WIND ASSISTED PROPULSION IN CRUIZERO PROJECT

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CruiZero Project

Objective:
"Develop one or more zero-emission expedition cruise ship concept designs by developing new and improved ship design processes through simulation tools handling new zero emission technology for the cruise ship market."

Compagnie du Ponant in the Antarcti

Participants:
- Vard
- ABB
- SINTEF Ocean

VESSEL AND MISSION:

- Passengers approx. 300
- Crew approx. 150
- From May 21th until September 7th the vessel operates a northern expedition route, its southern extreme is Tromsø (red dot)
- From November 23rd until March 22th it operates a southern expedition route where the northern extreme is Ushuaia (red dot)
- The vessel has a cruise-like transit between the expedition routes. The northern and southers transit route differs crossing the atlantic ocean, arrows shows the direction of these.

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Relevant Technology

- Hydrogen fuel cells
- Sails
- Re-generative propulsion
- Solar panels
- Backup power source alternatives
- Battery pack in keel for power storage and stability
- Maximized utilization of waste heat
- Alternative hullforms
- Circular resource economy (waste handling)
- Air lubrication
- Wave-foils and similar

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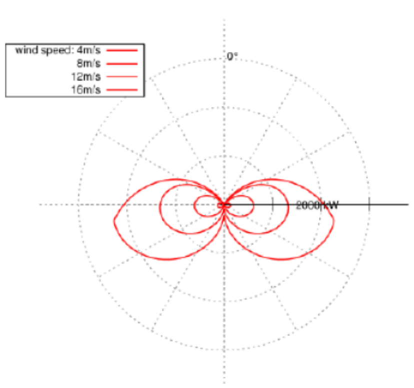
Wind Propulsion

CruiZero considerations:

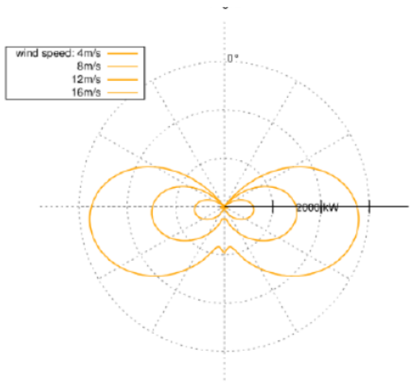
- ➢ Deck space area
- ➢ Heeling moment and angle
- ➢ View from bridge and passenger areas
- ➢ Vertical height
- ➢ Crew operations
- ➢ Aesthetics

Polar graphs

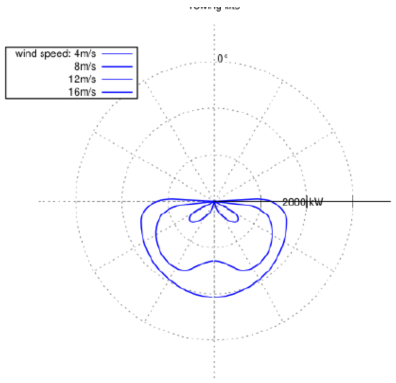
Rotor



Wing Sail



Kite



Sail area generating the same lift

Considered Wind Propulsion Concepts

Flettner rotors/ Rotor sails

+ **Highest lift ratio vs footprint** of all the available wind propulsors (Except for kite sails), i.e. requiring the least space per thrust force
+ Relatively **simple installation**
+ Relatively **simple operation**, limited crew training required
+ **Robustness**
+ Commercially available and **relatively mature**

- Requires a **driving motor** for rotation (require maintenance)
- **Low lift vs drag** ratio
- **Noisy**, vibrations travelling through the supports into the hull
- **Static drag in head winds** may be substantial
- **Lowering the rotors if poses a technical challenge** although tiltable concepts do exist.

