RETROFIT55
Funded by the European Union
Horizon Europe programme, grant agreement No. 101096068

RETROFIT55

RETROFIT SOLUTIONS TO ACHIEVE 55% GHG REDUCTION BY 2030

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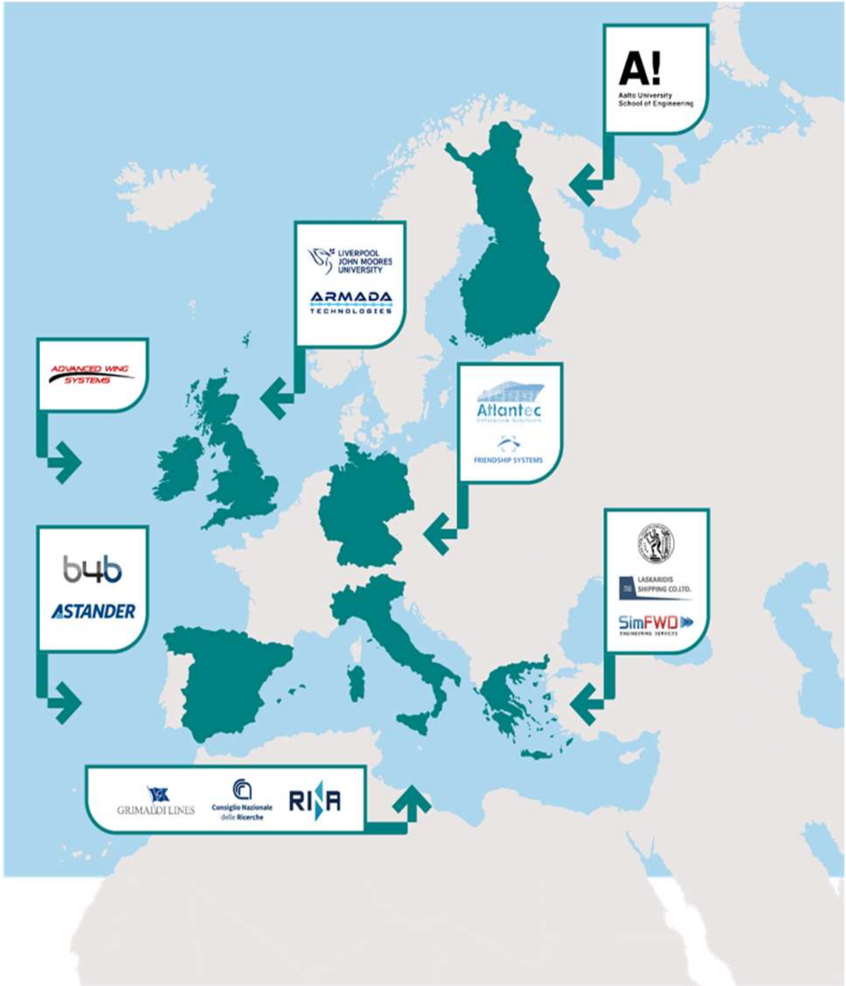
RETROFIT55 project

- RETROFIT55 aims to develop decarbonization solutions and green technologies which can be used by ship-owners to reduce fuel consumption and Greenhouse Gas (GHG) emissions.
- Focus on targets of the ZEWT partnership which is to develop and demonstrate solutions to be able to reduce the fuel consumption of waterborne transport by at least 55% before 2030 compared to 2008.
- Research Institutions, Class Society, Technology developers, Consulting & Engineering, Ship Construction and Repair, Ship Owners/Operators



RETROFIT55 project

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- No single GHG emission reduction solution can achieve the targeted fuel consumption reduction of 55% by 2030, so a combination of solutions is necessary. This is even more relevant in the context of the retrofitting where the solutions have to comply with the existing design and ship use and not all solutions are exploitable
- RETROFIT55 tackle the problem developing solutions to reduce the friction (Semi-Passive Air Lublication), to exploit renewable energies (Wind Assistence Ship Propulsion), to improve the original design, to introduce smarter and more efficient operation management (e.g. ship routing, hull and propeller fouling monitoring), to increase the ship electrification.
- All these aspects are dealt with in an integrated way, i.e. taking account of the impact each solution has on other subsystems.
- A Decision Support System (DSS) is under development which will assiste the user to combine different solutions and to perform a Cost-Benefit analysis in the life-cycle perspective. The DSS is fed by surrogate models of the different systems and retrofitting interventions.

Hydrodynamic Optimization

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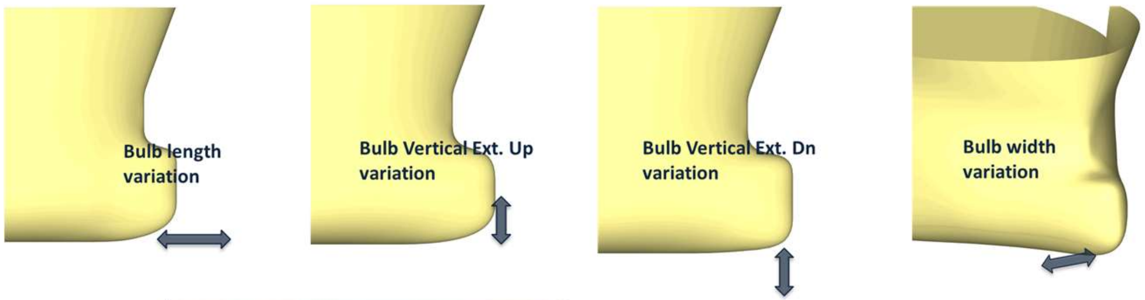
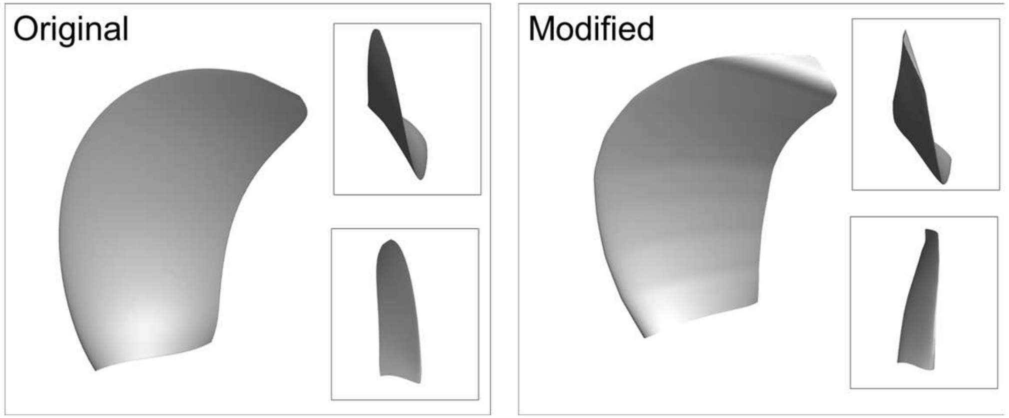
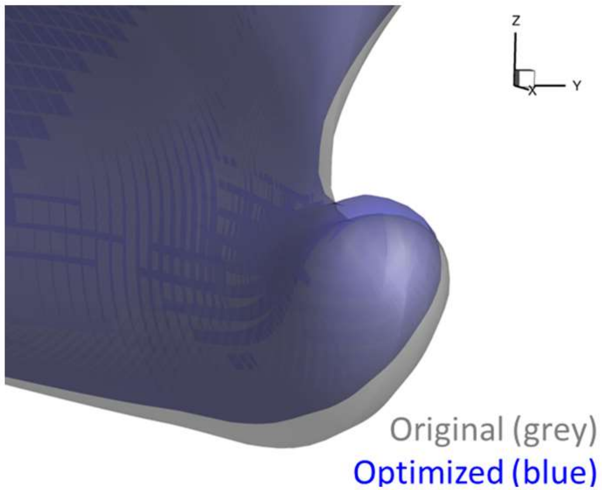
- Hydrodynamic optimization studies have been undertaken to optimize the hull shape and the propeller. Multi-fidelity flow solvers are used in the optimization process

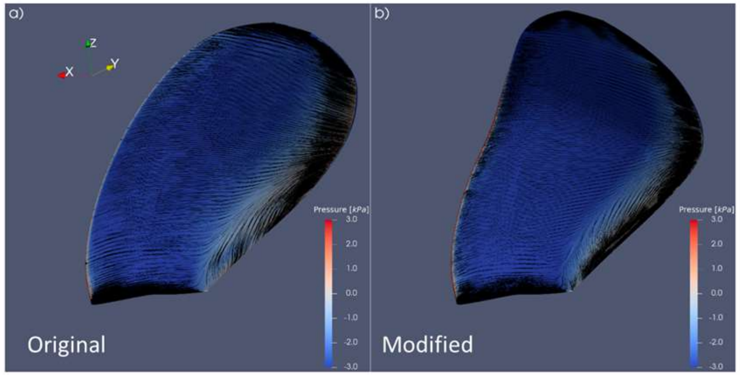
Bulk Carrier

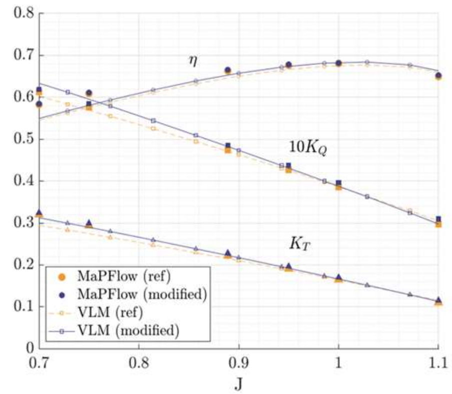




Ro-Ro







Hydrodynamic Optimization

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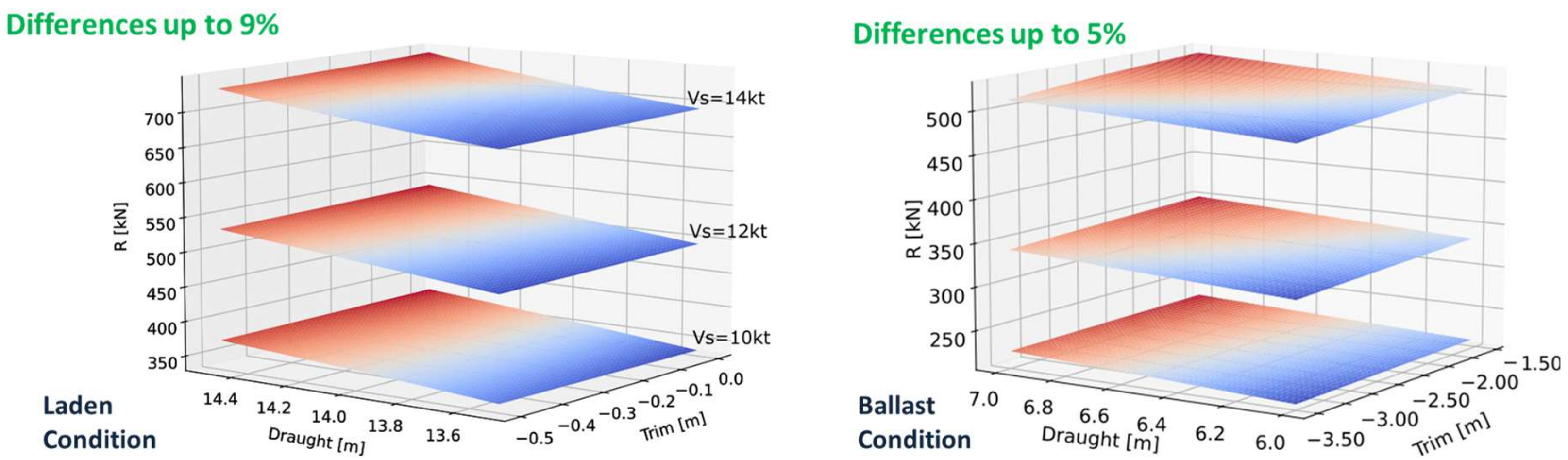
- A specific study has been conducted to evaluate the effect of the trim on resistance at different speeds and loading conditions

