Review and state of the art of ship powering, energy efficiency and emissions control, technical problems and related international rules

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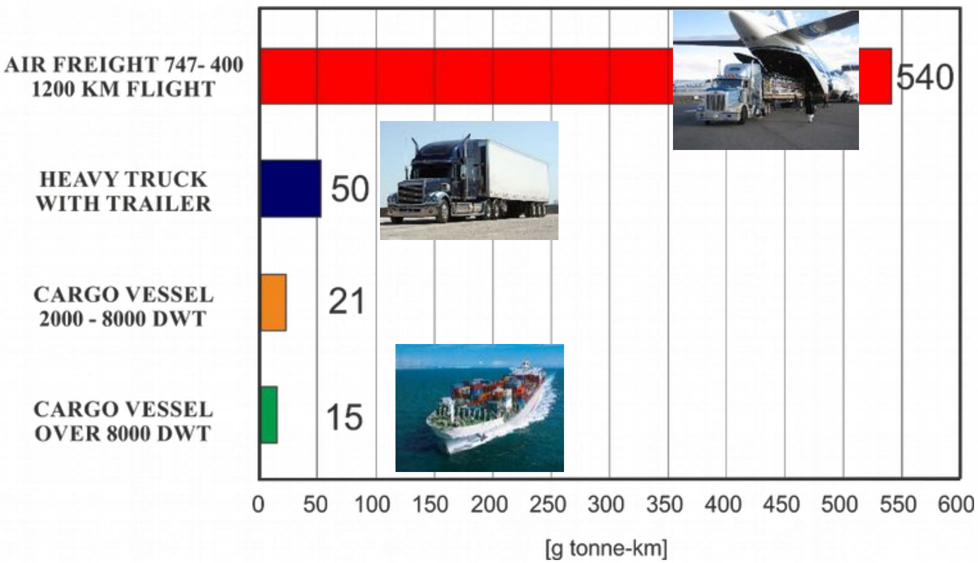
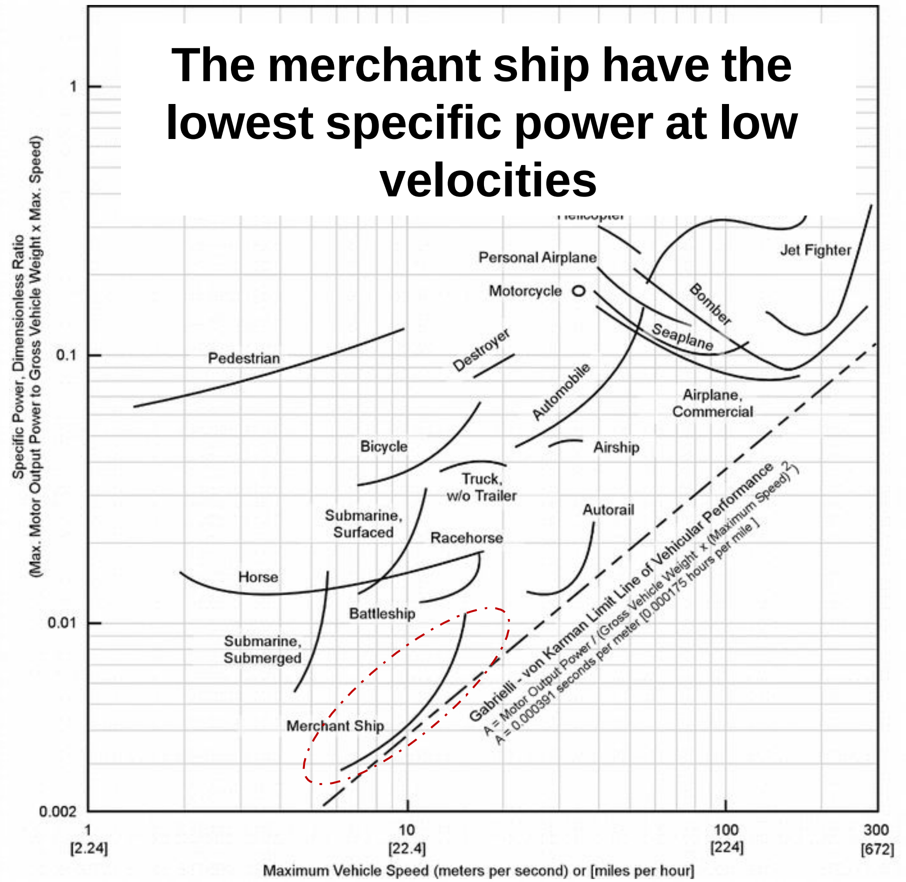
Outline

Sea shipping is a relatively environmentally friendly mean of transport when compared to others modes (**HEAVY TRUCK** or **AIRFREIGHT**).
However it is still an important source of air pollutants, mainly due to exhaust emissions of sulphur dioxide (SO2), carbon dioxide (CO2) and nitrogen oxides (NOx).

