Workshop MOSES 2017
Modelling and Optimization of Ship Energy Systems
23, 24, 25 October – EPFL Valais-Wallis, Sion, Switzerland

SHIP VOYAGE OPTIMISATION BY 3D DYNAMIC PROGRAMMING

Massimo Figari

Raphael Zaccone

Michele Martelli

Marco Altosole

Università degli Studi di Genova
Italy

with the collaboration of Ennio Ottaviani
OnAir Srl, Genova, Italy

UNIVERSITY OF GENOA
35000 Students
1300 Teaching Staff
1400 Administrative & Technicians Staff

DITEN Department

Electrical Engineering

Naval Architecture & Marine Engineering

Electronics Engineering

Background : emission reduction

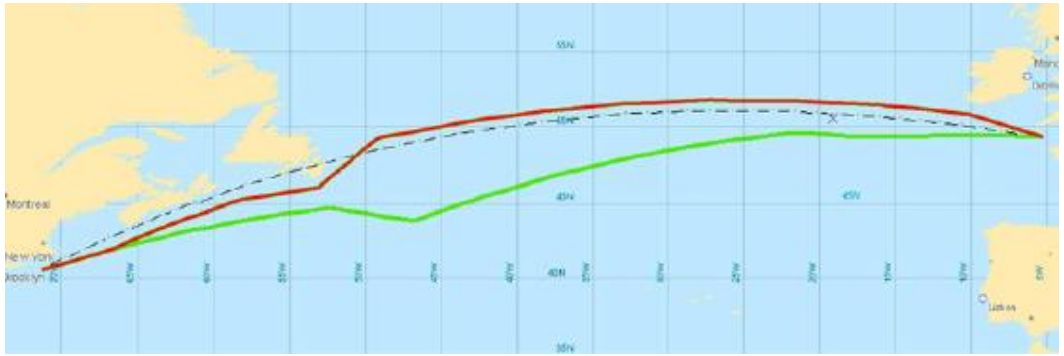
- REGULATION (EU) 2015/757 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29 April 2015 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/EC
- IMO EEOI should enter into force
- OBJECTIVES
  - monitor, report and verify CO2 emissions from ships as the first step of a staged approach to reduce greenhouse gas emissions
  - promote the reduction of CO2 emissions from maritime transport in a cost effective manner

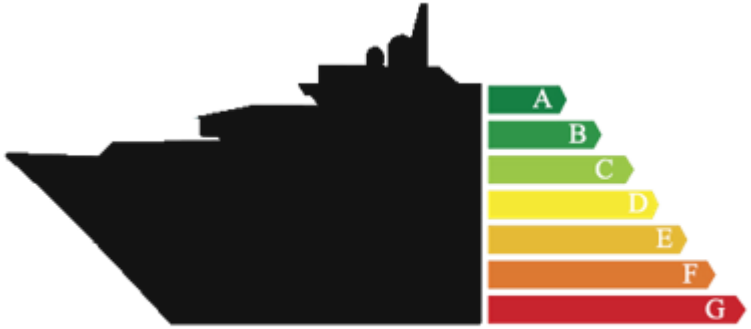
Background: improve operational capacity

- Optimise fuel consumption
- Improve comfort on board
- Improve crew behavior and effectiveness

Decision support systems

- energy optimisation
- voyage optimisation
- maximise ship operability at operational level in a real environment