Loading condition	TM [m] Range	Trim [m] Range	STW [kn] Range
Laden	[13.5, 14.5]	[-0.5, 0]	[9, 15]
Ballast	[6, 7]	[-3.5, -1.8]	[9, 16]



Hydrodynamic Optimization

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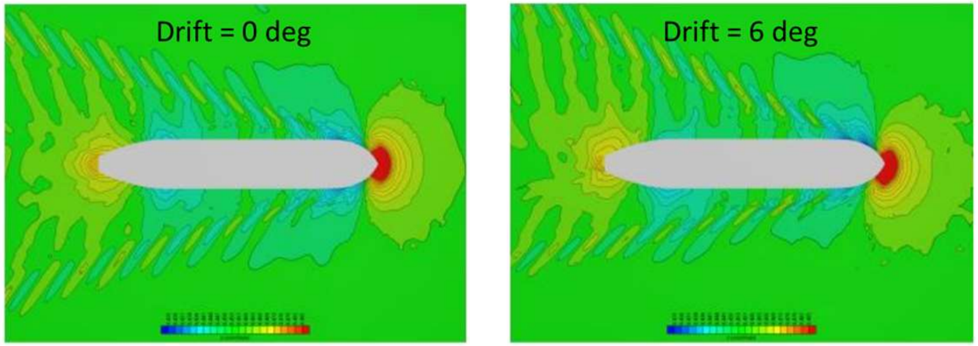
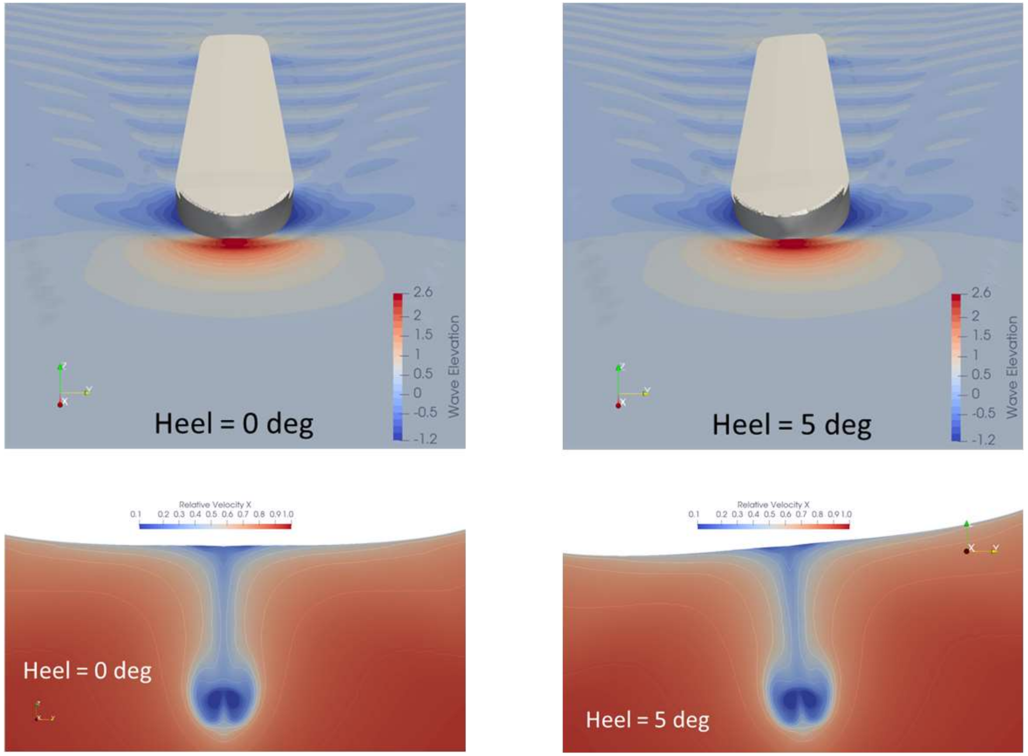
Use of WASP induces heel and leeway angles and can affect the resistance.

Leeway



Heel



Hydrodynamic Optimization

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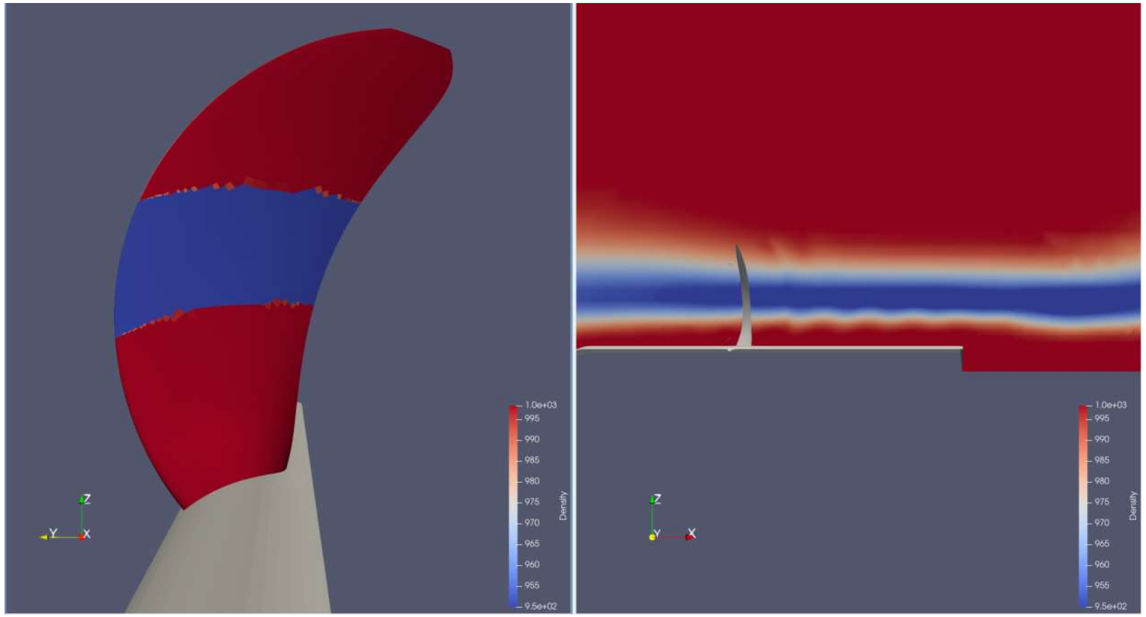
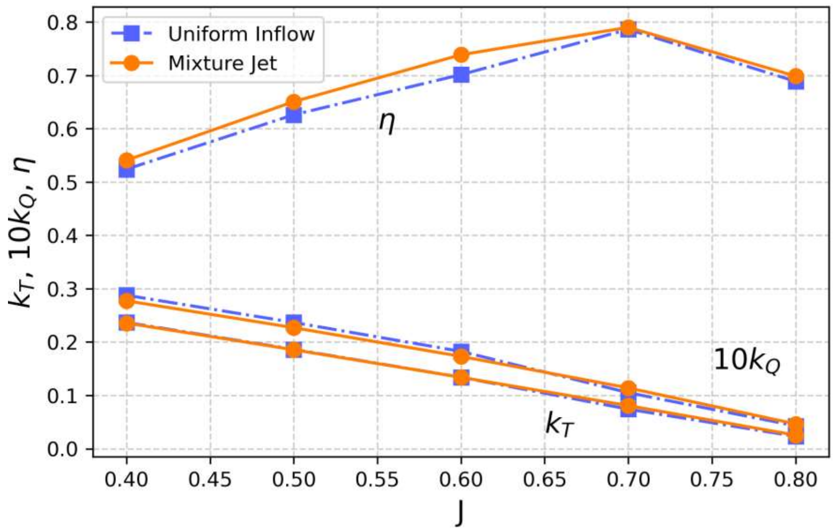
Effect of ALS on propeller performances

- Air/water mixture ratio equals to 5%
- Probably due to viscosity effects, beneficiary results are obtained for some cases





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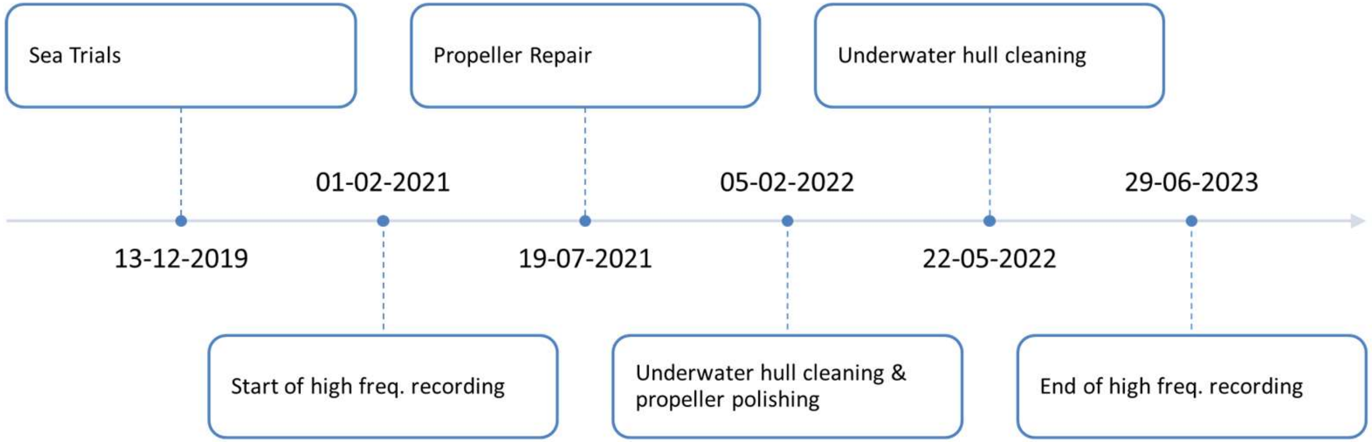
Operational Optimization

Case study: MV Kastor

Ship Type	Bulk Carrier
DWT	81,600 tn
Scantling Draft	14.45 m
Service Speed	14.3 kn
ME MCR	9,930 kW x 90.4 rpm

Vessel operation timeline



- <u>Operational data:</u> 30 months of high frequency (1 min) and noon report data (LASK provided the ship data)
- <u>Methodology</u>: Machine Learning (ML) models predicting SHP are employed to monitor the condition of the hull & propeller