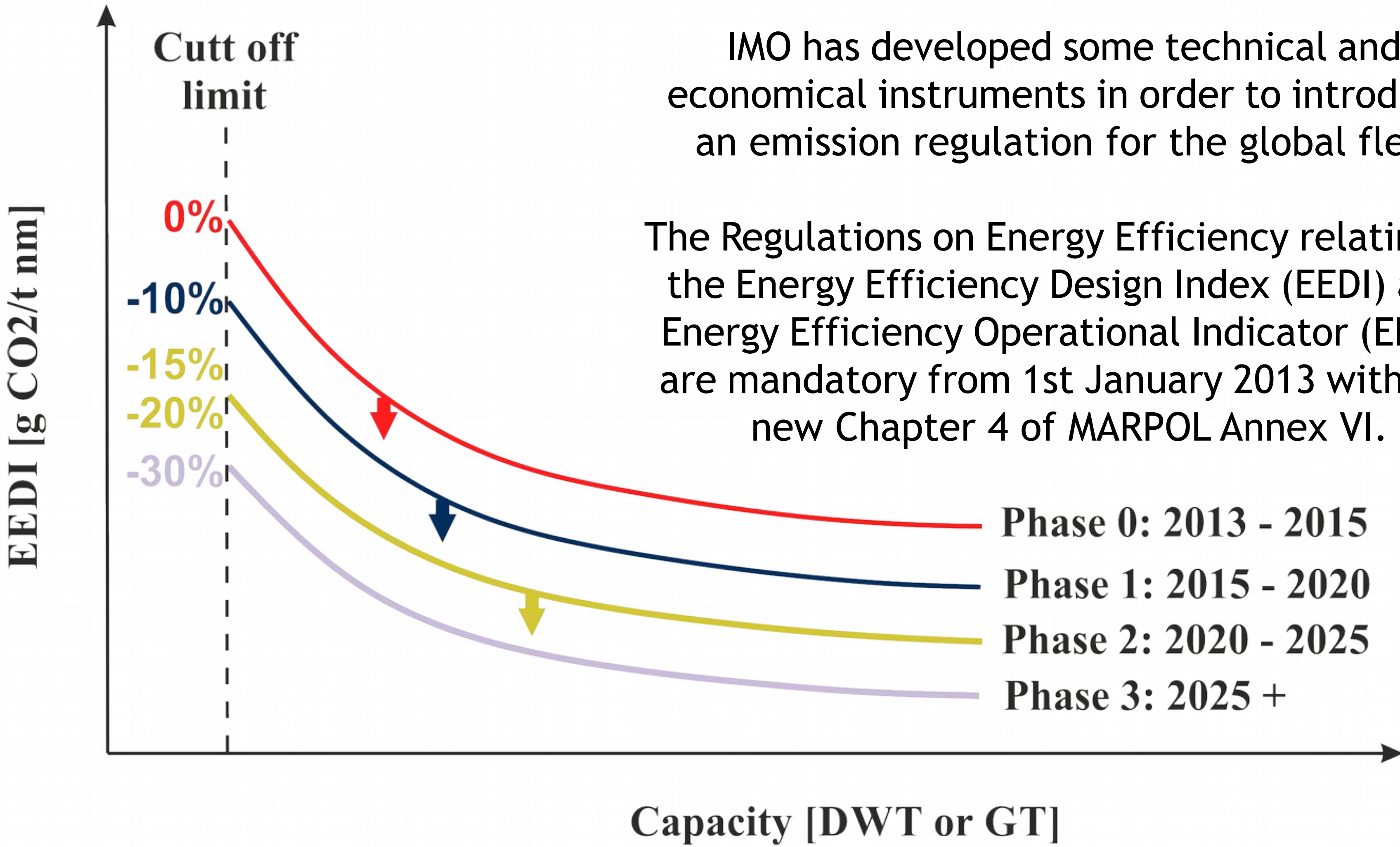




IMO has introduced greenhouse gas (GHG) emission reduction in its agenda since 1995

IMO has developed some technical and economical instruments in order to introduce an emission regulation for the global fleet

The Regulations on Energy Efficiency relating to the Energy Efficiency Design Index (EEDI) and Energy Efficiency Operational Indicator (EEOI) are mandatory from 1st January 2013 within a new Chapter 4 of MARPOL Annex VI.



Both indexes are measured by the ratio between emissions, in mass of CO_2, and the transported cargo quantity per sailed distance

Two different emission indexes for vessels have been adopted:

1. Energy Efficiency Design Index (EEDI)

$$\frac{\overbrace{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}^{\text{Main engine(s)}} + \overbrace{\left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}\right)}^{\text{Auxiliary engine(s)}} + \overbrace{\left(\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right)}^{\text{Energy saving technologies (auxiliary power)}} - \overbrace{\left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}^{\text{Energy saving technologies (main power)}}}{\underbrace{f_i \cdot f_c \cdot Capacity \cdot f_w \cdot V_{ref}}_{\text{Transport work}}}$$

2. Energy Efficiency Operational Indicator (EEOI).

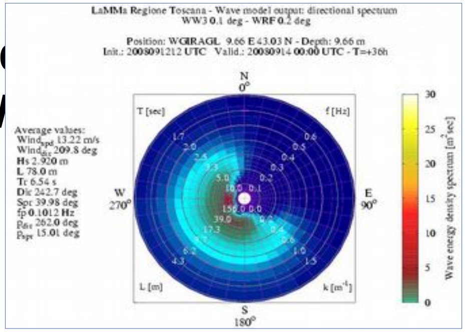
$$EEOI = \frac{\sum_{j=1}^{nFT} FC_{(j)} \cdot C_{F(j)}}{M_{cargo} \cdot D}$$

A key concept in ship design is the design point, a combination of the variables around which a design is developed and optimized.

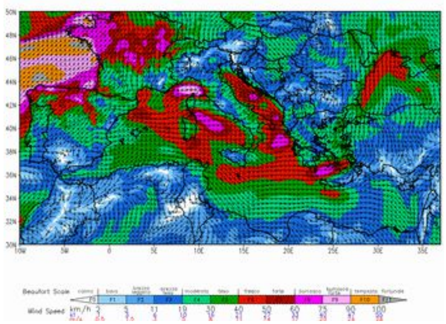
These can be **speed**, **draft**, **consumption**, **deadweight**, **weather**, **sea conditions**, **trim** and many other variables, depending on the ship type and operational profile.

A vessel designed around a certain design point would have the best optimization for the given variables, i.e. the least **fuel consumption**, and a certain draft, trim, cargo intake, propeller and hull cleanness and sea/weather conditions.

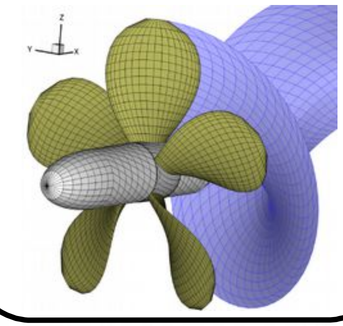
- But what happens if the vessel operates outside its design point?
- And how often does a vessel do so?
- What is the range of variation for the different variables?