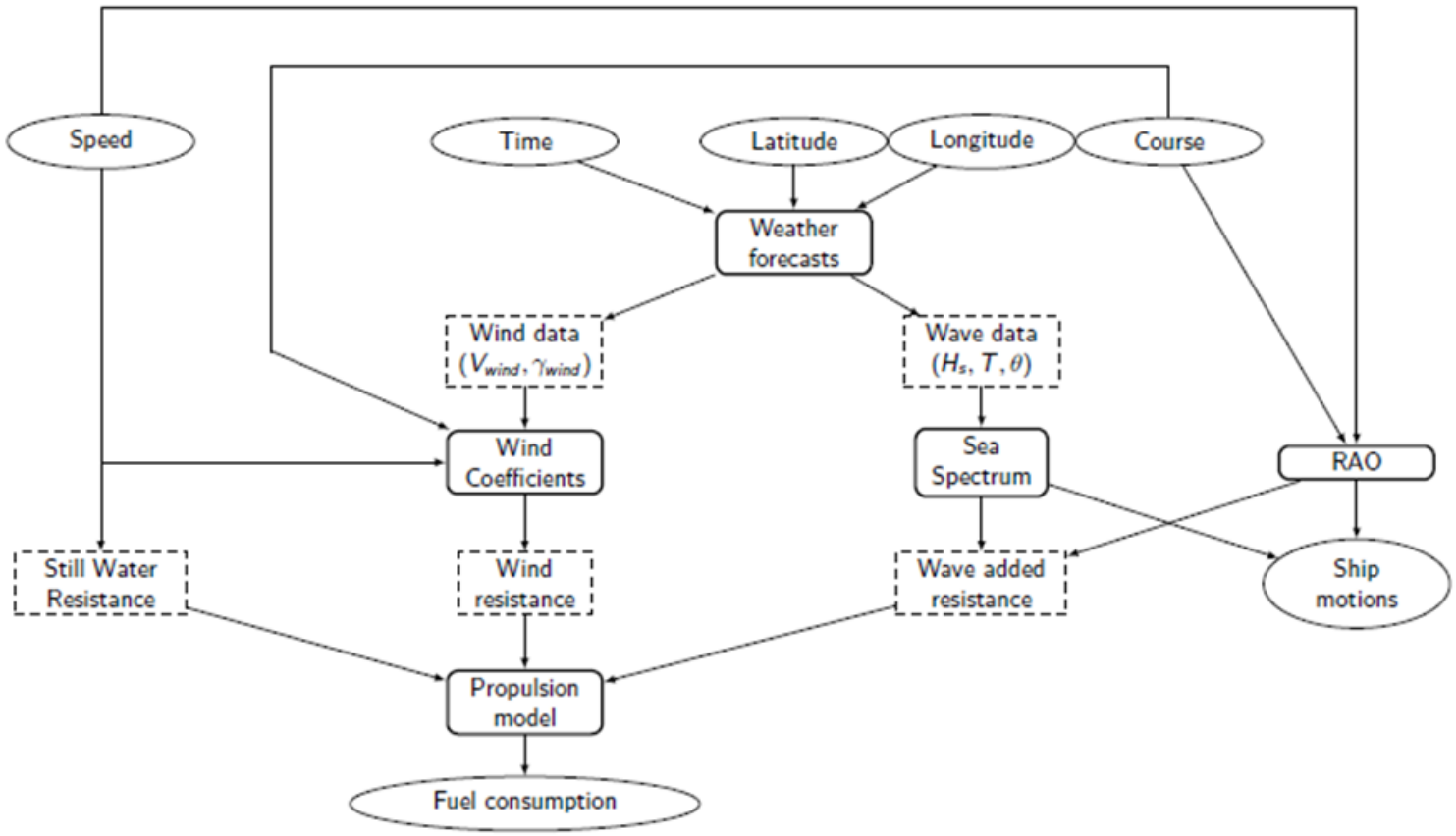
A COLLABORATIVE PROJECT

- UNIGE – Naval Architecture & Marine Engineering (DITEN)
  - Ship motion modelling
  - Ship propulsion modelling
  - Ship strenght modelling
- UNIGE – Weather Forecast (DICCA)
  - Sea state forecast
  - Surface wind forecast
- ONAIR Srl – (R&D performing SME)
  - Search path algorithms
  - Optimization algorithms

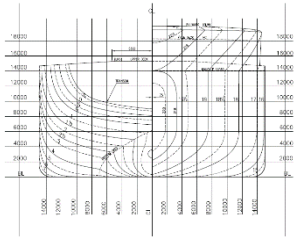
Work Flow

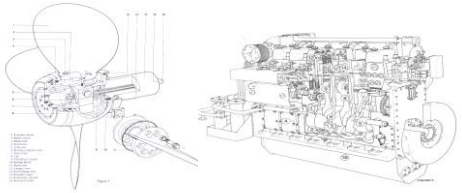
- Hull forms modeling, propulsion system modeling,
- Design Operational area, sea & wind forecast
- Ship motions calculation
- Motions effects on people onboard
- Motions effects on propulsion system performance
- Motions effects on structures (not yet available)
- Ship Operational capability
- Maximise capability: voyage plan optimisation

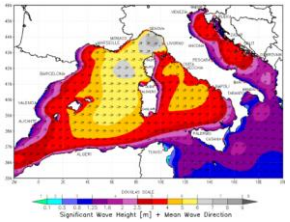
Workflow

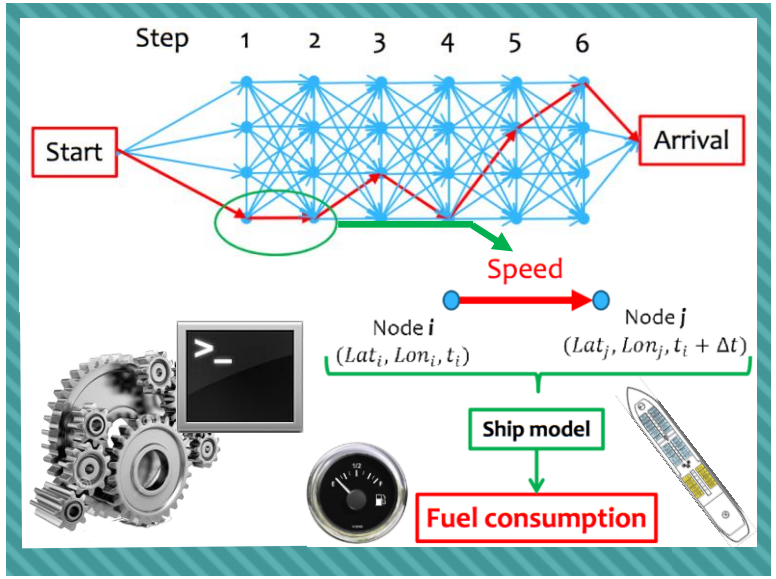

Speed
Time
Latitude
Longitude
Course
Weather forecasts
Wind data (V_{wind}, γ_{wind})
Wave data (H_s, T, θ)
Wind Coefficients
Sea Spectrum
RAO
Still Water Resistance
Wind resistance
Wave added resistance
Ship motions
Propulsion model
Fuel consumption

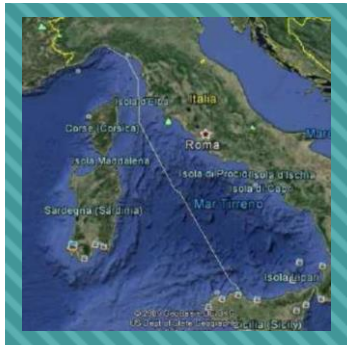
VOYAGE OPTIMIZATION











INPUT

- Ship model: built upon specific ship design data, (principal dimensions, resistance curves, hull geometry, propeller diagrams, engine consumption curves, etc.)
- Weather conditions: forecasted meteo data including wave spectral parameters and wind intensity and direction
- Minimum/maximum arrival time
- User defined constraints: search area, fixed waypoints, number of manouvers, maximum amplitude and accelartion of ship motions, allowed severity (slamming and deck wetness probabilities), maximum loading for engines.

OPTIMIZATION ENGINE

The optimization engine search all available routes, according to the given contraints in terms of arrival time, safety, waypoints, etc, comparing the fuel consumption and comfort/safety, computed by suitable indexes. Such quantities can be evaluated by the inclusion inside the optimization engine of a complete ship simulation model.

The search for all available routes is performed according to the orthodromic navigation scheme.

The engine adopts the most advanced optimization algorithms, both single and multi-objective, and exploits the specific features of the naval optimization to increase computational performances. The user can explore the full search space and perform *sensitivity analysis* of optimal routes by varying the imposed contstraints.