Operational Optimization

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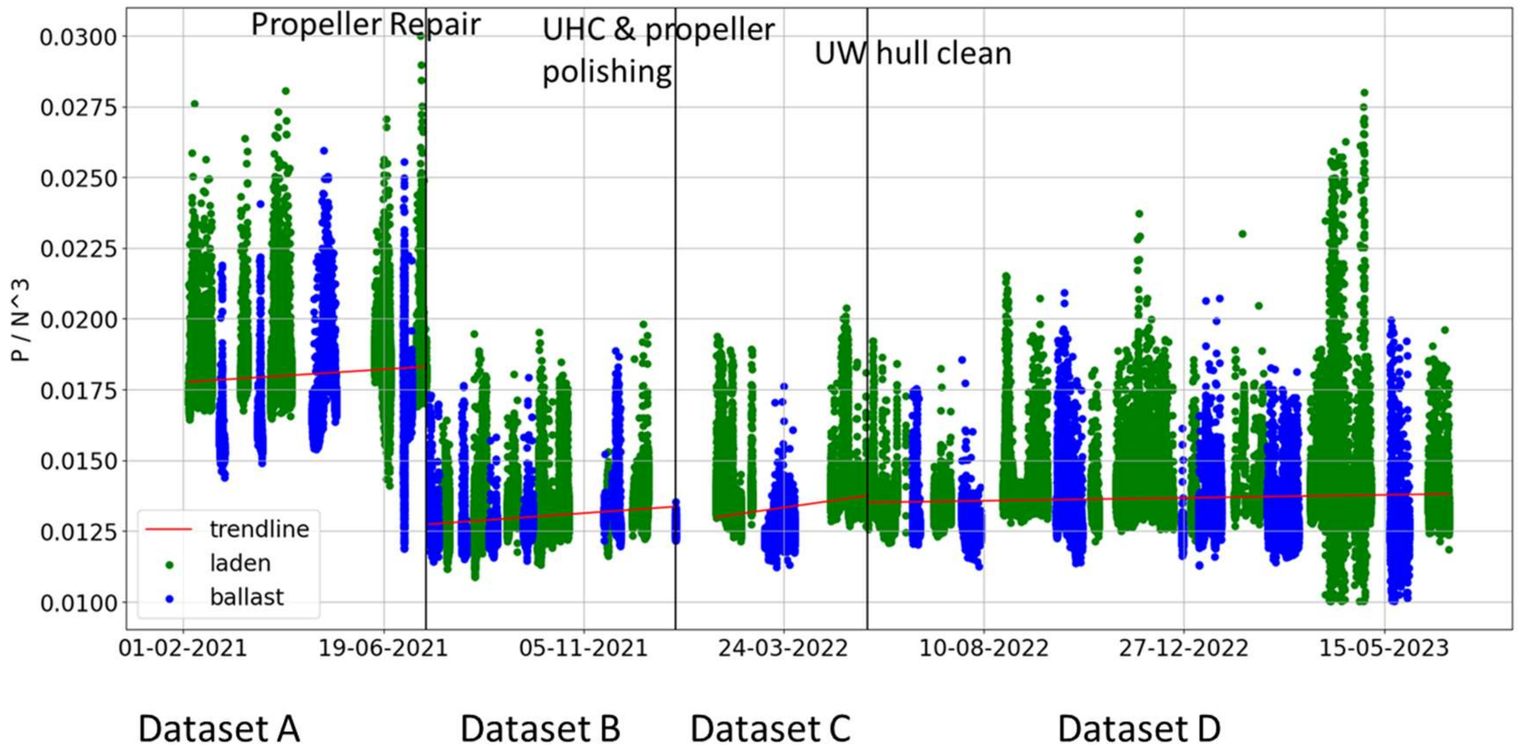
Identification of the effect of maintenance events using propeller curve's coefficient (P/N^3)



- Dataset A: Damaged propeller resulted in poor and non-representative vessel performance.
- Dataset B: Represents a period with accumulated marine growth.
- Dataset C: Captures a limited period with minimal fouling build-up.
- Dataset D: Spans over a year and provides an opportunity to study fouling accumulation.
- Dataset D1: Subset of D, covering the first 2.5 months.
- Dataset D2: Subset of D, covering the last 3 months.

Operational Optimization

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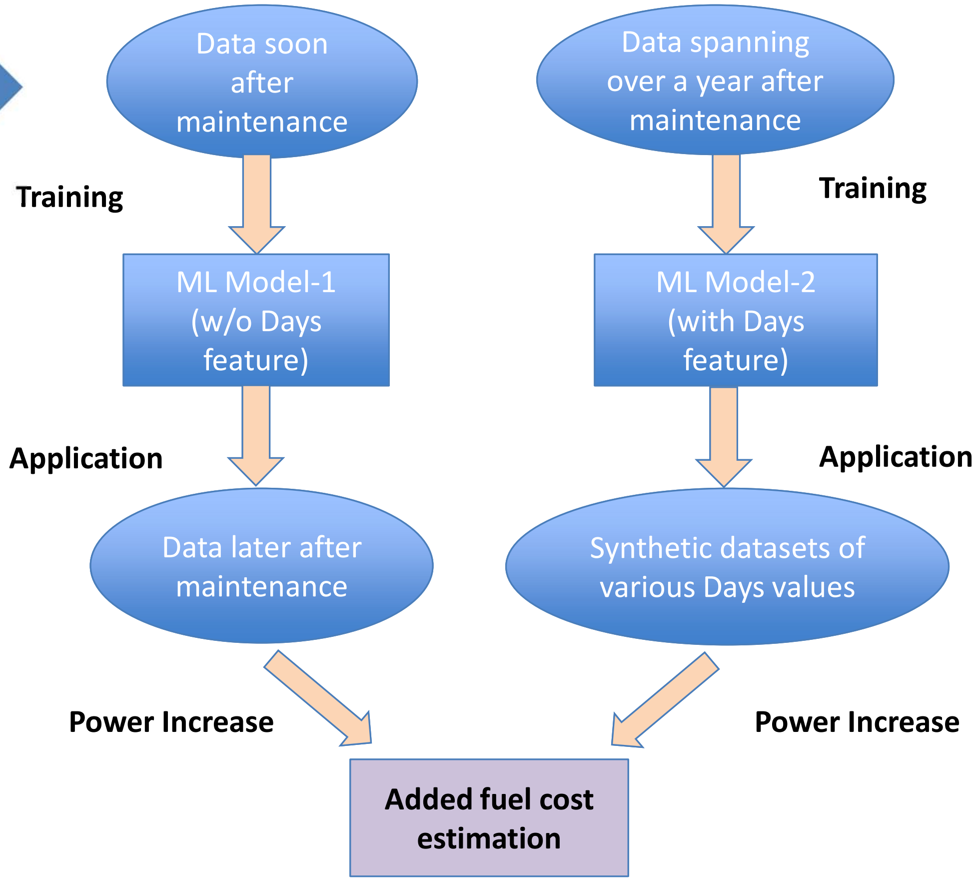
	Model-1	Model-2
Training set	Dataset D1	Dataset D
Feature set	STW Mean Draft Trim RoT Wind x Wave x Current -	STW Mean Draft Trim RoT Wind x Wave x Current Days



Operational Optimization

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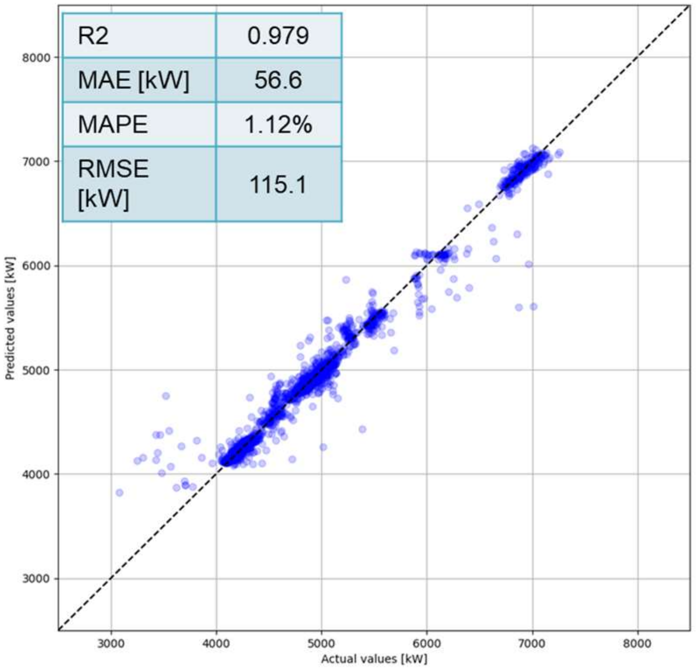
- The training dataset is randomly shuffled and split into training and test sets using an 80/20 ratio
- Tree-based ML algorithms (Extra Trees) are evaluated on the training set using 5-fold Cross Validation and Randomized Search