Wind Resistance



Propeller Performance



Fuel Consumptio
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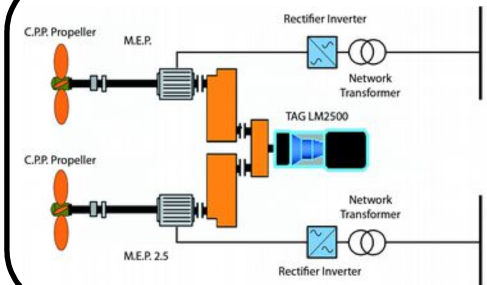
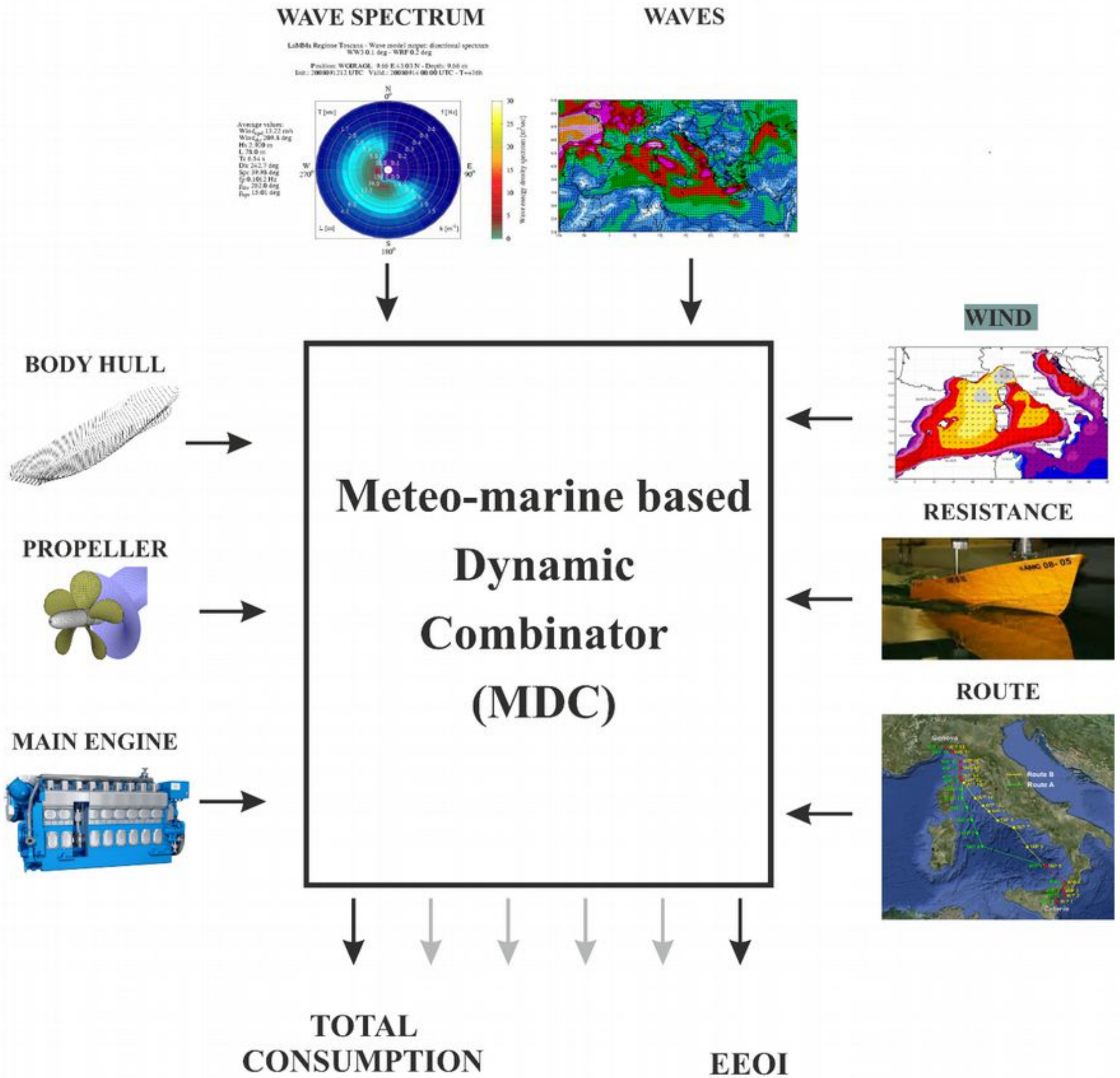
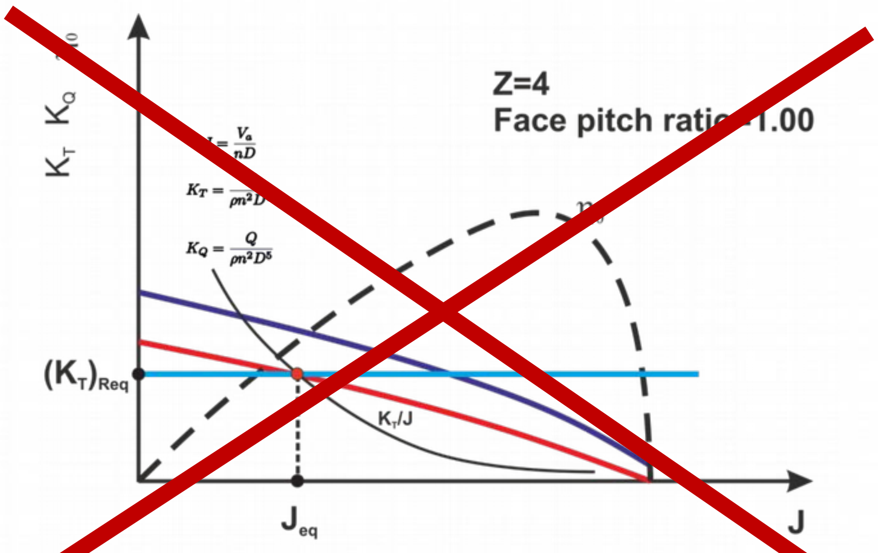
Propulsion Plant



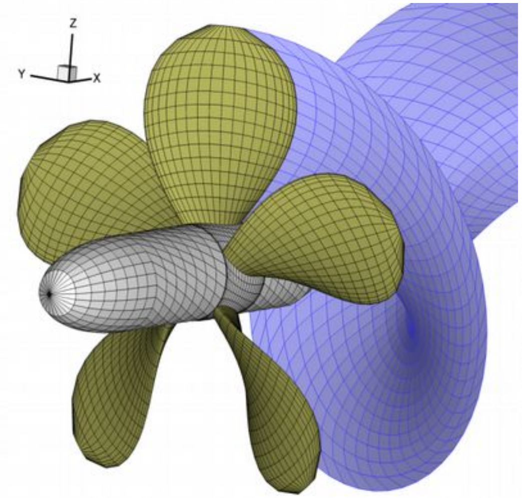
Calm Water Hull Resistance

Route

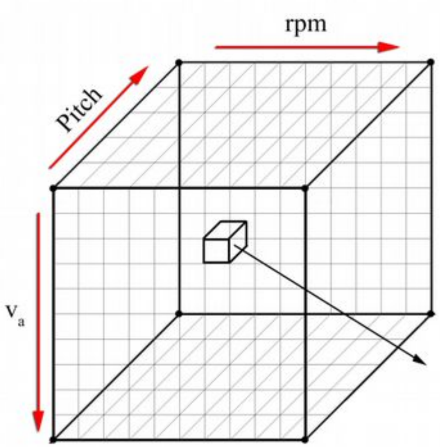

WAVE SPECTRUM
WAVES
WIND
BODY HULL
PROPELLER
MAIN ENGINE
RESISTANCE
ROUTE
Meteo-marine based Dynamic Combinator (MDC)
TOTAL CONSUMPTION
EEOI