OUTPUT

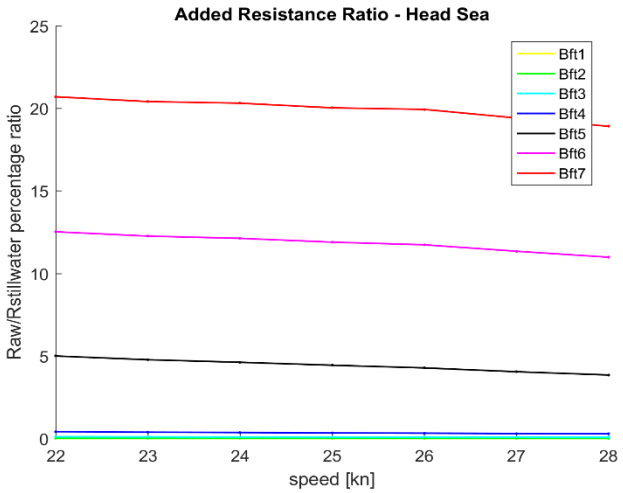
Optimal routing, including the speed profile to be followed in every route segment.

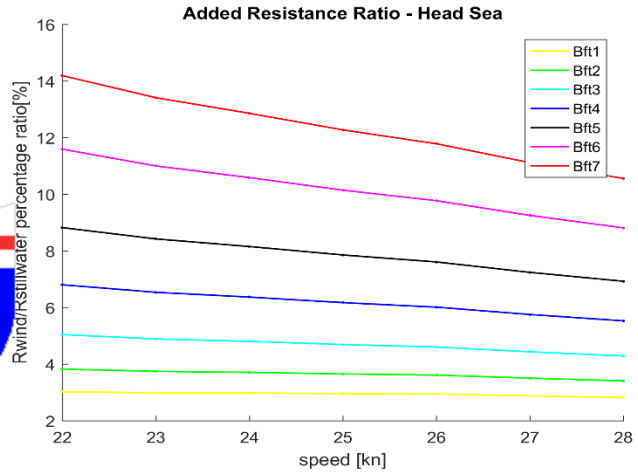
The route is generated in the standard KML format, allowing an easy representation by Google Earth tools.

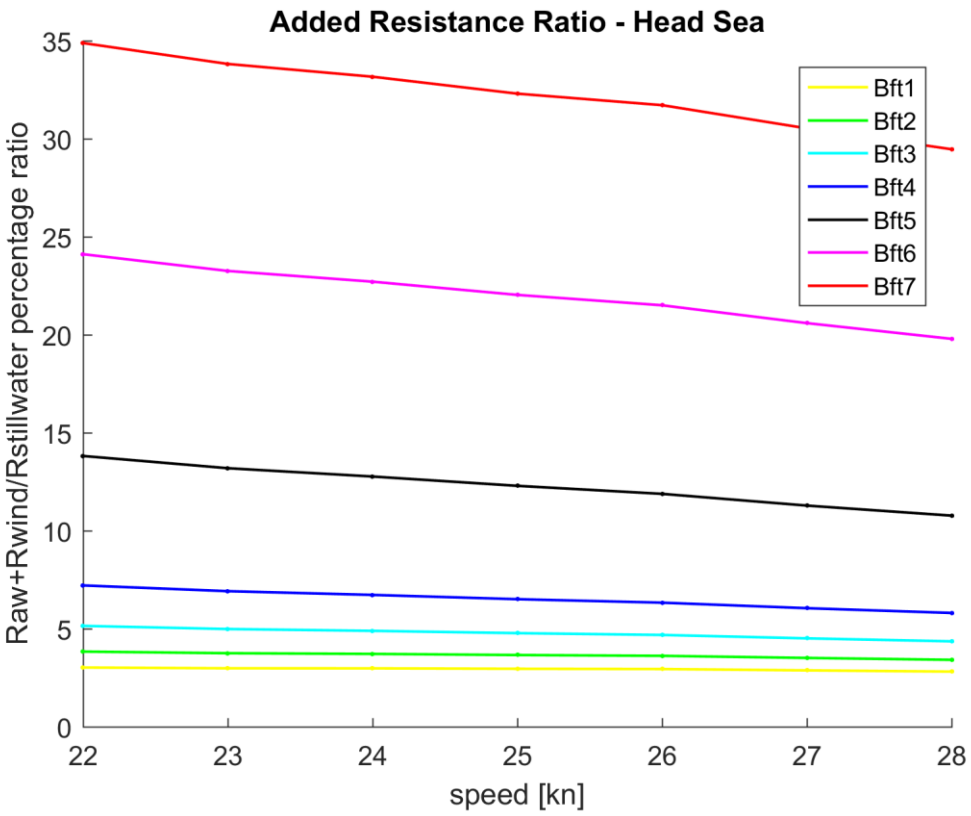
Ship Motion

- Ship response $S_{\eta i}(\omega,\theta,V) = |H_{\eta i}(\omega,\theta,V)|^2 S_\zeta(\omega,\theta)$
- Added resistance $R_{aw}(V) = 2\int_0^\infty \int_0^{2\pi} \Phi_{aw}(\omega,\theta,V) S_\zeta(\omega,\theta) d\omega d\theta$
- Sea spectrum forecast $S_\zeta(\omega,\theta)$
- Wind forecast V_W