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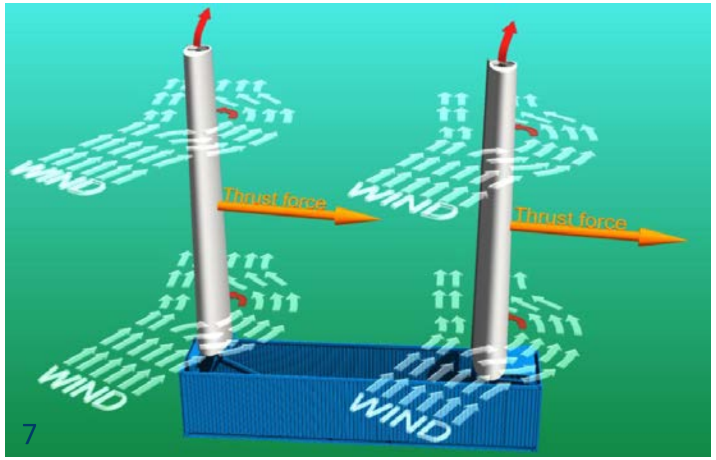
Considered Wind Propulsion Concepts

Suction Wing Sails / Ventilated foil systems



+ Produces **large lift force** compared to footprint.
+ Relatively **simple installation**
+ Relatively **simple operation**, limited crew training required
+ Assumed **robust design** (although yet to be proven in long term operation)

- Requires a fan (although low power consumption is indicated by suppliers)
- Fan bearings require **maintenance**
- Problems with **noise** and/or **vibrations**?
- **Static drag in head winds** are probably larger than for wing sails (but foldable technologies are available. The boundary layer control can potentially also decrease the drag in head winds – but the cost-benefit versus the power needed for the fan is uncertain.

Considered Wind Propulsion Concepts

Rigid Wing Sails

+ High aerodynamic **efficiency** (lift to drag ratio)
+ Able to provide thrust for a **larger range of apparent wind angles**
+ Able to provide **thrust at higher ship speeds** (because of the point above)
+ **Low drag in head winds** (by reefing or aligning the profiles to the wind direction)
+ Wing sections are stable and of relatively **robust** materials
+ **Minimal power required** for adjusting sail orientation and reefing/furling.

- **Limited market experience** (except for racing boats)
- **Limited market availability**
- Challenging **mechanical design** (adjusting sail orientation, reefing)
- **Inspection** and **maintenance** (bearings, gaskets, etc).
- Demanding to design a solution which **provide enough sail** area without conflicting with other requirements

Considered Wind Propulsion Concepts

Soft Wing Sails

+ High aerodynamic **efficiency** (lift to drag ratio), can be improved by **adjustable camber and twist**
+ Able to provide thrust for a **larger range of apparent wind angles**
+ Able to provide **thrust at higher ship speeds**
+ **Low drag in head winds** (by reefing or aligning the profiles to the wind direction)
+ Wing sections are stable and of relatively **robust** materials
+ **Minimal power required** for adjusting sail orientation and reefing/furling.

- **Limited market experience** (except for racing boats)
- **Limited market availability**
- Challenging **mechanical design** (adjusting sail orientation, reefing)
- **Inspection** and **maintenance** (bearings, gaskets, etc).
- Demanding to design a solution which **provide enough sail** area without conflicting with other requirements
- **Strength and durability of the soft cloth** (exposed to forces, sun radiation, heat, cold, ice, humidity, etc.)

Considered Wind Propulsion Concepts

Soft Sails

+ Able to provide thrust for a **large range of apparent wind angles**
+ Provide **thrust at higher ship speeds** (compared to Flettner rotors)
+ **Low drag in head winds** (furling or aligning the profiles)
+ **Small amount of added power** required for adjusting sail orientation and for reefing/furling.

- **Low aerodynamic efficiency**
- **Limited market experience** on large vessels
- **Limited market availability**
- Challenging **mechanical design** (adjusting sail orientation, reefing)
- **Inspection** and **maintenance** (bearings, gaskets, etc).
- **Provide enough sail** area (conflict with other requirements)
- The **soft cloth strength and durability (**forces, sun radiation, heat, cold, ice, humidity, etc.)