Typical curves of thrusth, torque and efficiency for propeller in open water



PANEL METHOD

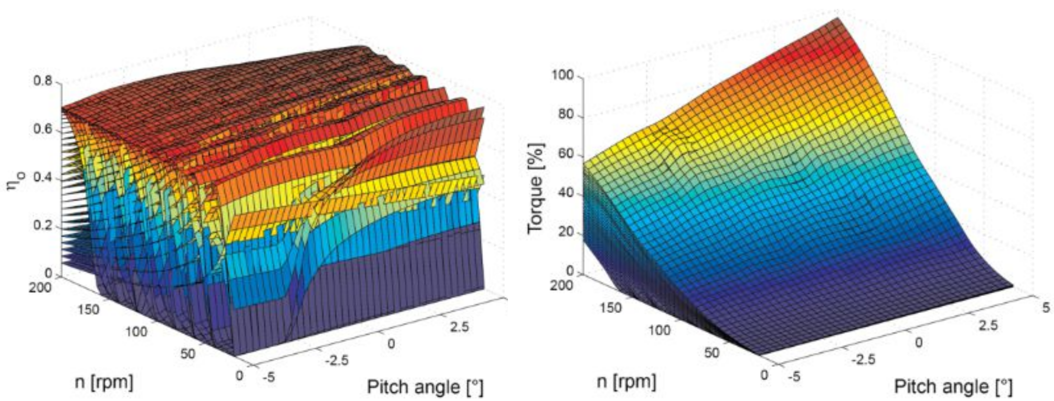


$K_{T\ i,j,k}$

$K_{Q\ i,j,k}$

$\eta_{o\ i,j,k}$

$A_{cav\ i,j,k}$

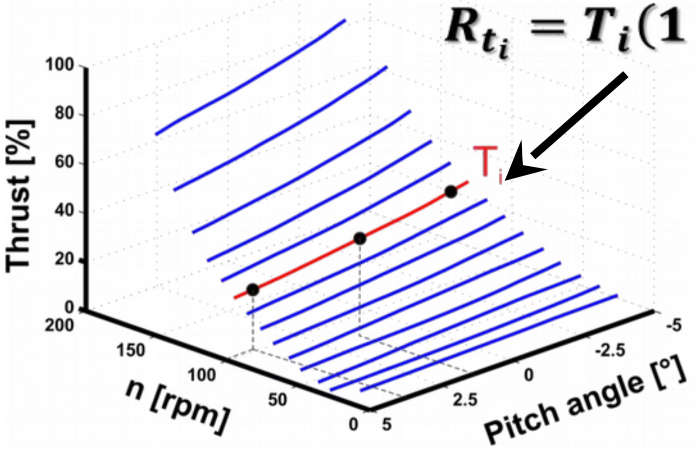


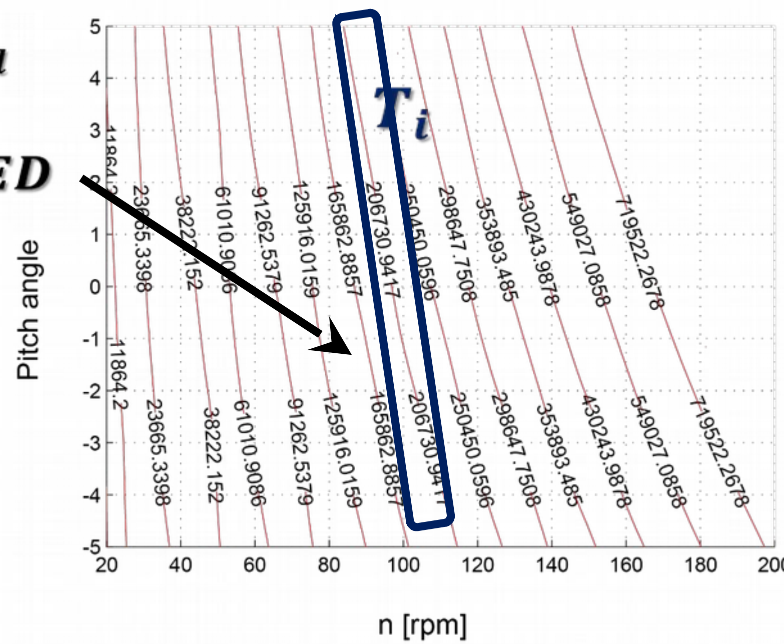
As in the traditional engine-propeller matching the equilibrium points are computed one by one for all the ship speed.

As the velocity and the correspondent ship resistance R_i have been fixed, it is possible to identify all the pairs of propeller pitch and rate of revolutions that deliver the required thrust.

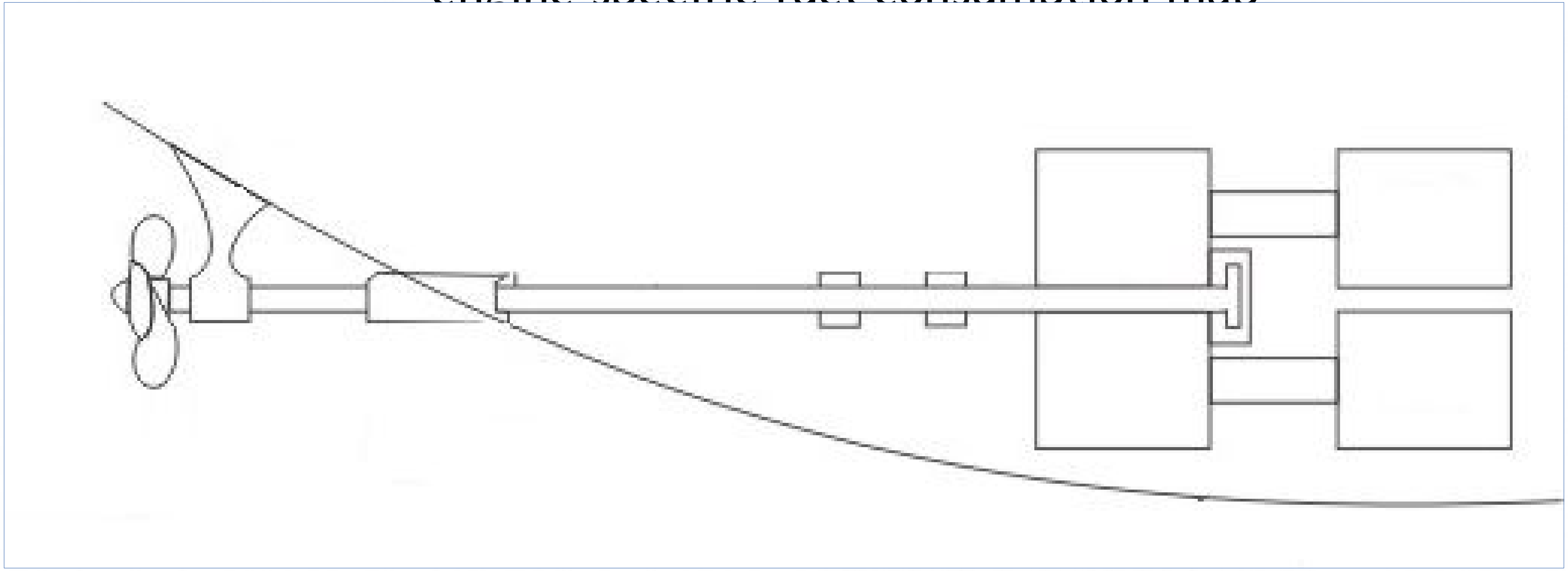
$$R_{t_i} = R_{hull} + R_{aw} + R_{wind}$$

