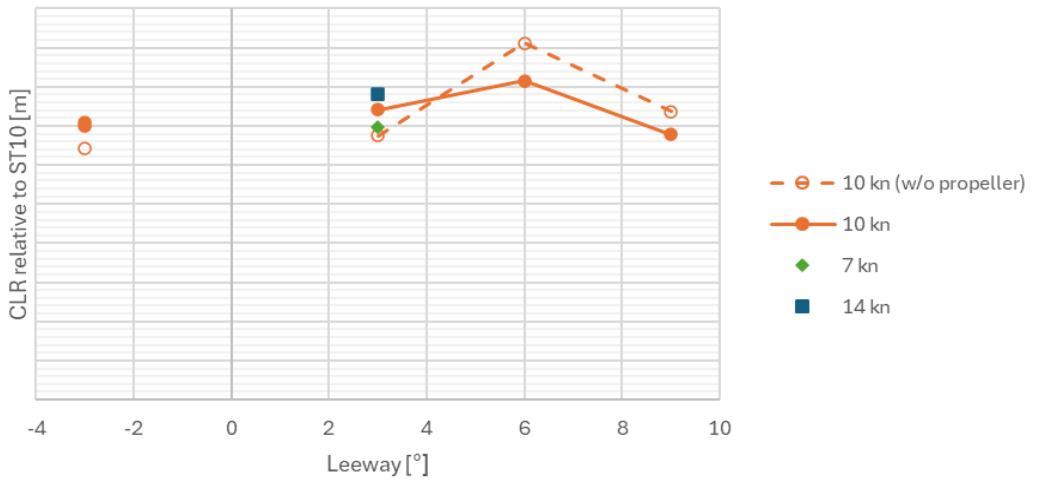
15 Model tests

- **Model tests performed with a semi-captive model**
  - Effect of appendages (with and w/o rudder, bilge keels)
  - Effect of trim