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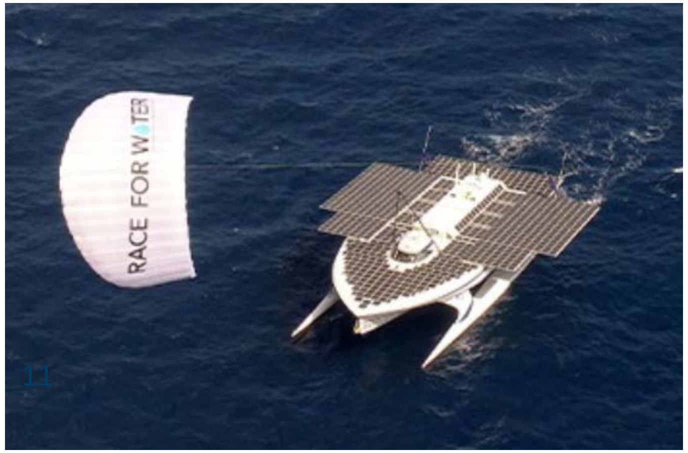
Considered Wind Propulsion Concepts

Kite Sails



+ **Minimum deck space** requirements
+ Does **not block view** from bridge or passenger areas
+ Operating at **strong and stable wind speeds** due to the high operating altitude.
+ **No added wind resistance when not in use**.
+ Can be installed in **addition to a deck mounted wind propulsion system**.

- **Unable to provide thrust in head wind sector** (~280-80 degrees)
- **Manual operations are needed for launching and recovery**
- In case of operation failure, **recovery of the system can be challenging** and cause line entanglement.
- The kite and rope strength and **durability**, under exposure to forces, sun radiation, heat, cold, ice, humidity, etc. is a potential issue, and they will likely need regular **maintenance**