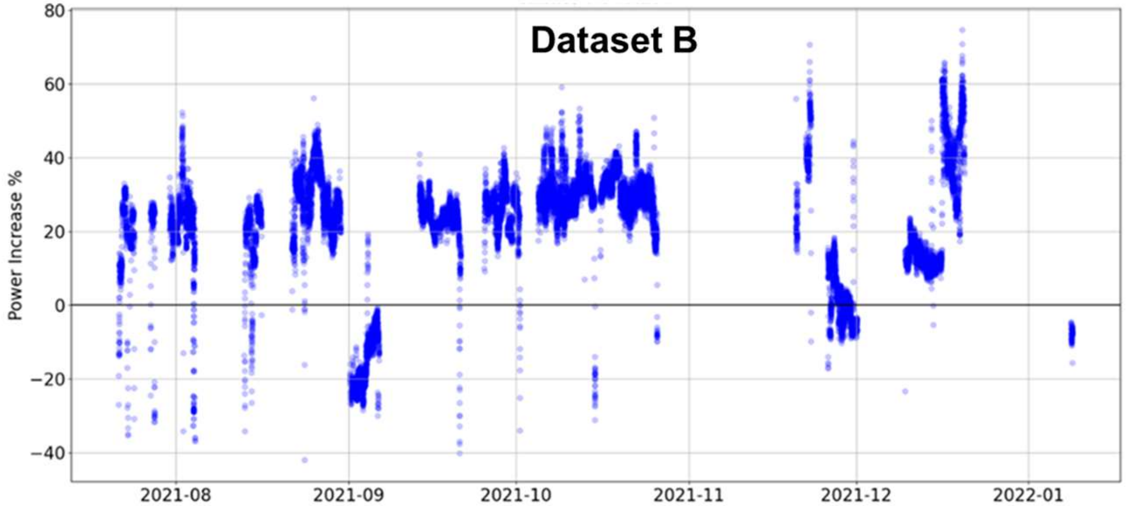
Evaluation of Model 1 on the test set



R2	0.979
MAE [kW]	56.6
MAPE	1.12%
RMSE [kW]	115.1

Results of Method-1 on dataset B

Mean actual SHP	6,342 kW
Mean predicted SHP	5,209 kW
Mean Power Increase	21.7%



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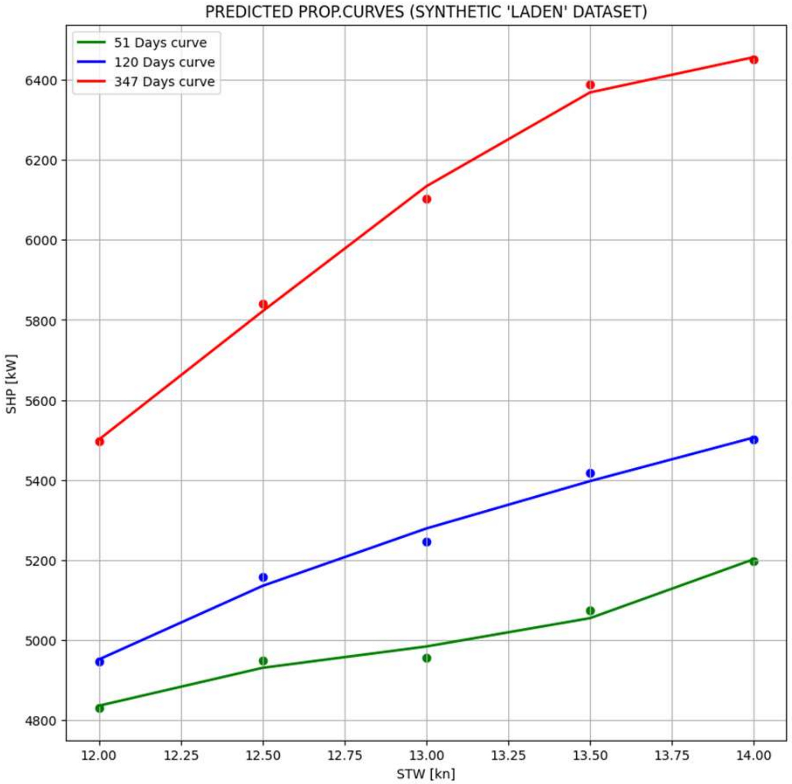
Operational Optimization

- Model-2 is utilized to monitor the advancement of biofouling during the dataset D timeframe.
- Synthetic datasets are created to evaluate the effect of "Days" by assigning specific values to the model's features.

	Laden
STW (kn)	12.0, 12.5, 13.0, 13.5. 14.0
Draft (m)	14.4
Trim (m)	-0.13
RoT (deg/min)	0
Wind x (m/s)	0
Wave x (m)	0
Current (kn)	0
Days	51, 120, 354

Model-2 is applied to the synthetic datasets, and predictions are grouped by loading condition and day.



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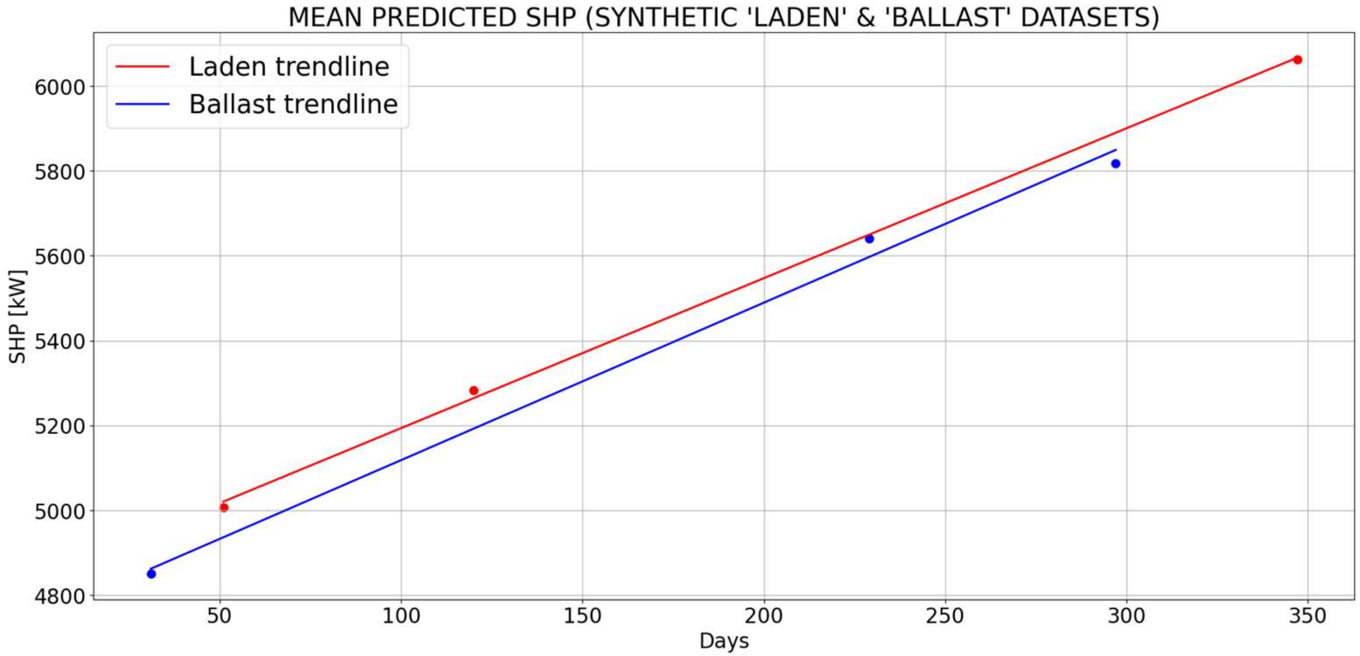
Laden

	Mean predicted SHP (kW)	Mean power increase
Days=51	5,006	-
Days=120	5,283	5.5%
Days=347	6,062	21.1%

Ballast

	Mean predicted SHP (kW)	Mean power increase
Days=31	4,851	-
Days=229	5,640	16.3%
Days=297	5,817	19.9%



- Estimation of an average daily fuel cost increase of $2,249 over approximately 10 months due to biofouling.
- The next maintenance action can be determined based on accumulated additional fuel cost due to fouling, cost of maintenance ($15,000 to $18,000) and ship schedule

Operational Optimization

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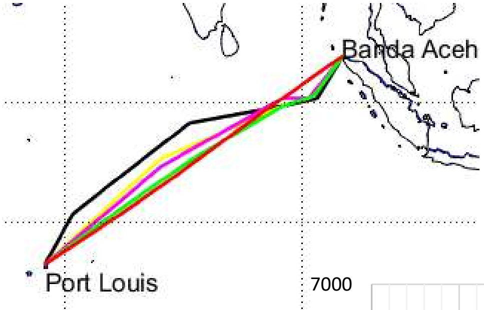
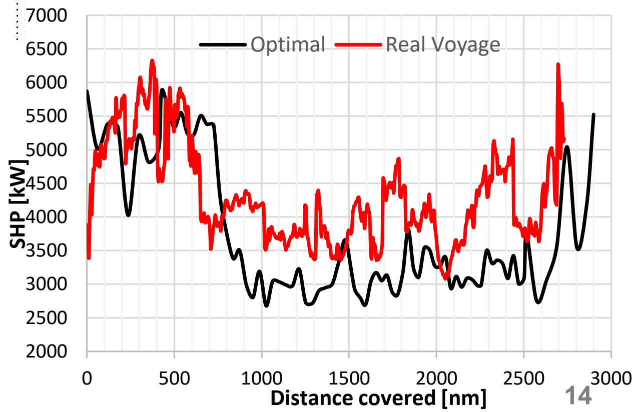
- Improved Ship Model based on the Digital Twins developed in RETROFIT55 for the different systems (hydrodynamics, seakeeping, added resistance, WASP, ALS, main engine curve, propeller performances, FOC prediction method, aerodynamic resistance)
- The improved Ship Model used to improve the reliability of Route Optimization

	FOC		Distance		FOC/dist.		Time
	[t]	[%]	[nm]	[%]	t/nm	[%]	[days]
"Real" Voyage [red]	182.96	-	2731	-	0.067	-	10.26
Optimal [black]	168.24	-8.04	2899.01	+6.15	0.058	-13.37	10.92
Optimal [yellow]	174.97	-4.36	2785.44	+1.99	0.062	-6.23	10.49
optimal [magenta]	175.94	-3.83	2788.24	+2.09	0.063	-5.80	10.50
optimal [green]	178.78	-2.28	2757.83	+0.98	0.064	-3.23	10.39
"Real" Voyage [red] (with Improved hydrodynamic case)	175.69	-3.97	2731	-	0.064	-	10.26
Optimal [black] (with Improved-hydrodynamic case)	161.48	-11.74	2899.01	+6.15	0.056	-16.85	10.92





Wind-Assisted Propulsion

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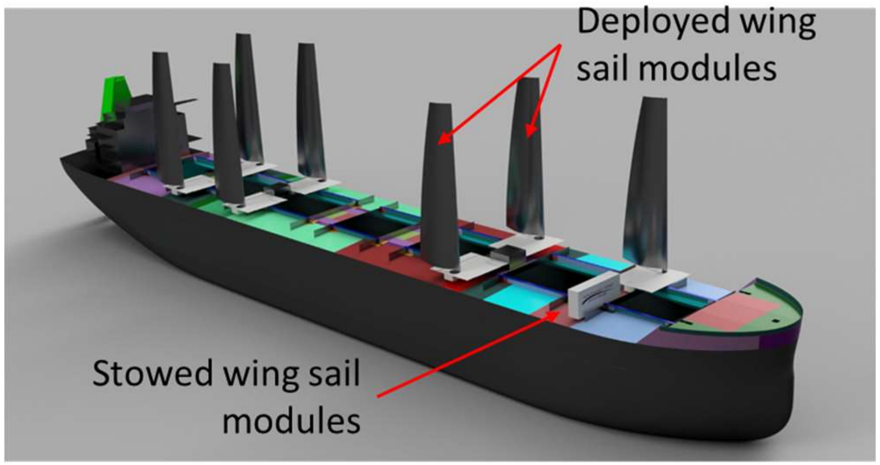
- WASP based on Rigid (B4B) and Flexible (AWS) solutions
- Particular attention focused at the development of standardized and containerized solution for easy installation of the flexible sail solution



Wind-Assisted Propulsion

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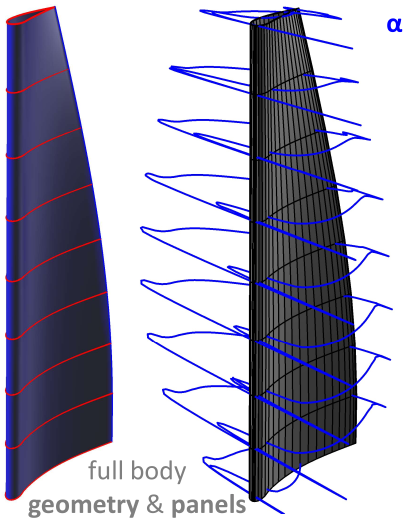
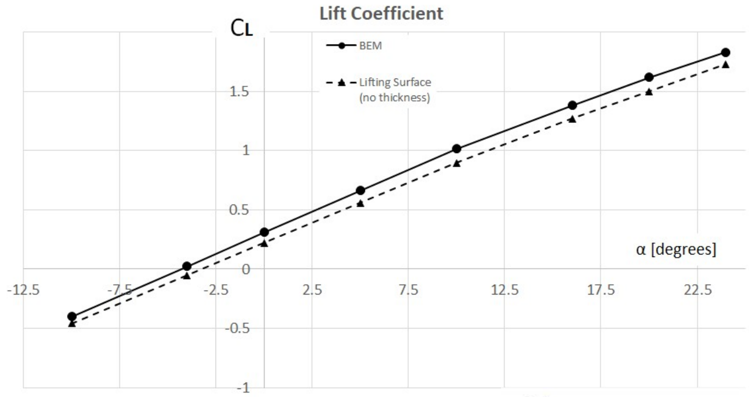
Potential Flow - Results : BEM and Lifting surface (on steady state)