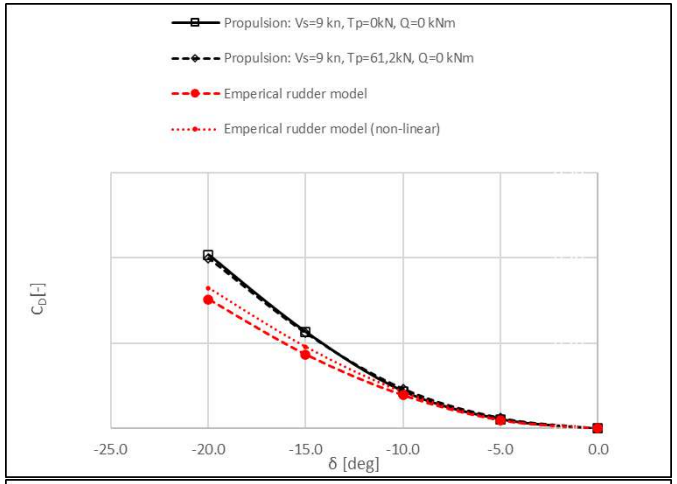


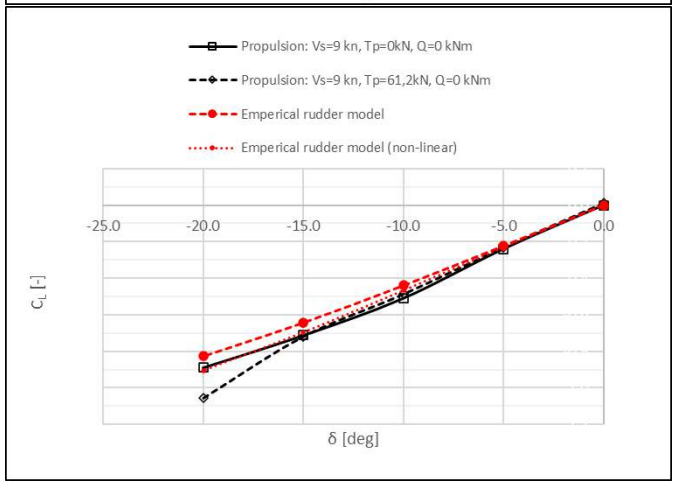


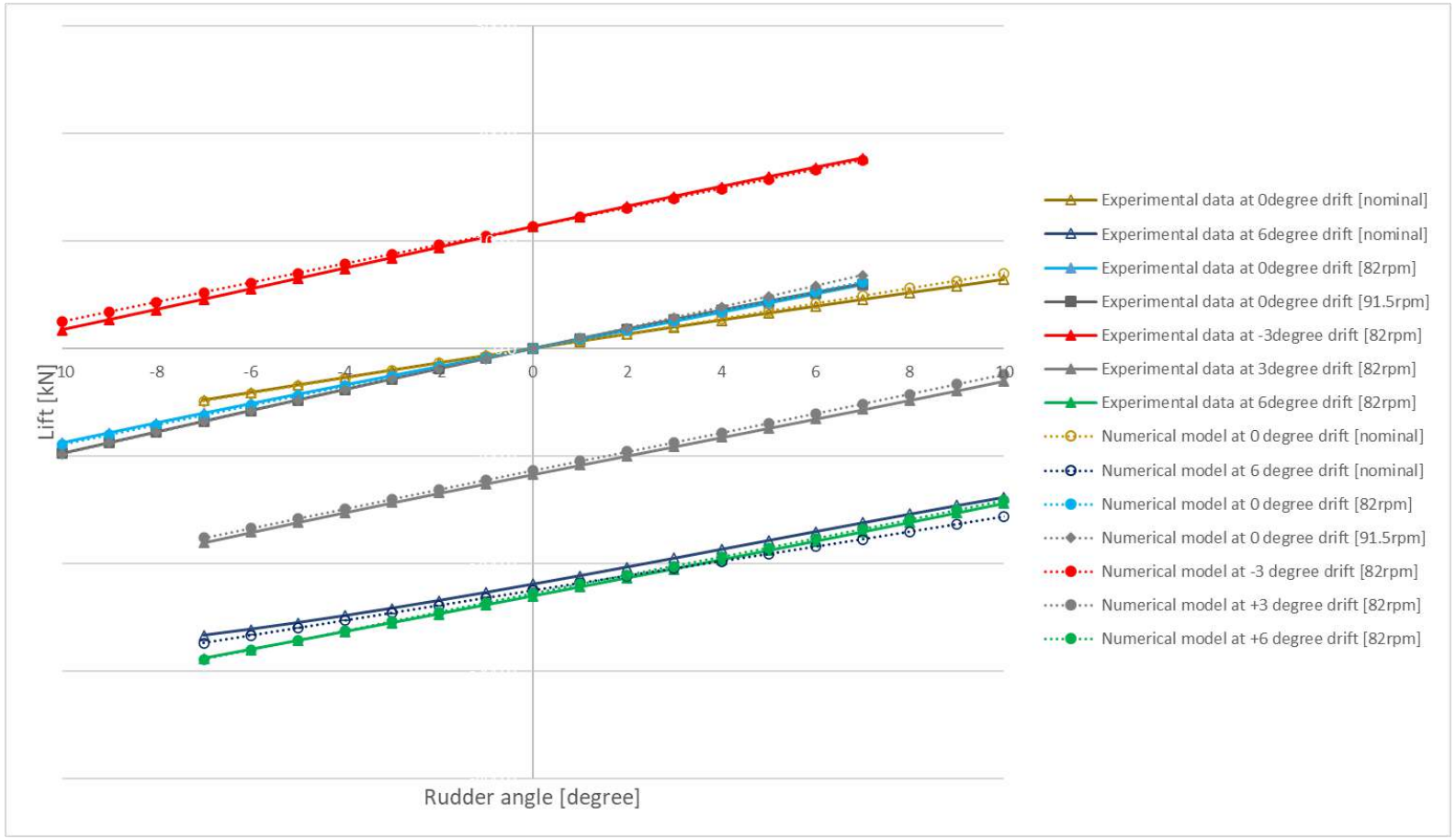


Tuning of numerical model

- **Tuning of the numerical model based on the results of the model tests**
  - CL / CD model of the hull
  - CL / CD model of the rudder