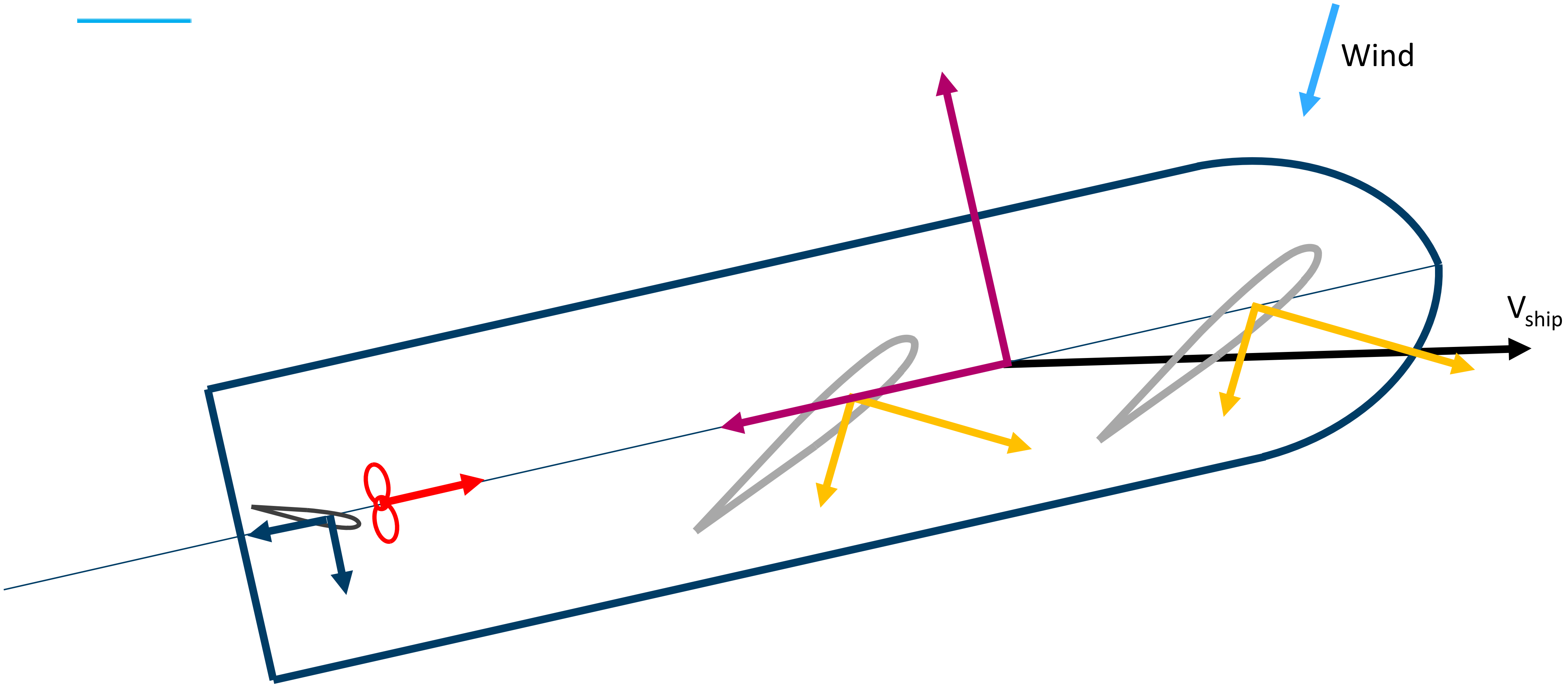
Work in progress – VPP software

- Develop efficient software to calculate thrust from wind propulsor
- Challenge: Find sails settings (orientation of sails, rotation speed for Flettner rotor) that requires minimum additional thrust from conventional propeller.