$$R_{t_i} = T_i(1 - t_i) \Rightarrow FIXED$$





The **efficiency chain** lets to map all the propeller working points onto the engine layout and to assign at each point (one for each ships speed and pitch setting) the corresponding specific consumption value using the engine specific fuel consumption map

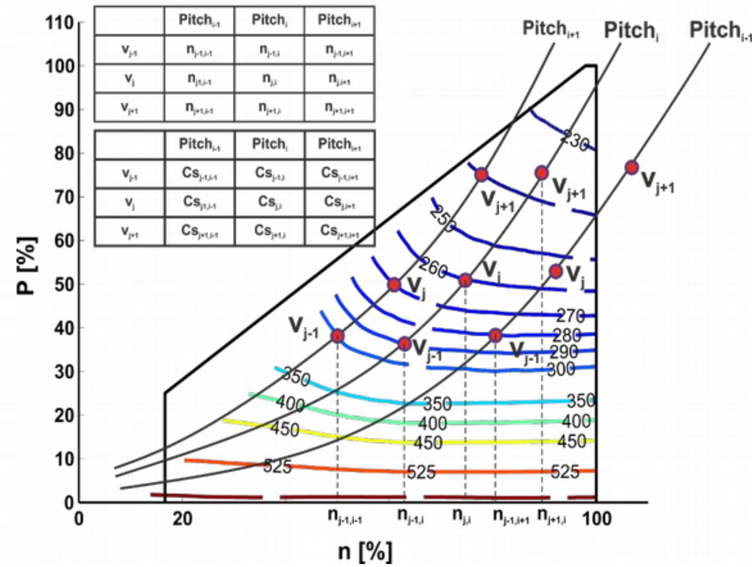


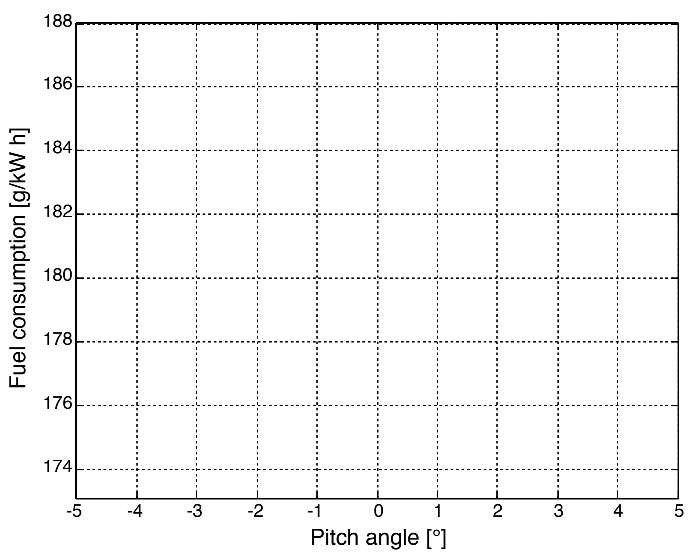
η_B: Efficiency behind the hull

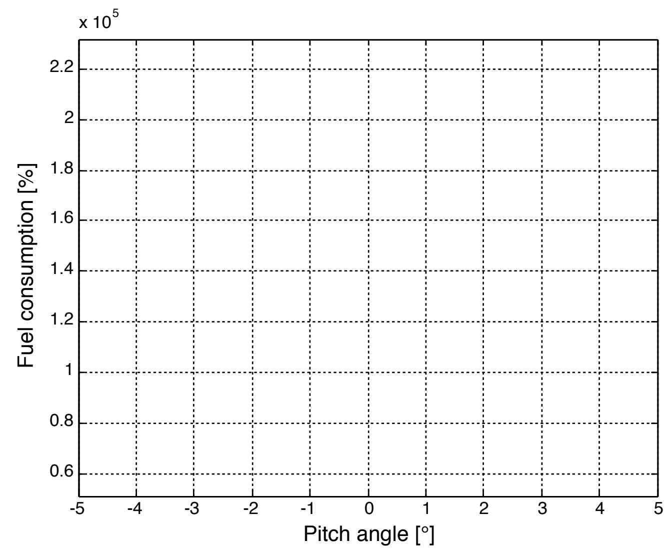
η_H: Hull Efficiency

η_r: Relative rotative efficiency

The best combination of propeller rate of revolutions and pitch can be identified through a minimization procedure of a weighted function of absolute fuel consumption and cavitation area of the equilibrium points.