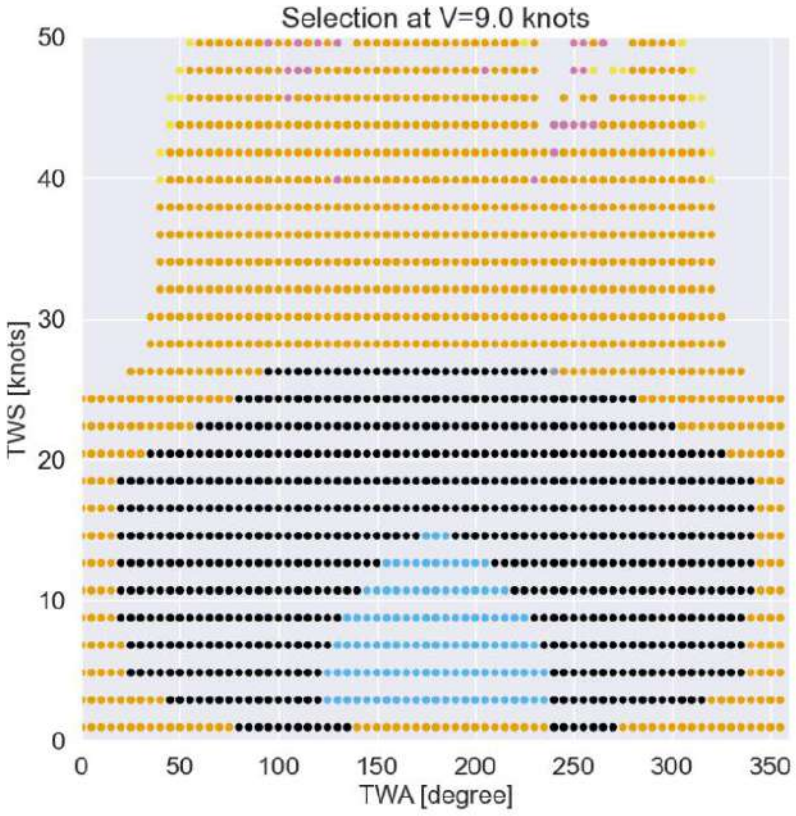


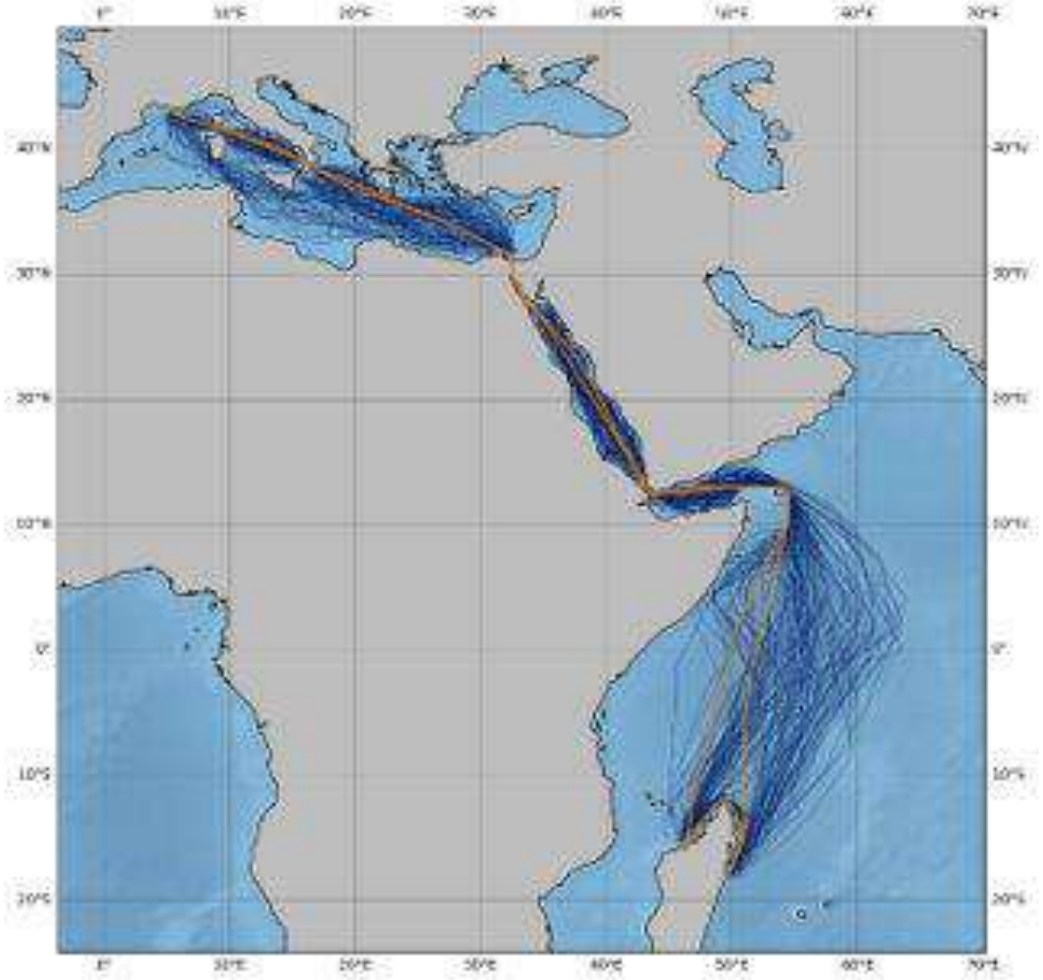




Final PPP and voyage simulations

- **After the numerical models have been tuned, the PPP and voyage simulations were executed once again**