$R_{ADDED}=R_{WIND}+R_{WAVE}$

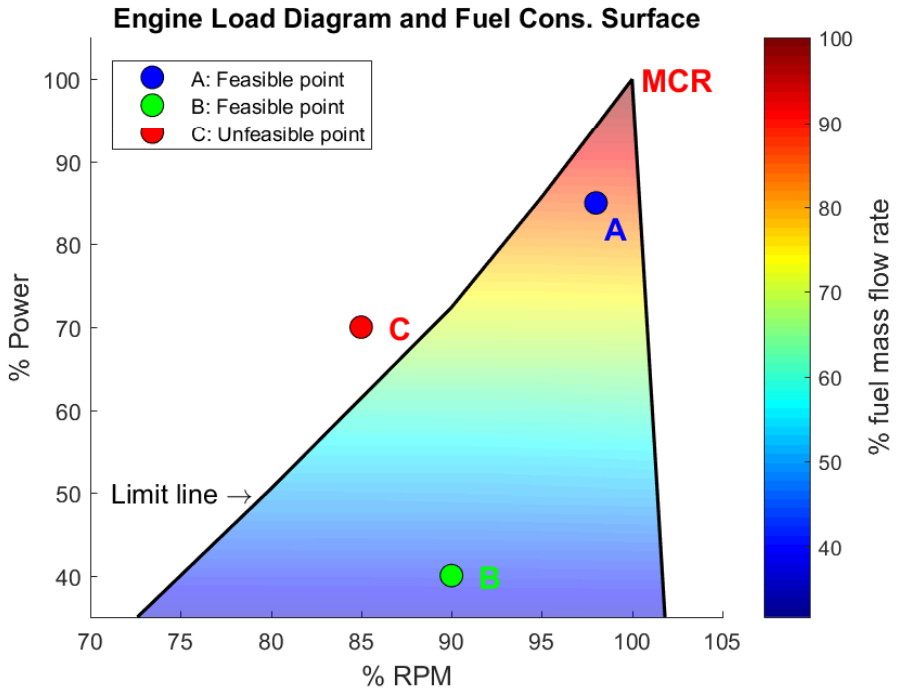




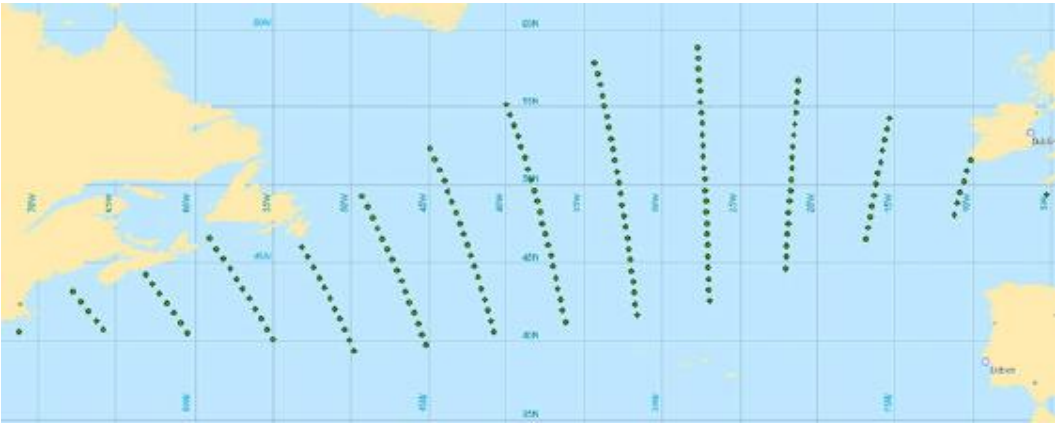


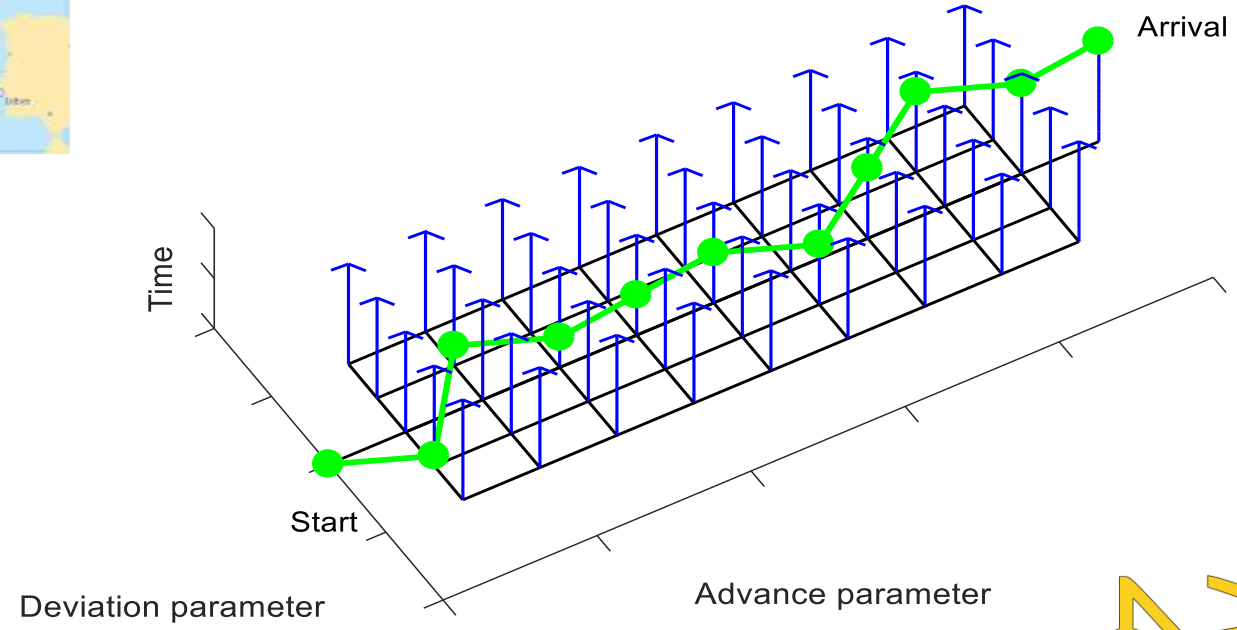
Engine modelling

- Stationary model
- Engine load limits