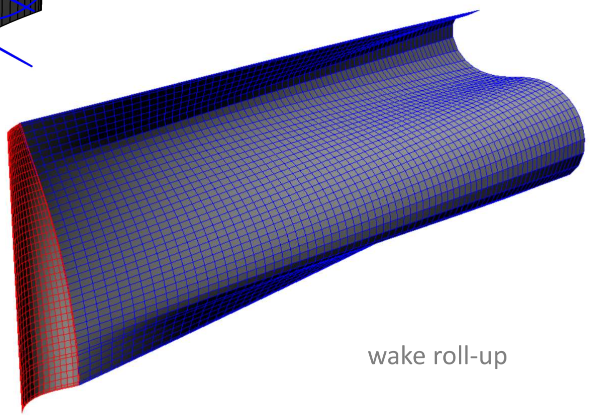


pressure coefficient **curves**
(scaled and magnified for graphical purposes)

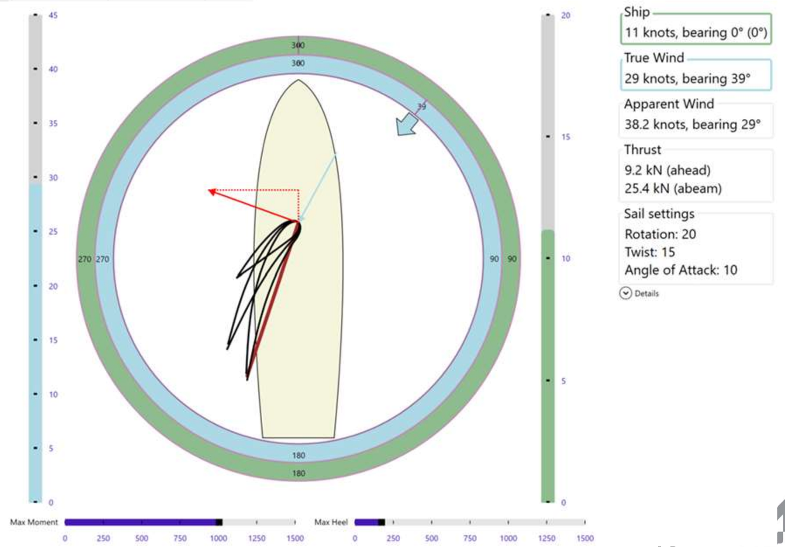
full body
geometry & panels



configuration 10
Mast Rotation-25
Twist-15
Mast Size-650
Taper-1.00
Luff-20000
Foot-6500
Head-3250
Flatten-1



wake roll-up



Wind-Assisted Propulsion

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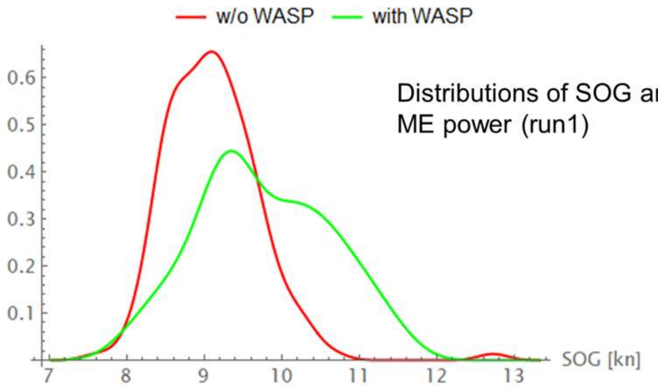
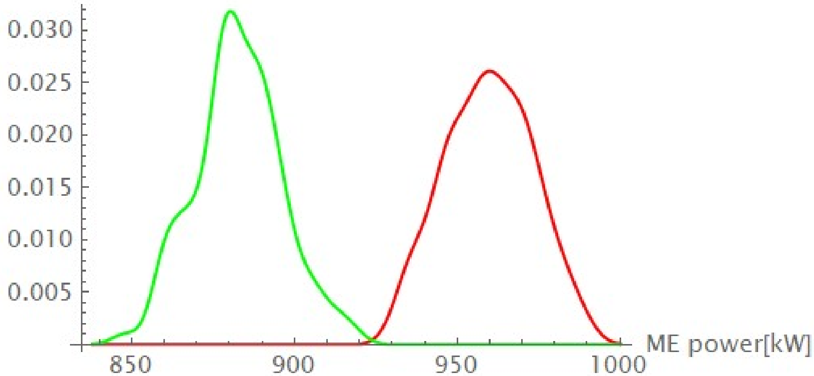
- Application of a Rigid Sail Solution on a Bulk Carrier
- The ship model has been extended to account for the Rigid WASP and used to simulate a route.
- The distribution of Speed Over Ground and Main Engin power have been computed



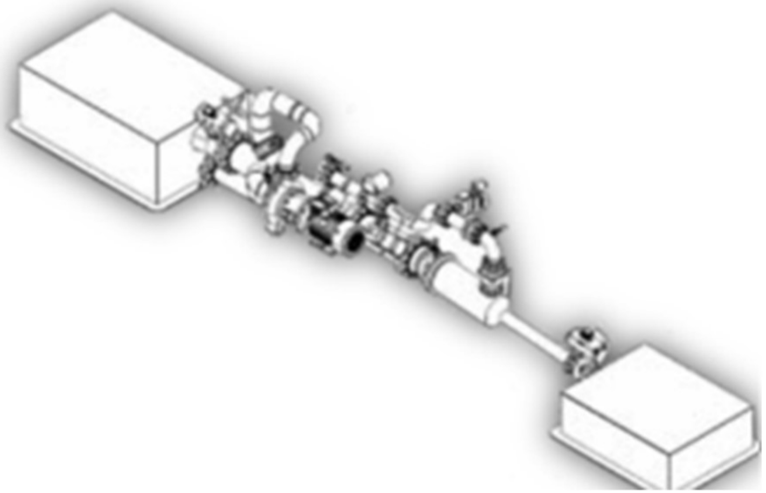
Distributions of SOG and ME power (run1)

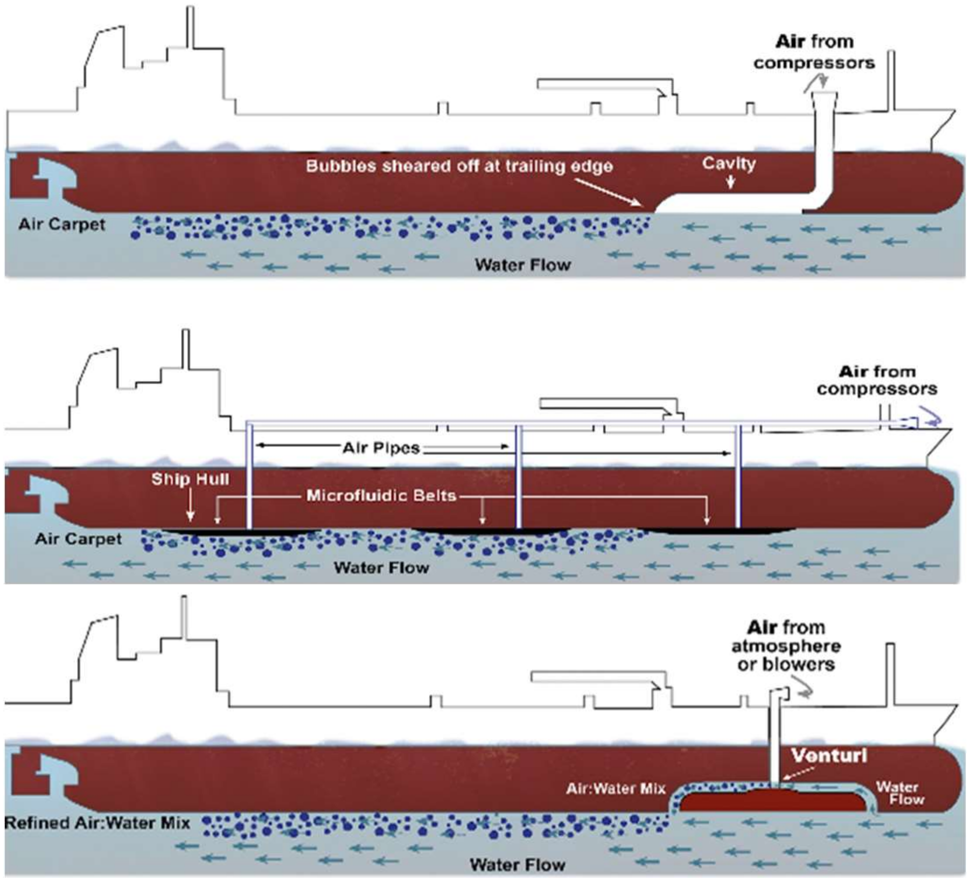


Passive Air-Lubrication

Horizon Europe programme, grant agreement No. 101096068

- ARMADA Technology Passive Air Lubrication Solution





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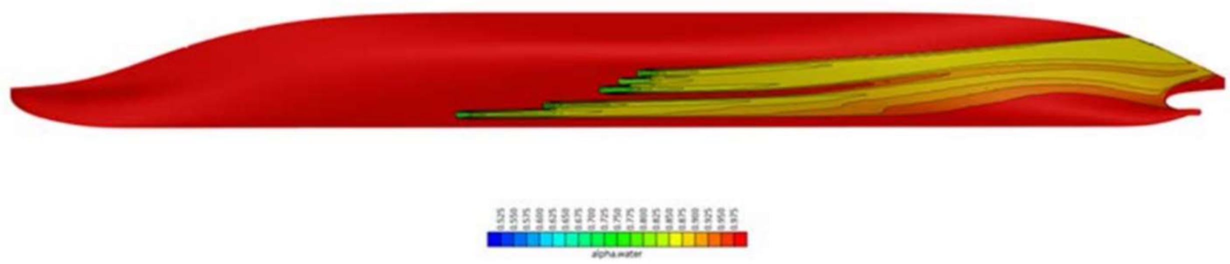
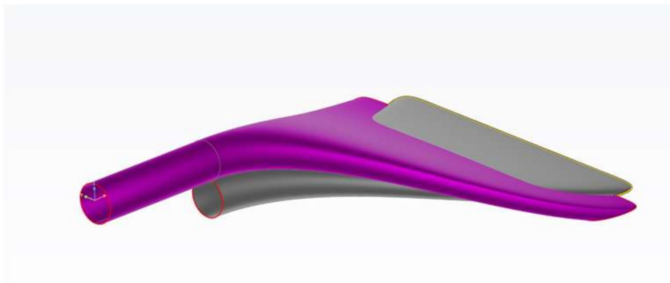
Passive Air-Lubrication

- CFD simulations and optimization to define the number and position of the injectors: 14 Outlets for the JBC were found to be optimal whilst 10 for the A2B