18 Final PPP and voyage simulations

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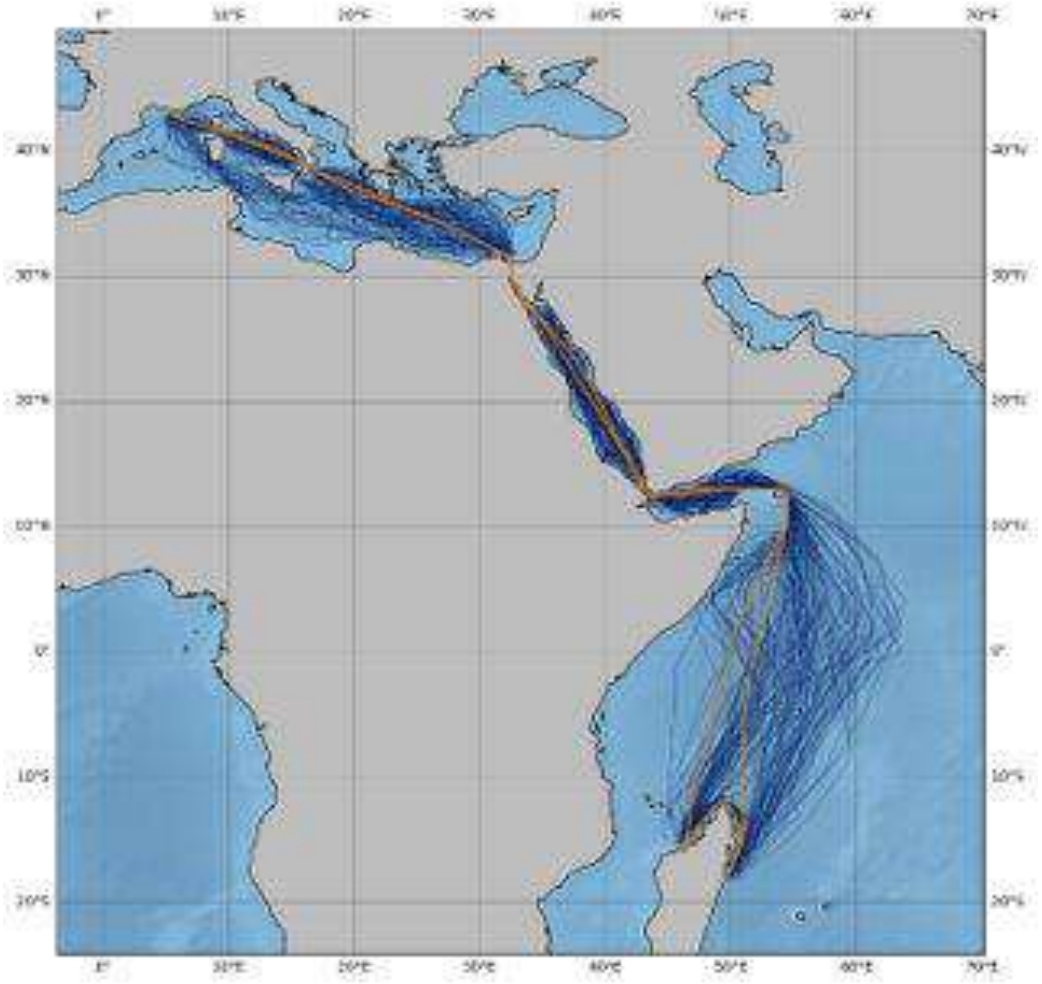

Route optimisation benefits		
Leg	**At Ballast**	**At Design**
Marseille - Suez North	+20.6%	+16.9%
Suez North - Suez South	0.0%	0.0%
Suez South - Djibouti North	+14.8%	+10.1%
Djibouti North - Djibouti South	0.0%	0.0%
Djibouti South - Tamatave	+45.3%	+41.0%
Tamatave - Diego Suarez	+9.7%	+6.3%
Diego Suarez - Majunga	+2.8%	+3.3%
Majunga - Djibouti South	+26.7%	+22.7%
Djibouti South - Djibouti North	0.0%	0.0%
Djibouti North - Suez South	+25.7%	+19.5%
Suez South - Suez North	0.0%	0.0%
Suez North - Marseille	+29.5%	+24.8%
Total voyage	**+27.3%**	**+23.2%**

19 Conclusions

- **The WINDCOOP project was subject to a new hydrodynamic optimization approach**

- In this approach the hull form was optimized considering the particular conditions encountered by a sailing ship:
  - Sailing straight and sailing under drift and heel
  - Importance of the route
  - Importance of good anti-drifting performance versus resistance

- Each hull form and appendage variation was subject to a separate PPP calculation

- Target was lowest CO2 emissions along route, with and without rerouting

- The optimal skeg was found to be the largest from all variations, highlighting the contribution of efficient anti-drifting measures (high lift, low drag) on the final CO2 emissions.

- Still some improvements in the process are needed:
  - Improve the streamlining process between numerical and experimental work
  - Extend the scope of the optimization to include propeller design

Thank you