INTEGRATION OF SEAKEEPING AND POWERING COMPUTATIONAL TECHNIQUES WITH METEO-MARINE FORECASTING DATA FOR IN-SERVICE SHIP ENERGY ASSESSMENT

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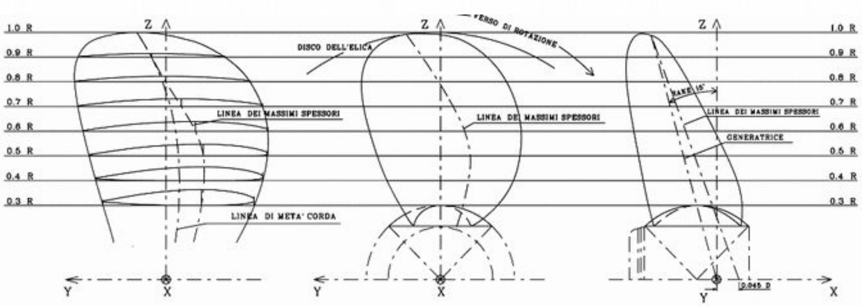
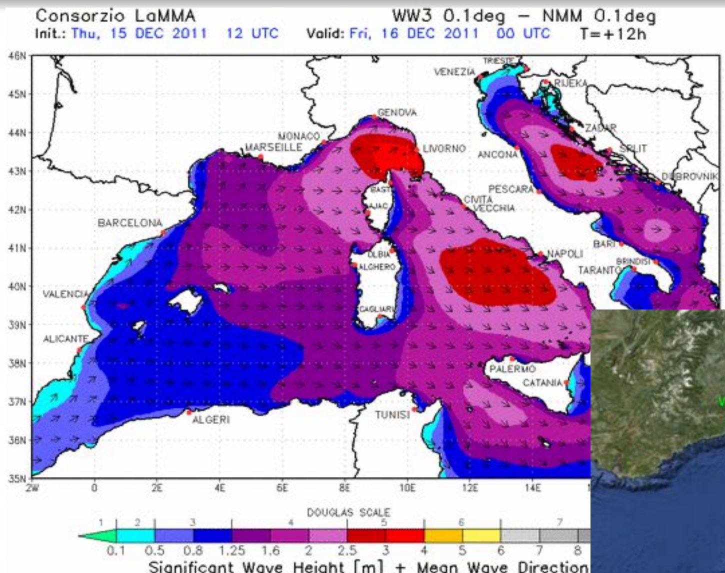
15th International Congress of the International Maritime Association of the Mediterranean

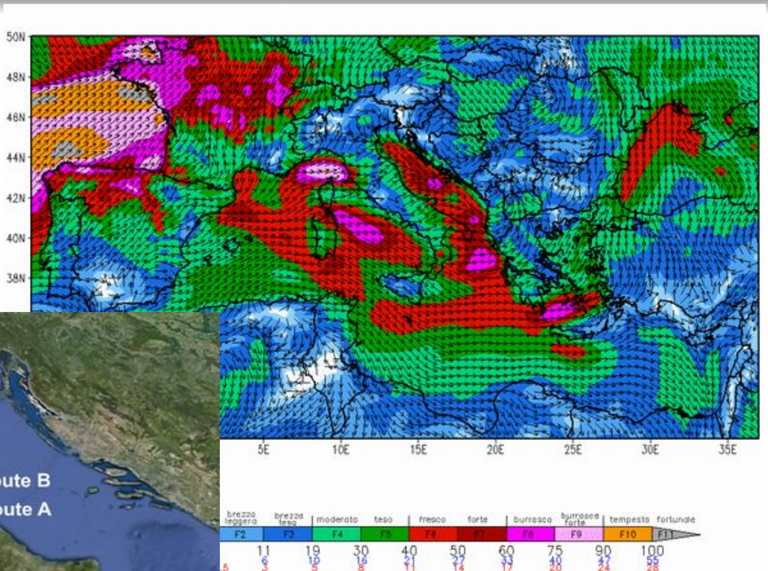
MAIN ENGINE:
4 X WARTSILA 16V46
BRAKE POWER:
4 X 16800 KW

PROPELLERS: 2 X 4 BALDES CPP



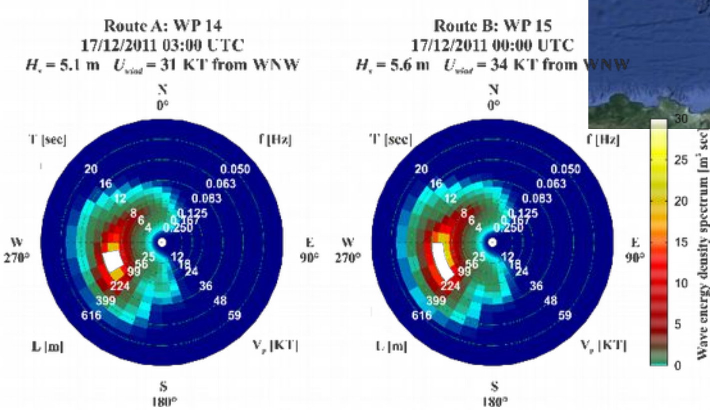
Volume		25226	m3
Length between perpendicular	LPP	186.2	m
Beam	B	30.4	m
Depth	D	15.5	m
Mean Draft	T	7.4	m
Vertical center of gravity	VCG	13.4	m

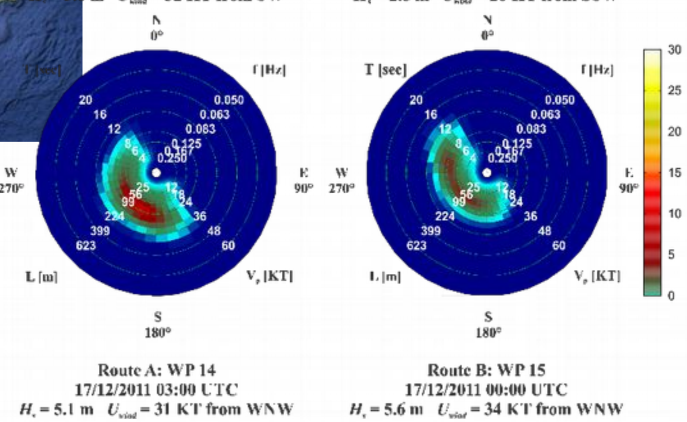




SIMULATED VOYAGE:
(CATANIA-GENOVA)

TIME OF DEPARTURE:
16/12/2011 00:00 UTC





FIXED SHIP SPEED: 20 KT AS CONSEQUENCE CONSTANT HULL RESISTANCE (R_{hull})