- CFD optimization of the internal shape of the injectors for two shapes , JBC – Magenta and A2B - Grey



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Passive Air-Lubrication

- A device has been designed to deliver the proper air/water mixture to be injected at the different conditions
- The injectors have been installed on the A2B and tests are ongoing

Ship Electrification

Horizon Europe programme, grant agreement No. 101096068

- Analysis of the electrical power systems of a selected case study and definition of the most suitable technologies for enhancing the ship's efficiency

- Assessment of the most promising technologies for improving the ship efficiency indicators, identification of several solutions that align with the retrofitting concept
- Detailed data from the ship M/V Kastor (bulk carrier), provided by LASK were extensively analyzed
- The mean Specific Fuel Oil Consumption (SFOC) of the three Diesel generators of the M/V Kastor were determined

Measure	Design stage	Retrofit feasible	Mature technology	Technology needs further development
Optimal selection of generator sets	Appropriate if not mandatory	Difficult, if not impossible	✓	
Active and reactive load analysis	Appropriate if not mandatory	Difficult, if not impossible	✓	
Shaft Generator systems	Yes	Possible	✓	
Cold ironing	Yes	Yes	✓	
Power Converters for large motors	Yes	Yes	✓	
Photovoltaic solar panels	Yes	Possible	✓	
Optimum operation of electric energy system	Yes	Difficult, BUT not impossible	✓	
Direct Current integration	Yes	Difficult if not impossible	✓	
Waste heat recovery - TEG	Yes	Possible	✓	
Fuel Cells	Yes	Difficult, BUT not impossible		✓
Batteries	Yes	Possible		✓

Ship Electrification

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Methodology Flowchart

Data Collection

- Technical specifications
- M/E and A/Efuel flowmeter data
- Grid Powers
- Running hours
- Rpm and the load of M/E and A/Es

Data Preparation

- Cleaning of missing values
- Filling or removing empty cells
- Conversion of fuel consumption to metric tons
- Grid total energy calculations
- Calculation of the daily distance that the vessel made

Formation of Scenarios

- Design of different fuel cell/battery/ WHRS configurations for marine power distribution unit.
- Gathering technical specifications of the systems.
- Calculation of fuel consumption of different scenarios. and required tank capacities.

Analysis of the Compliance with Regulations

- Attained EEXI calculation of all scenarios and comparison with the base scenario and required EEXI.
- Attained CII calculation and the determination of the CII rating for each scenario in upcoming years by applying the reduction factors.

Environmental Analysis

- Calculation of the operational emissions of each scenario using the emission coefficients.
- Computation of upstream emissions of the utilized fuels by employing the models from the literature.

Economic Analysis

- The investigation of fuel and system prices this year and gathering projections for upcoming years
- Calculation of the economic performance parameters for each model for the years 2023, 2030, and 2050.

Objectives

- To determine the suitable fuel cell, battery and Waste Heat Recovery Systems configurations.
- To create a simulation to calculate the potential fuel savings
- To calculate the required tank and equipment capacities
- To decide environmental (operational and upstream emissions) impact, economic (cost-benefit analysis) performance and regulatory compliance (EEXI, CII, design and safety requirements).

Ship Electrification

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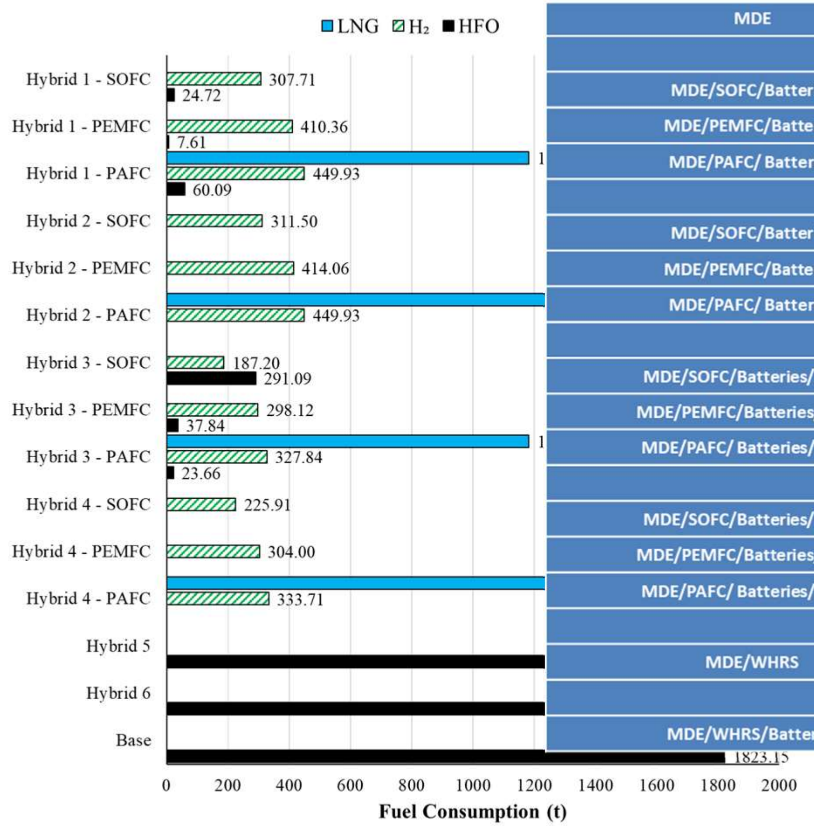
Results - Fuel Cons



Equipment	Number of AEs	Power (kW)	Number of FCs	Power (kW)	Battery Capacity (kWh)	Weight (t)	Equipment Volume (m^3)
MDE	3	720	0	0	0	25.25	49.96
Hybrid 1							
MDE/SOFC/Batteries	2	720	2	500	220	38.51	54.00
MDE/PEMFC/Batteries	2	720	3	600	120	20.74	36.67
MDE/PAFC/ Batteries	2	720	1	440	280	47.12	62.34
Hybrid 2							
MDE/SOFC/Batteries	1	720	4	1000	440	51.77	58.03
MDE/PEMFC/Batteries	1	720	5	1000	440	16.32	22.58
MDE/PAFC/ Batteries	1	720	2	880	560	68.99	74.72
Hybrid 3							
MDE/SOFC/Batteries/WHRS	2	720	1	250	273.00	28.62	43.87
MDE/PEMFC/Batteries/WHRS	2	720	2	400	123.00	19.69	35.61
MDE/PAFC/ Batteries/WHRS	2	720	1	440	83.00	45.98	62.08
Hybrid 4							
MDE/SOFC/Batteries/WHRS	1	720	3	750	493.00	41.88	47.90
MDE/PEMFC/Batteries/WHRS	1	720	4	800	443.00	15.27	21.52
MDE/PAFC/ Batteries/WHRS	1	720	2	880	363.00	57.18	65.24
Hybrid 5							
MDE/WHRS	3	720	0	0	0	8.42	16.65
Hybrid 6							
MDE/WHRS/Batteries	3	720	0	0	600	11.90	17.45

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Ship Electrification

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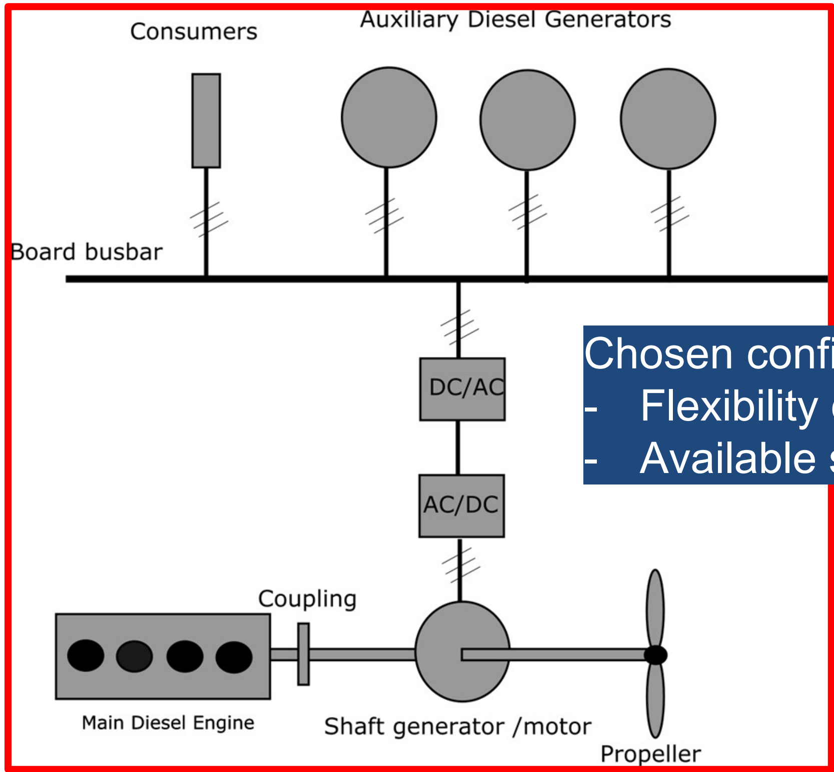
Shaft generator systems often met as Power Take Off (PTO) systems are coupled to the main propulsion engine and generate electricity supplied either directly to the main ship grid or to specific loads onboard.

Motivation

- Lower burn of extra fuel by diesel gensets;
- Fuel savings;
- Decrease of operating hours of diesel gensets;
- Main engines run at a more efficient operating point with lower fuel consumption.

Technological solutions

- PTO/gear constant ratio (PTO-GCR)
- PTO/constant frequency mechanical (PTO/CFM),
- **PTO/constant frequency electrical (PTO-CFE)**



Chosen configuration
- Flexibility of use
- Available spaces

Ship Electrification

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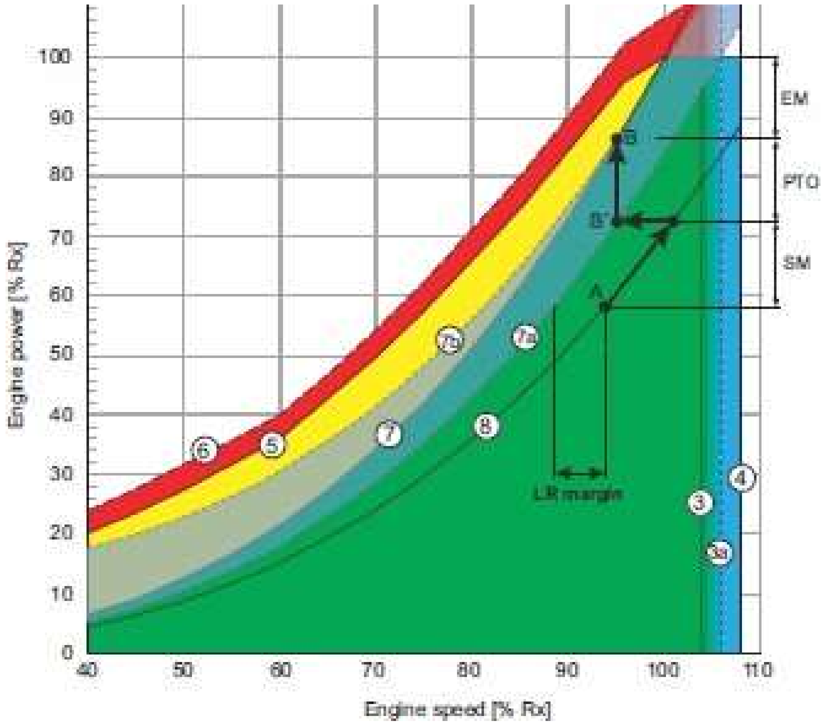
Adopted PTO/PTI design methods

- Method 1: PTO design on the basis of the electric load analysis
- Method 2: PTO design for the instantaneous minimization of the main engine specific oil consumption



Method 1 The demand of the PTO is specified and then added to the propeller power demand curve, therefore generating a new power demand curve and a new MCR.