- SFOC surface

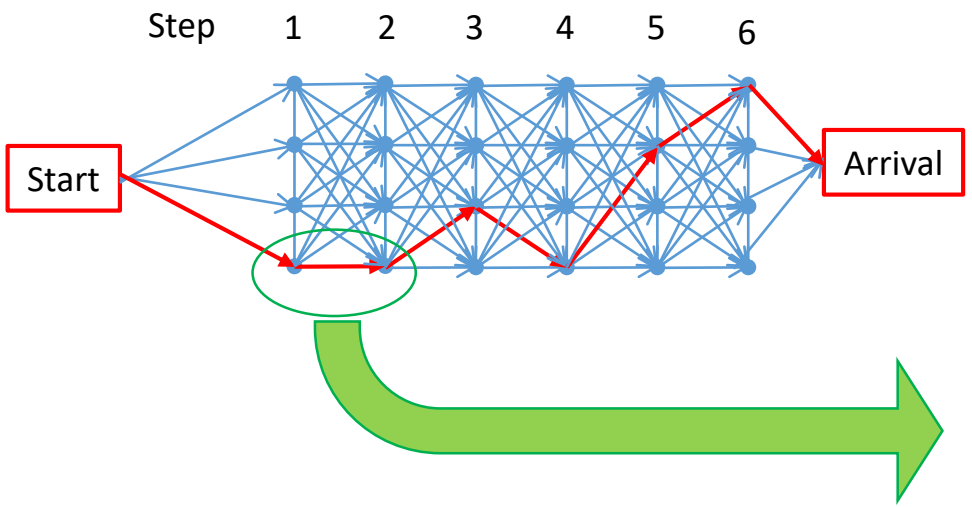


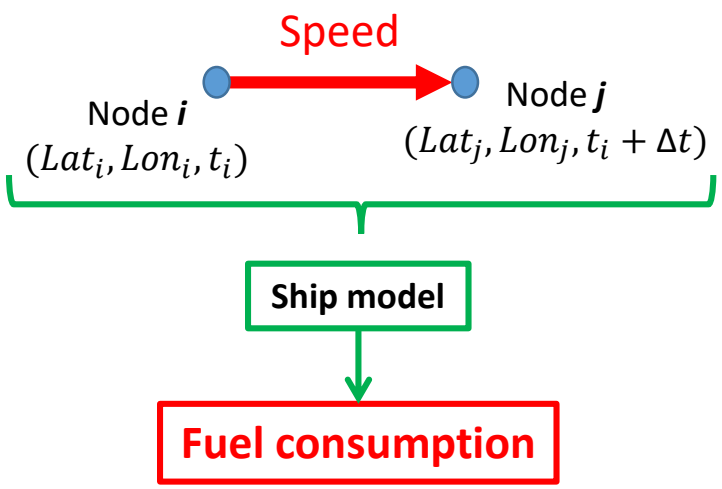
Route parametrization





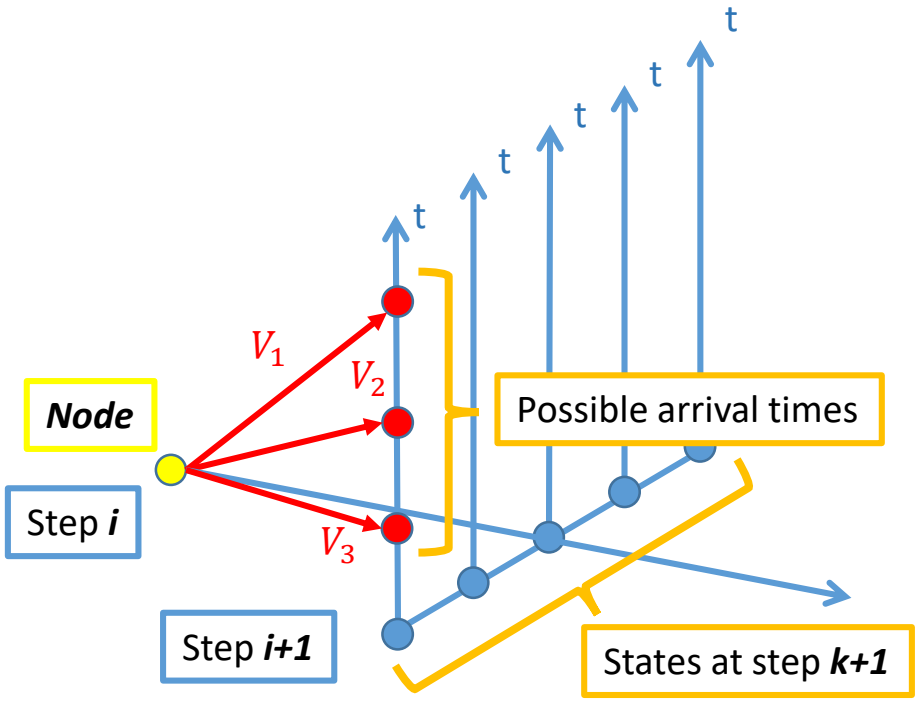
Optimal path search:
3D dynamic programming