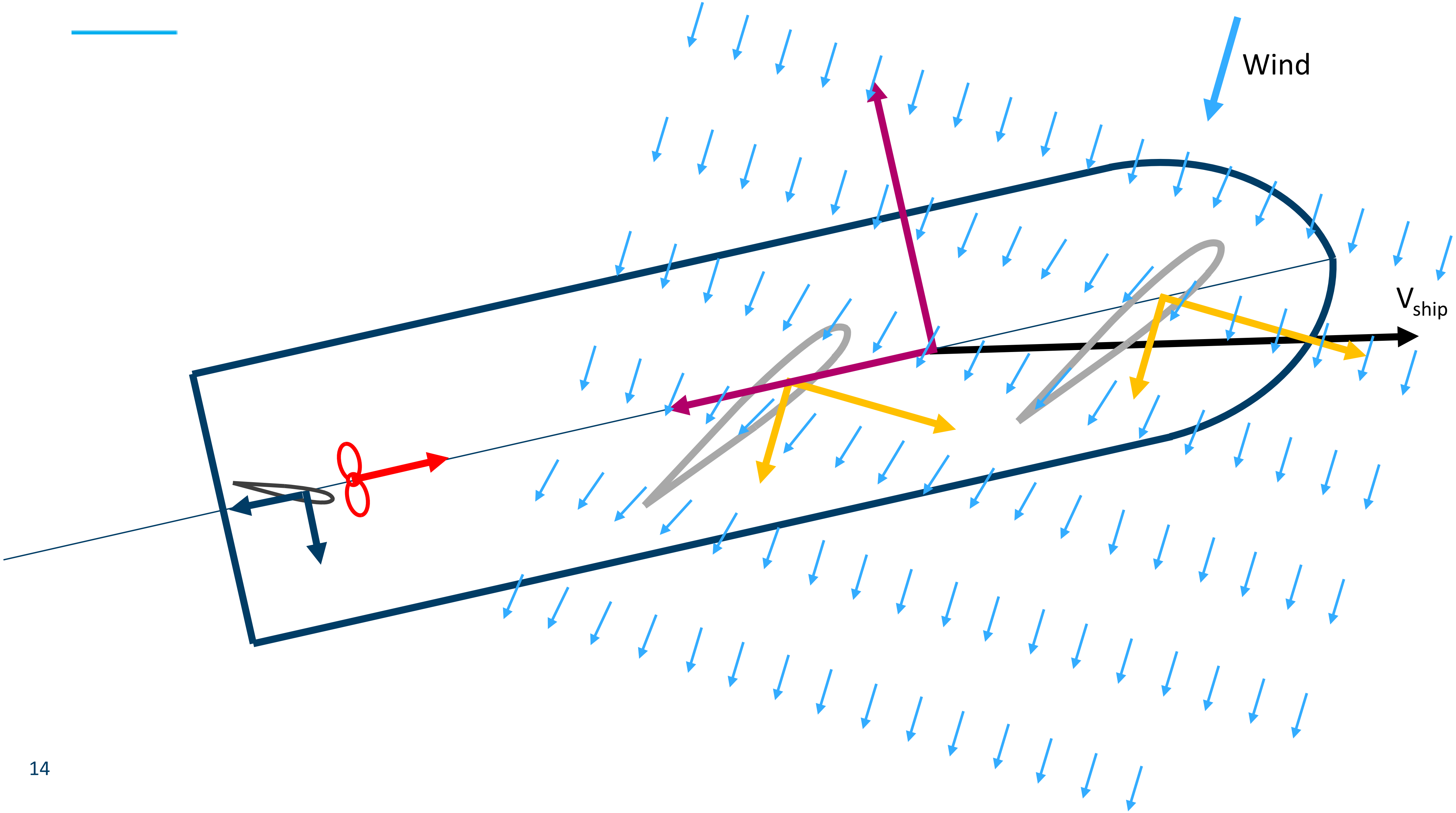
  => Optimization problem

- Developed tool will be included in the **ShipX** workbench and used together with the **Gymir** ship power prediction software in combination with the **RuteSim** software for weather routing optimization.

Hydrodynamic and Aerodynamic Forces



Sail/Sail interaction



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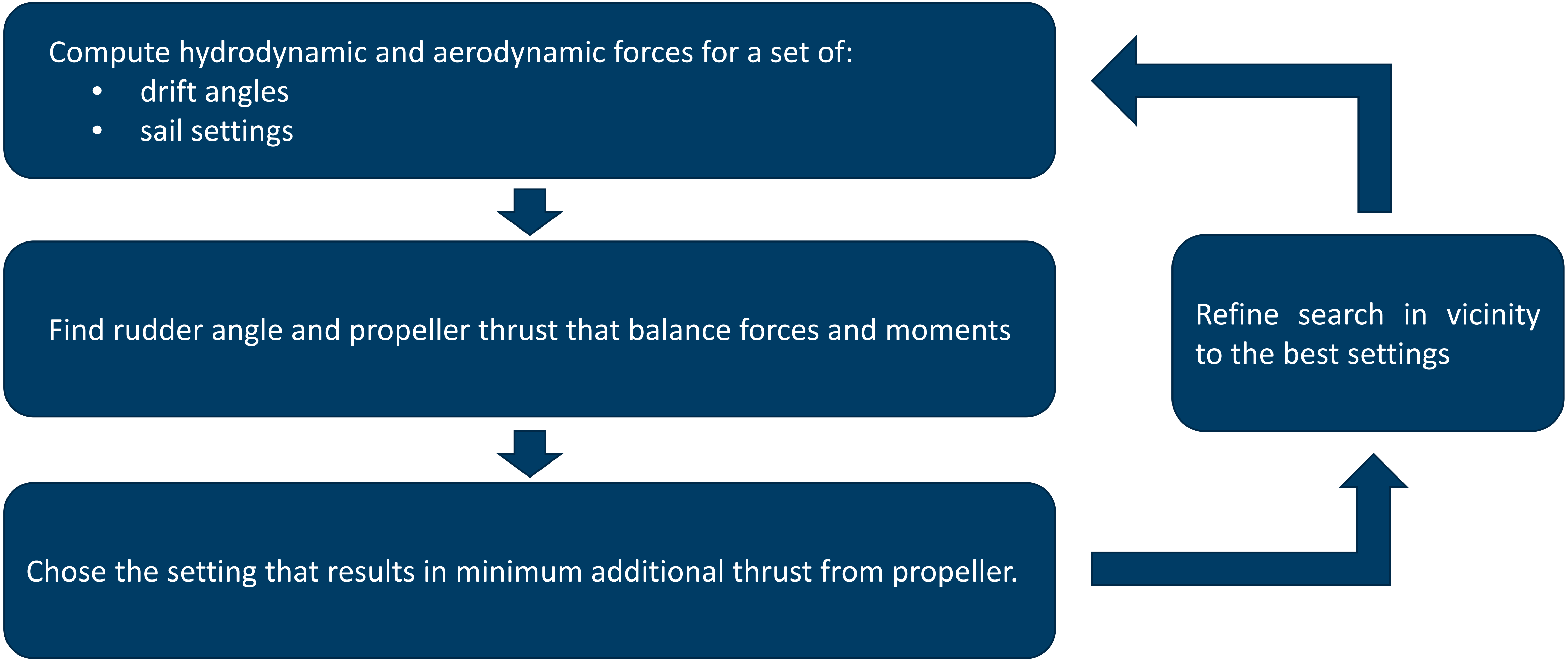
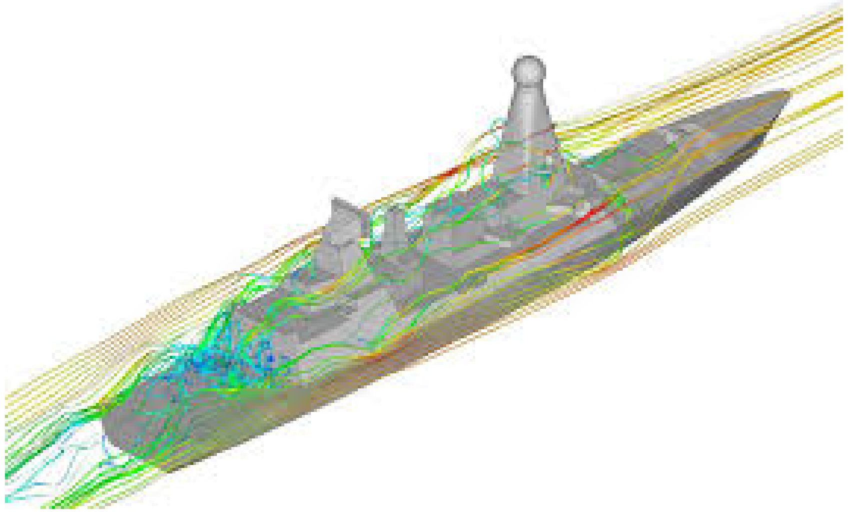
Solution Method