Then a new MCR will be defined corresponding to a PTO implementation. The vertical distance between B' and B depict the amount of power specified for PTO usage.

Ship Electrification

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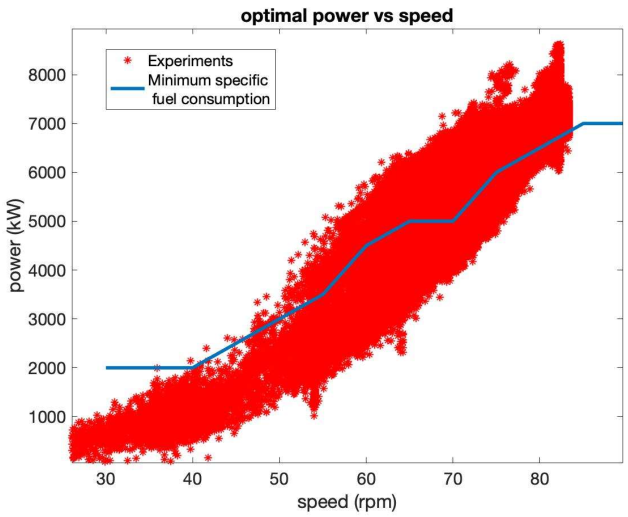
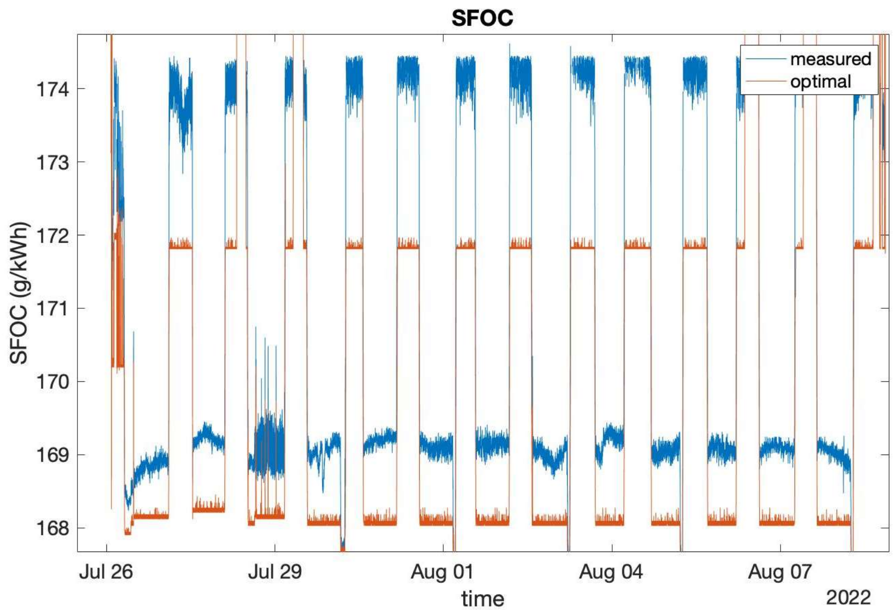


Method 2



- ✓ Operating points show that the ME is not always operating at minimum SFOC
- ✓ PTO/PTI can be designed so to make the ME work at it minimum SFOC for each rotating speed.
- ✓ Assuming a 89.29% overall efficiency, the rated power of the electric machine would be 2900 kW, higher than the maximum measured electric power equal to 937.6 kW.
- ✓ The variation of the SFOC obtainable tracking the minimum SFOC for each ME speed has been found (red curve) and compared with the actual one (black curve) on the mission profile

Ship Electrification

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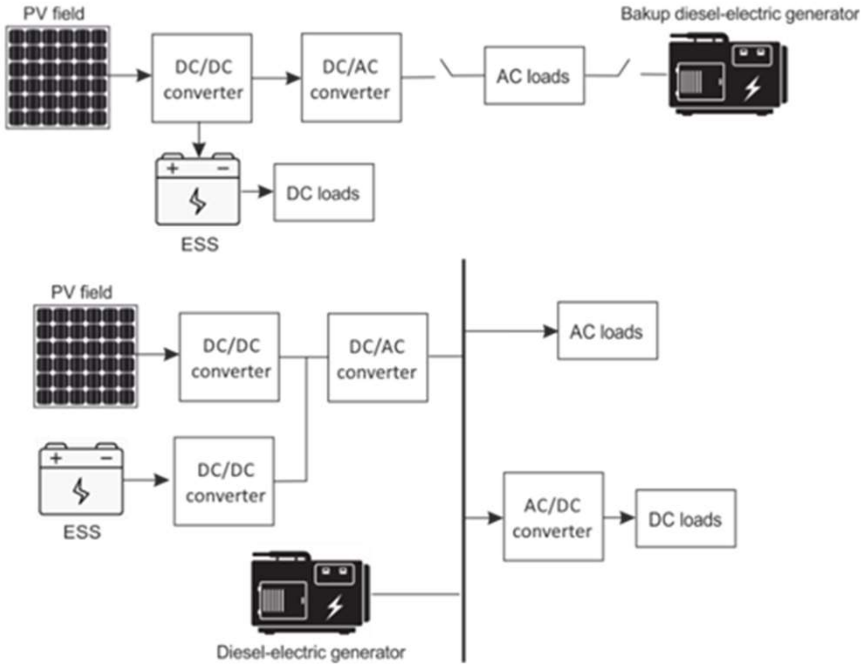
Integration of PV plant in the shipboard power system: main options



Off-grid (upper) and grid-connected (lower) principle schemes of a shipboard PV plant

Pros & cons. – **Off-grid**
Simplicity
No need for synchronization issue with the on-board AC grid
Large ESSs required to ensure the continuity of electricity supply to the loads pertaining to the PV source.

Pros & cons. – **Grid Connected**
Reduced storage size,
Control design to ensure that the PV output conforms in voltage, frequency and phase to the electrical characteristics of the shipboard power grid required.

Web-Based Catalogue & DSS

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- Web-based decision support system for ship designers and operators
  - Easy to access
  - Easy to operate

- Quickly evaluate most promising options for retrofit projects
  - … for a distinct vessel
  - … with any selectable combination of retrofitting options
  - … according to individual optimisation targets (e.g., compliance, cost, efficiency, downtime, …)
  - … life-cycle oriented (retrofit → operation → maintenance → …)
  - … not perfect but good enough for meaningful pre-selection (80/20 rule)

Web-Based Catalogue & DSS

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- **Many Retrofitting options**
  - New bow (e.g., different bulb)
  - Different propeller (e.g., tip rake)
  - Extra energy-saving device (ESD)
  - Wind-assisted propulsion (WASP)
    - Which system, how many and where?
  - Air lubrication system (ALS)
    - Which system and what set-up?
  - Electrical system optimization
  - … and many more

Challenges & Solutions

Can we consider all combinations?

- Easily adds up to a lot of scenarios
  → **weighted sum of likely combinations**

How can we handle high complexity?

- Each retrofitting option requires a lot of analyses (e.g., numerical simulations)
  → **surrogate models**
- Different retrofitting options influence each other
  → **synthesis**

How can we speed up the design process?

- Even simplified design procedures require iterations and optimizations
  → **process modelling** and **automation**

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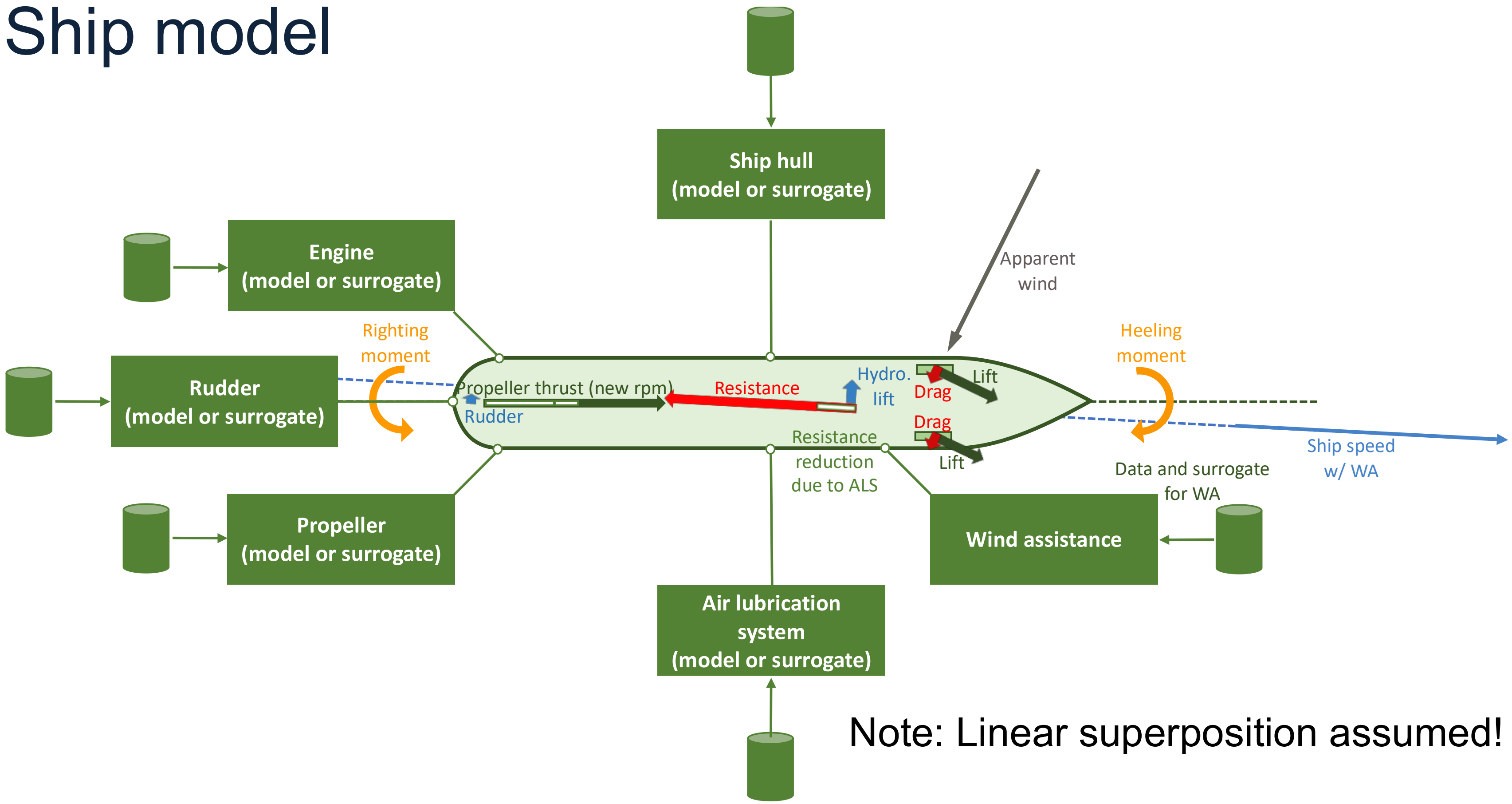
Synthesis: Ship model



Note: Linear superposition assumed!