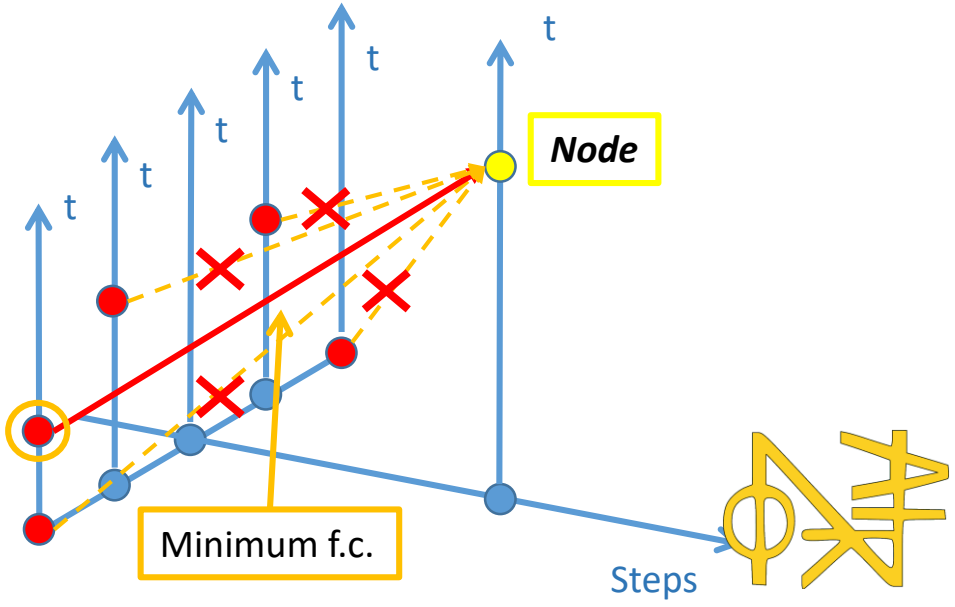


Optimal path search: 3D dynamic programming

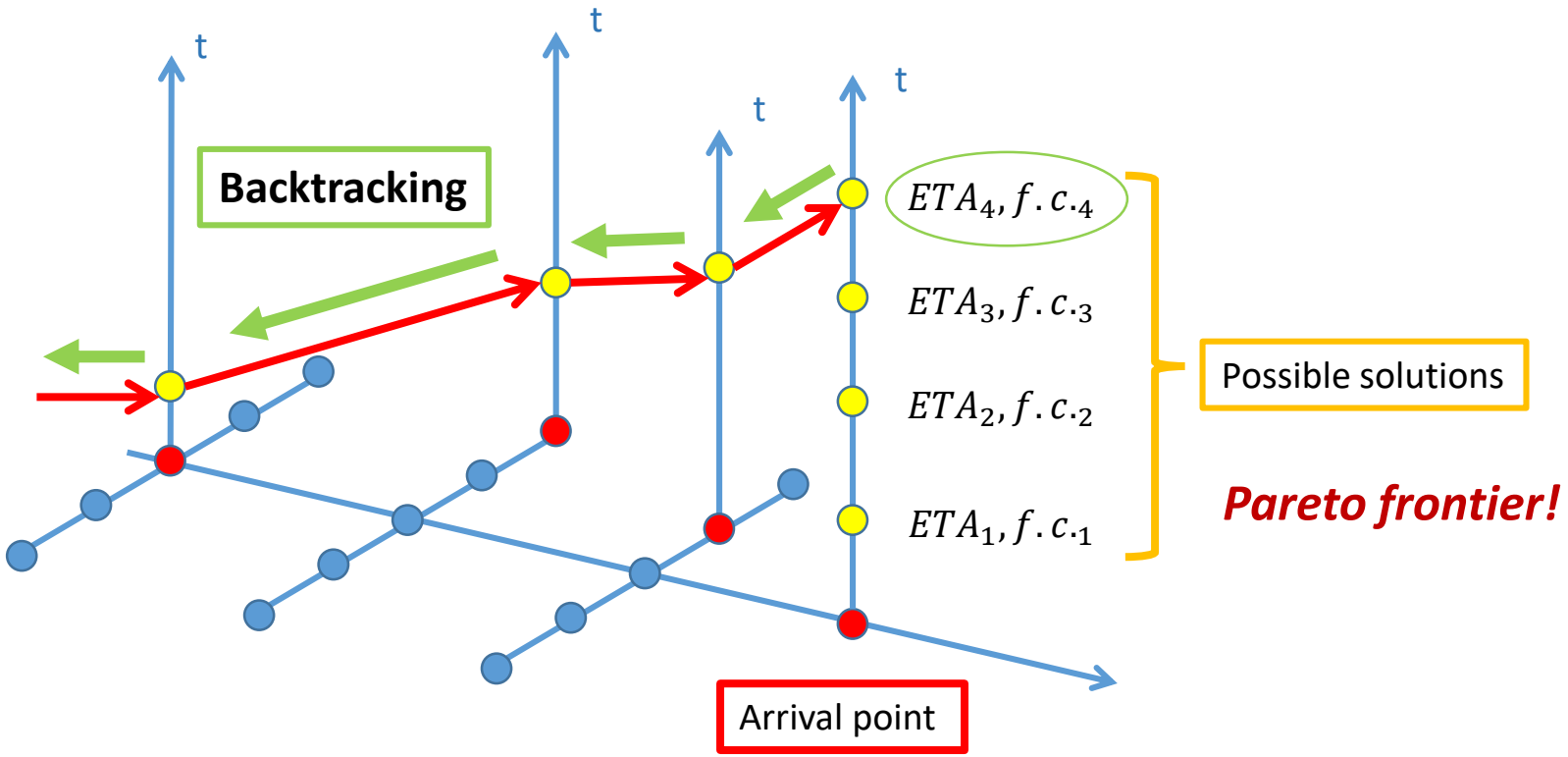
Nodes propagation



Pruning strategy



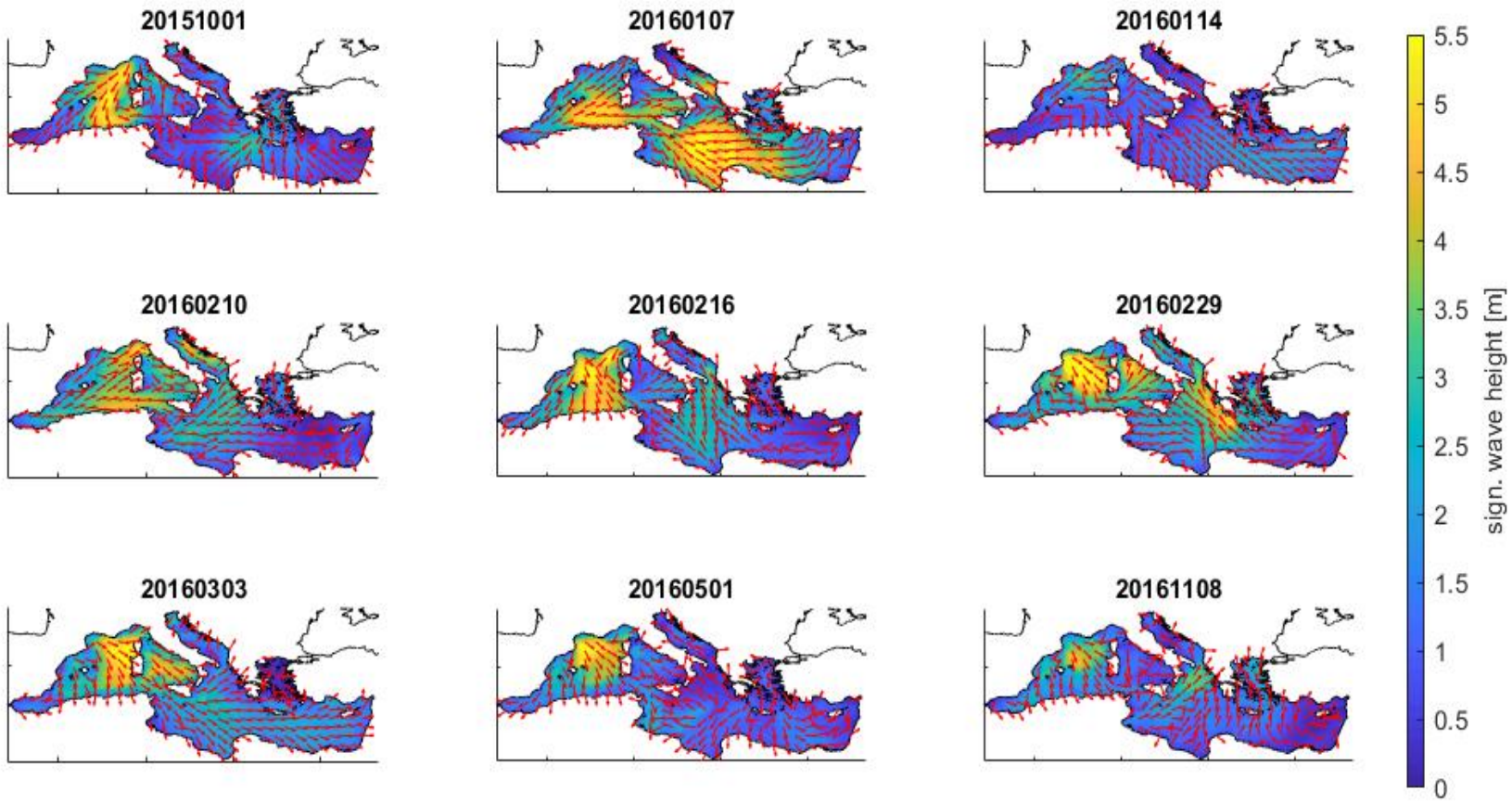
Optimal path search:
3D dynamic programming