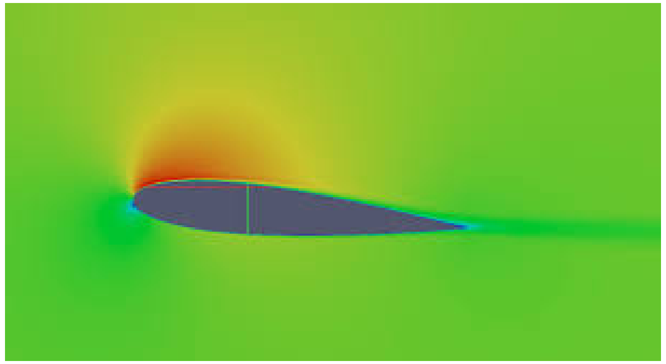


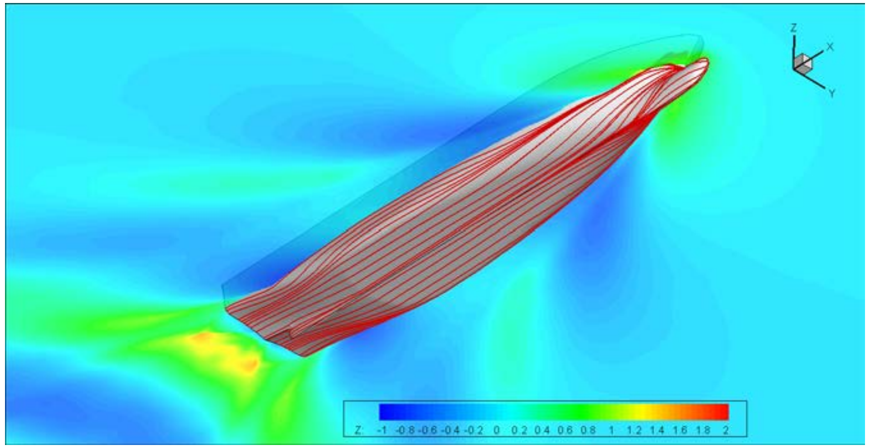
Solution Method

Prior to simulations, use CFD to create data base with force and moment coefficients for:

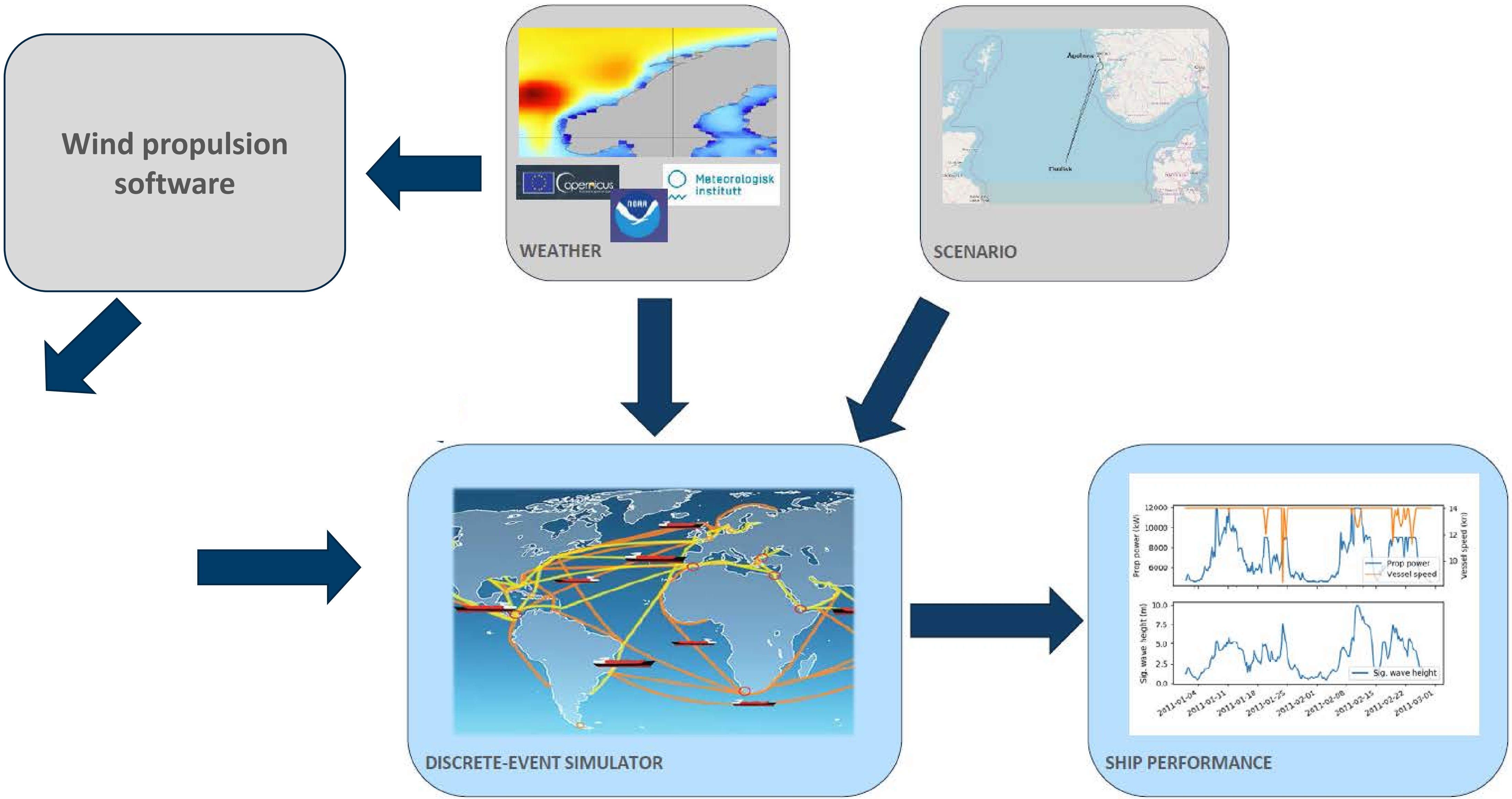
- Aerodynamic forces on superstructure for different wind headings
- 2D/3D wind force coefficients for wind propulsor
- Hydrodynamic forces and moments for hull at different leeway angles







Implementation in Gymir



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