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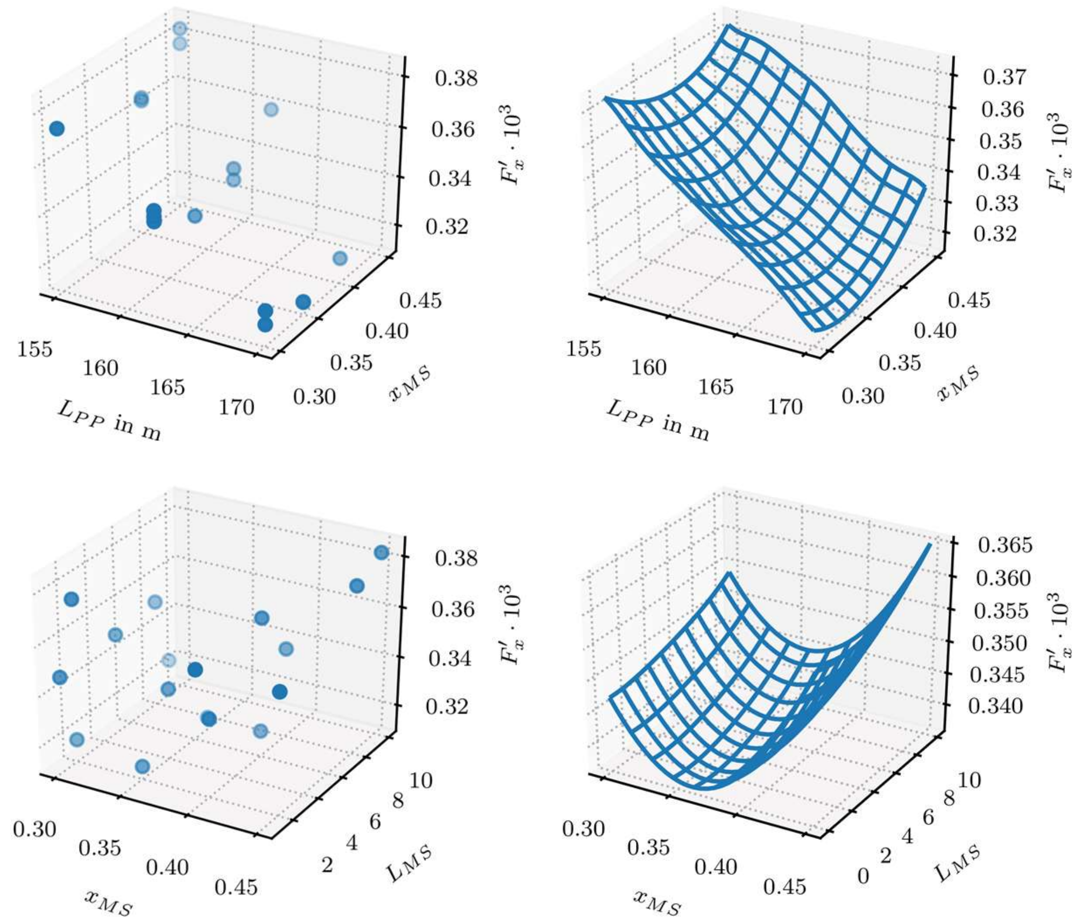
Synthesis: Surrogate models

- n-dimensional approximation
  - Polynomial regression
  - Kriging
  - Artificial Neural Networks (ML)
- Used as extremely fast look-up tables once simulations have been done upfront



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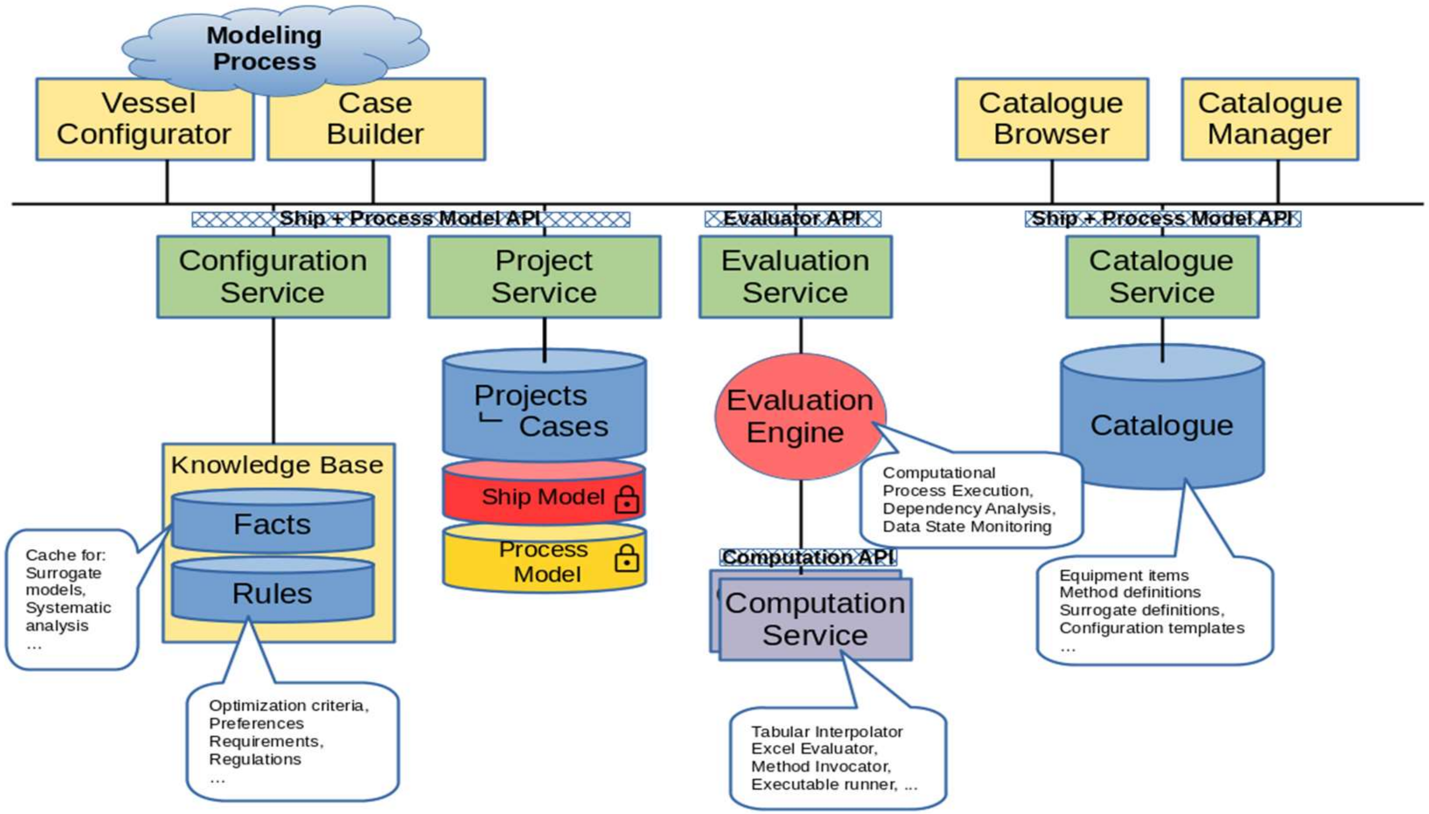
The Catalogue and the DSS



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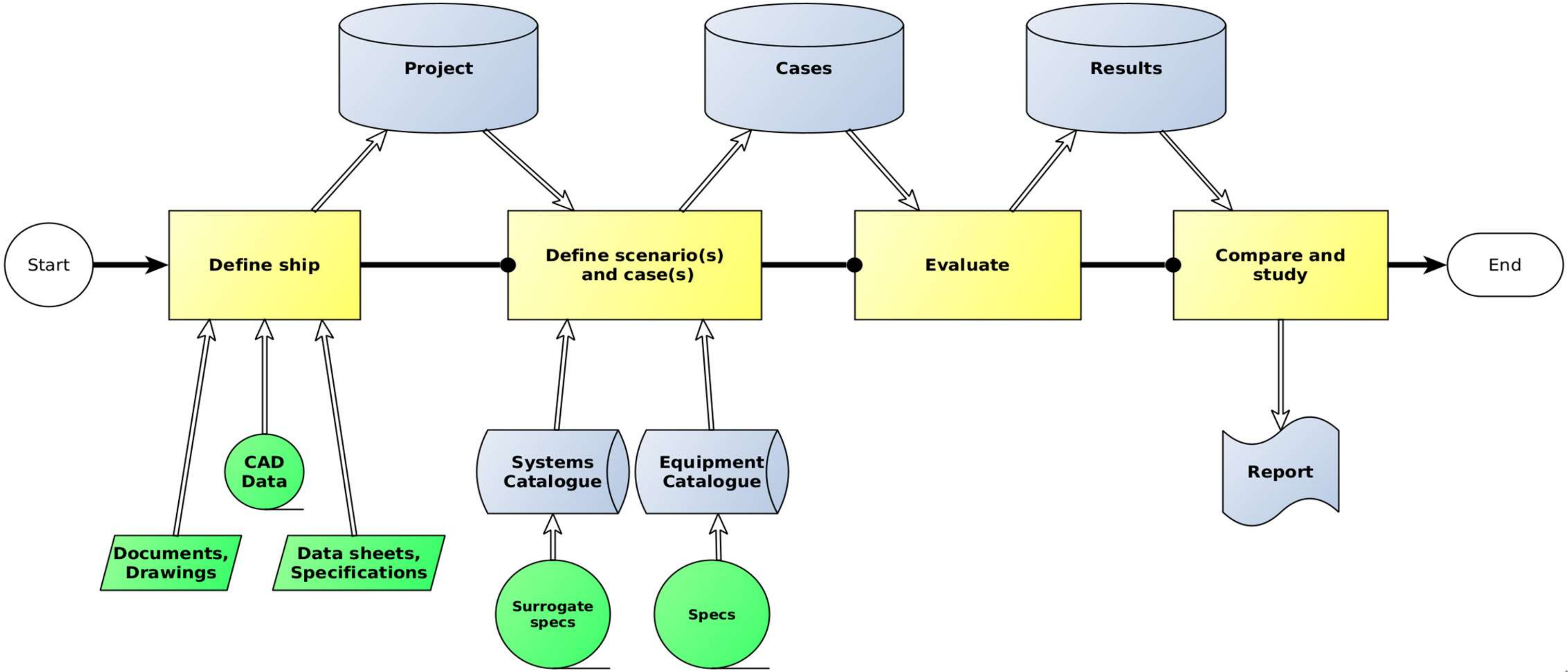
The Catalogue and the DSS



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- Please visit www.retrofit55.eu for further information and updates