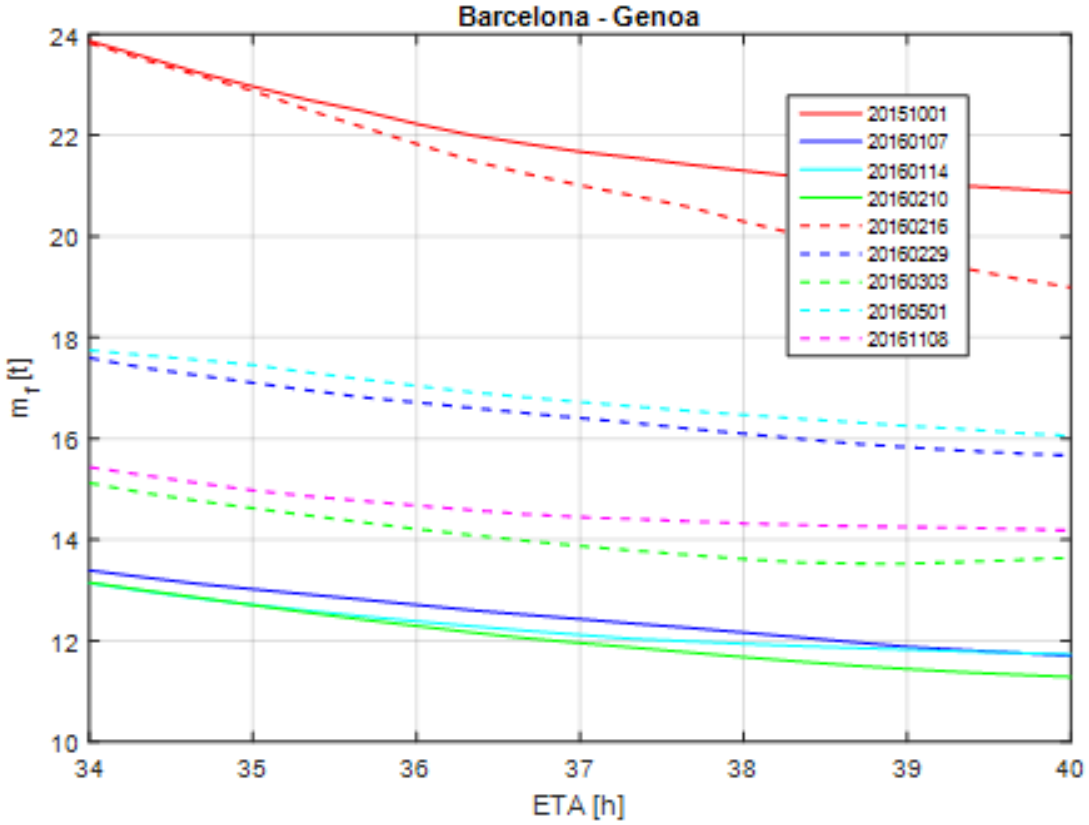
Case study

Lenght b.p.	182 [m]
Bream	31 [m]
Draft	9 [m]
Displacement	41577 [t]
Deadweight	40846 [t]
Propeller	1 x FPP, 4 blades, 6m Diameter
Main engine	1x10 MW, 113 RPM 2 stroke diesel engine