CALM WATER BASELINE:

$$R_{Tot} = R_{hull}$$

SCENARIO SIMULATION IN REALISTIC CONDITIONS:

$$R_{Tot} = R_{hull} + R_{aw} + R_{wind}$$

1. Design mode: with fixed combinator curve
2. MDC Optimization: with optimized combination

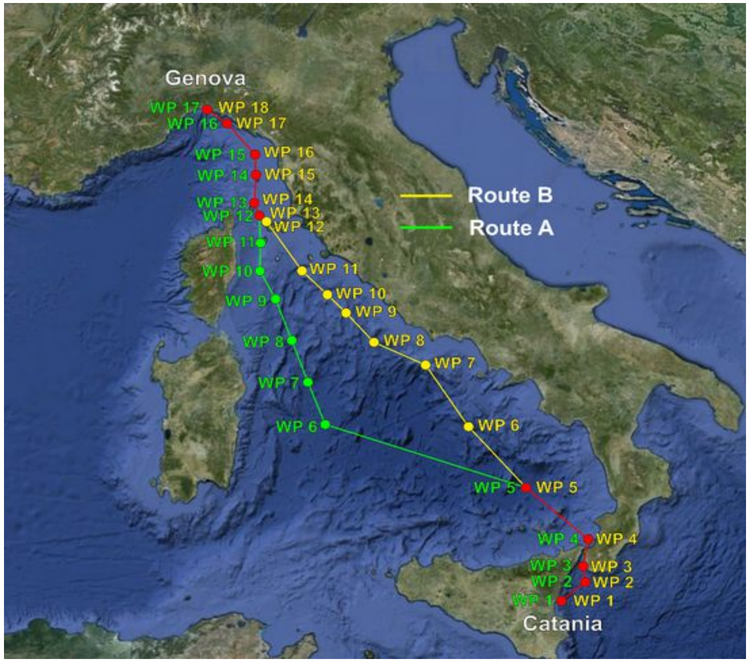
SIMULATED VOYAGE (CATANIA-GENOVA)

TIME OF DEPARTURE: 16/12/2011 00:00 UTC

TIME OF ARRIVAL:

Route A: 17/12/2011 05:40 UTC (Tot. Dist. = 550 nmi Voyage Time: 29h40m)

Route B: 17/12/2011 03:50 UTC (Tot. Dist. = 515 nmi Voyage Time: 27h50m)



FIXED SHIP SPEED: 20 KT

CONSTANT Hull Resistance → $R_{Tot} = R_{hull}$

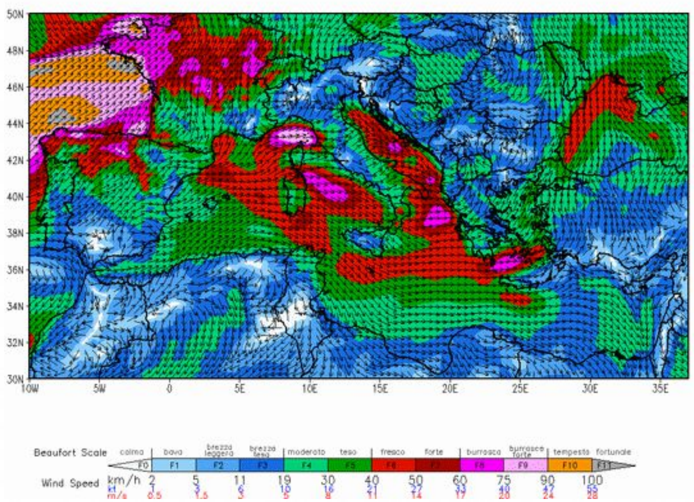
		Route	
		A	B
Distance	km	1100	1030
Total consumption	t	94.1	88.1
Consumption index	t/nm	0.16	0.16

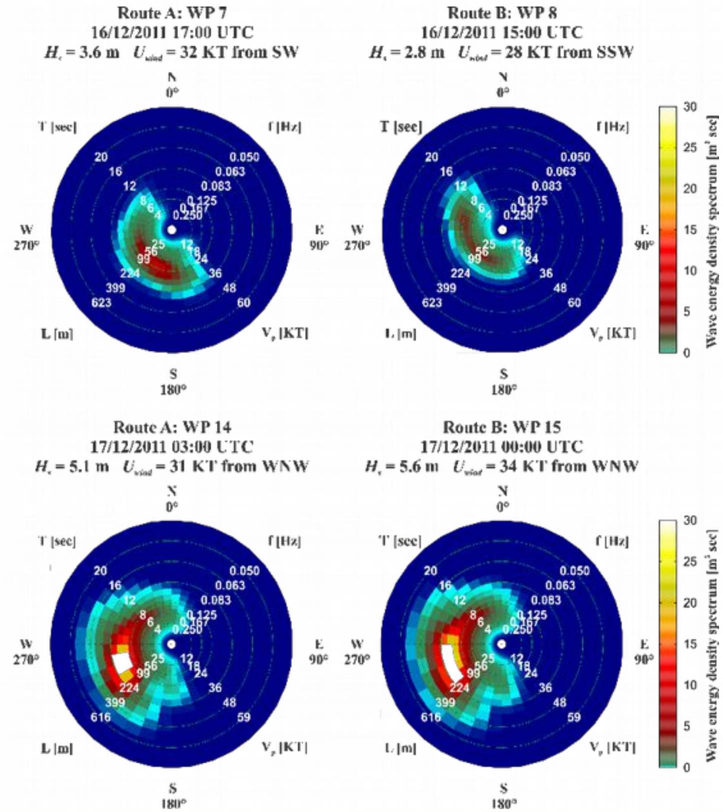
The detailed computations performed allow an analysis of the evolution of the resistance components due to meteo-marine conditions along each route.

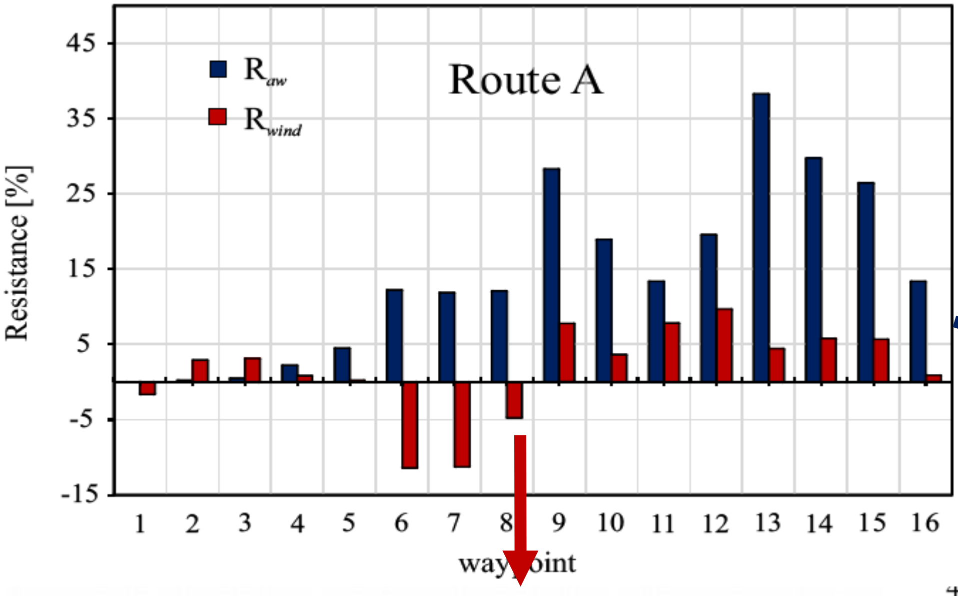
$$R_{Tot} = R_{hull} + R_{aw} + R_{wind}$$

CONSORZIO LaMMA DATASET:

- HOURLY DATA
- SPATIAL RESOLUTION 12 Km
- DIRECTIONAL WAVE SPECTRA
- WIND DATA FROM FORECAST MODELS



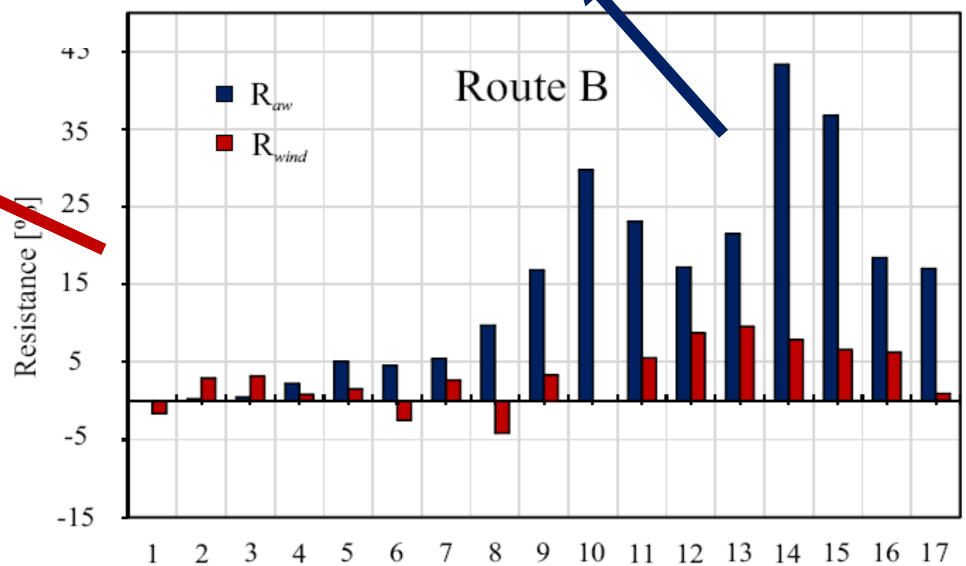




These two components of the total resistance *Rtot* have been computed along route A and route B respectively as percentage values with respect to the constant value of the calm water resistance *Rhull* at 20 knots

$$\frac{R_{AW}}{R_{HULL}}\ [\%]$$

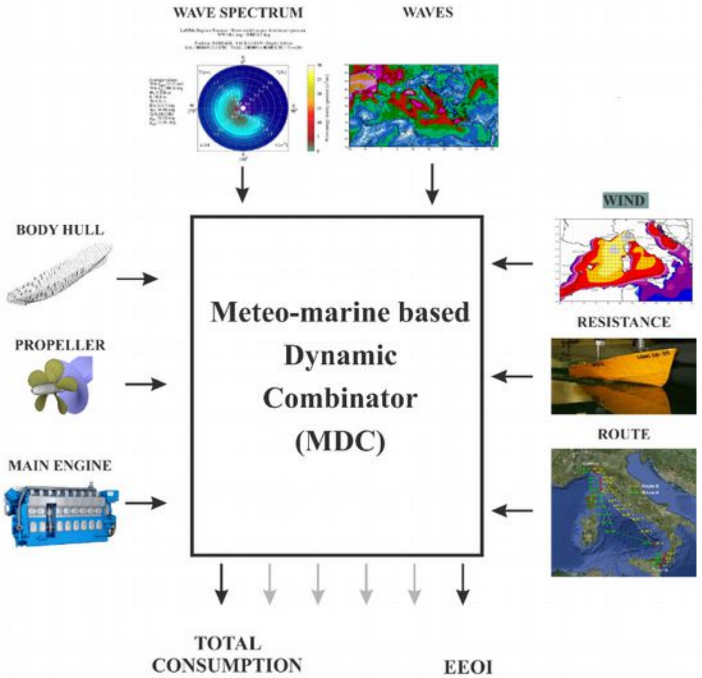
$$\frac{R_{WIND}}{R_{HULL}}\ [\%]$$



RESISTANCE VALUES IN PERCENTAGE

OF CALM WATER RESISTANCE

	Distance	Speed	Total Consumption	
			MDC Optimal	Design
	km	knots	%	%
Route A	1100	20	+7.42	+9.67
Route B	1030	20	+6.69	+8.93



- NOT NEGLIGIBLE INCREMENT OF FUEL CONSUMPTION DUE TO METEO-MARINE CONDITIONS WITH RESPECT TO CALM WATER CONDITIONS
- MDC OPTIMIZATION ALLOWS FUEL SAVINGS AROUND 2% WITH RESPECT TO FIXED COMBINATOR ENGINE SETTINGS
- SUCH SAVINGS ARE CONFIRMED ALONG BOTH TESTED ROUTE VARIANTS
- THESE ARE PRELIMINARY RESULTS, IN FURTHER IMPROVEMETNTS OF THE STUDY WE WILL CONSIDER:
    1. WIDER AREAS AND MORE REALISTIC RUOTE VARIANTS
    2. STATISTICAL SAMPLES OF METEO-MARINE CONDITIONS, E.G.
        - UNSUPERVISED CALSSIFICATION OF WAVE SPECTRA FOR DETAILED INFORMATION ON WAVE CLIMATE

- DETAILED INTEGRATION OF METEO-MARINE FORECAST DATA WITH SEAKEEPING AND POWERING ALGORITHMS
- PROPOSED AND PRELIMINARILY TESTED AN ENGINE SETTINGS OPTIMIZATION ALGORITHM (MDC OPTIMIZATION) FOR SHIPS WITH CPP
- OBTAINED ESTIMATES OF NOT NEGLIGIBLE FUEL SAVINGS

PROPOSED APPLICATIONS:

- WEATHER ROUTING ALGORITHMS: TO IMPROVE THE OPTIMALITY OF ROUTE SOLUCTIONS FOR FUEL CONSUMPTION REDUCTION
- OPERATIONAL GUIDANCE SYSTEM
- INNOVATIVE ENGINE CONTROL SYSTEMS
- SHIP DESIGN WITH SCENARIO SIMULATIONS WITH STATISTICAL DATA

THANK YOU FOR YOUR KIND ATTENTION