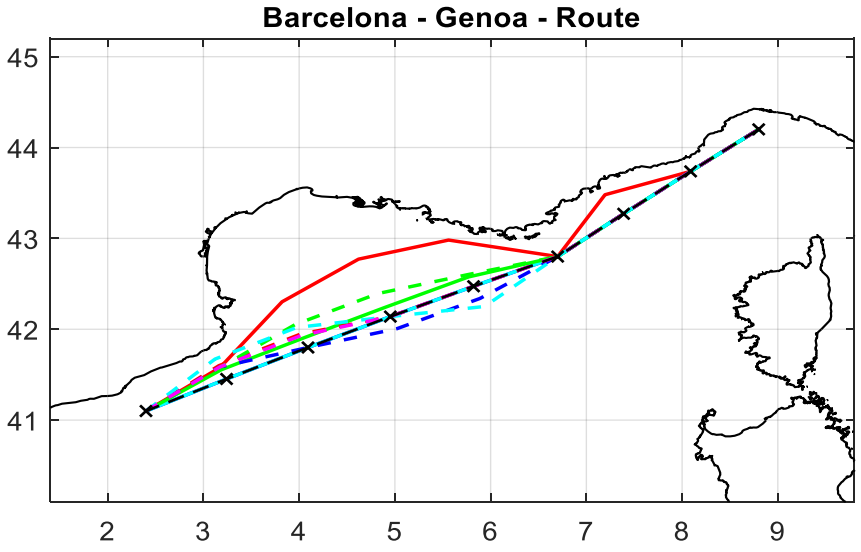
High resolution weather forecast

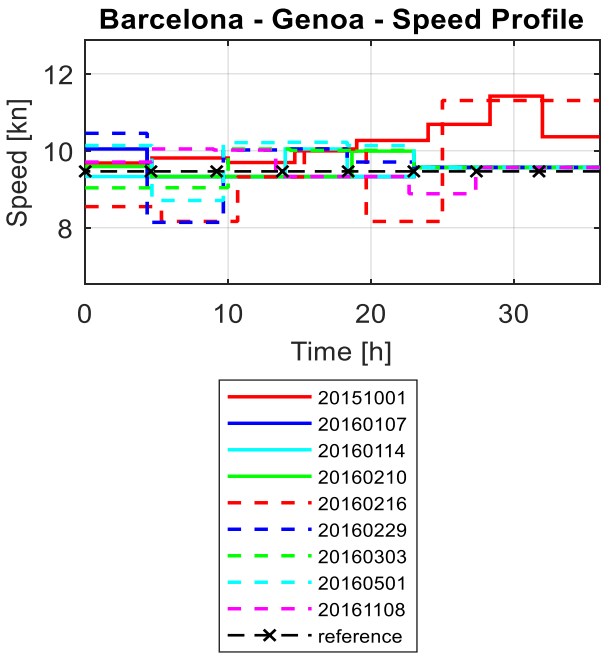


Trade-off curves: fuel vs. time

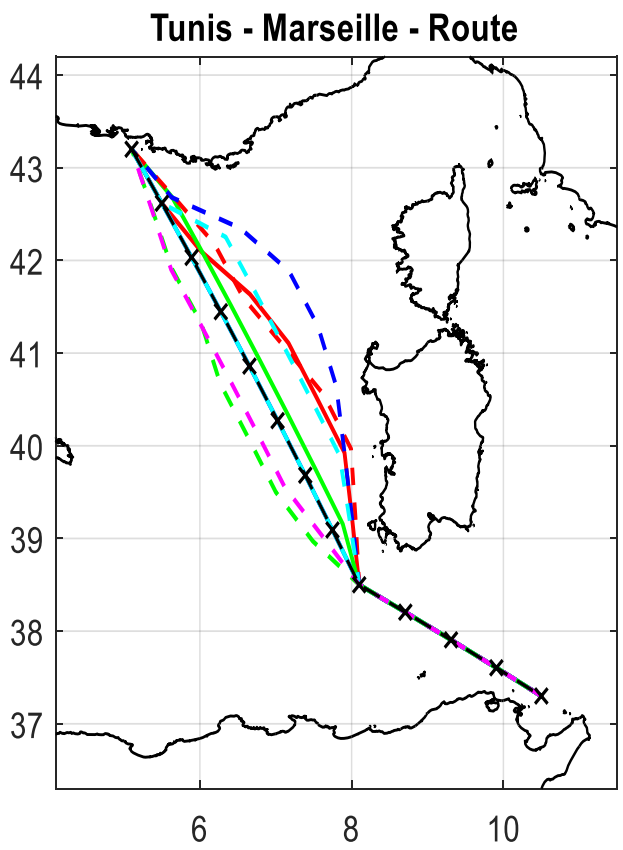


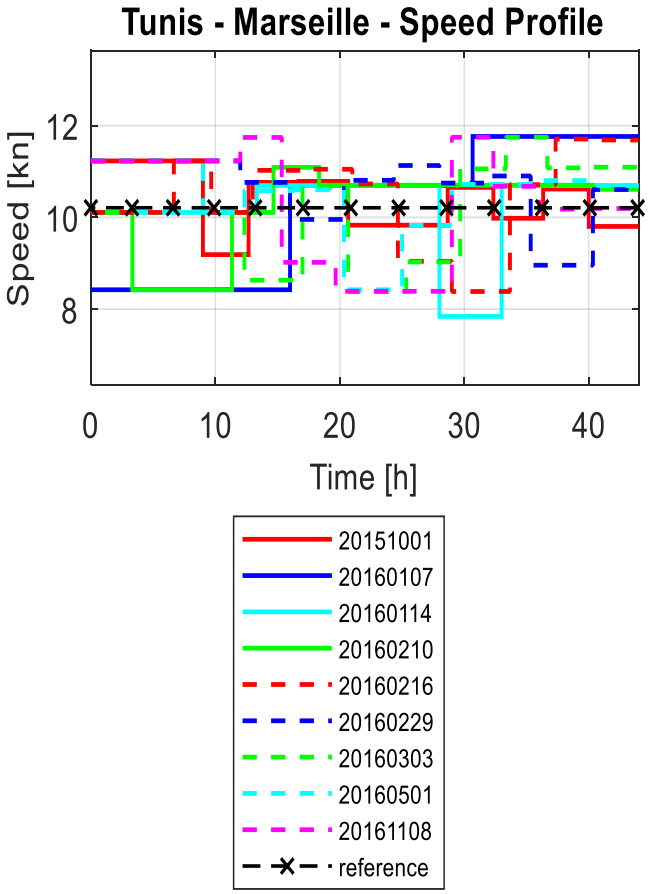
Genoa - Barcelona



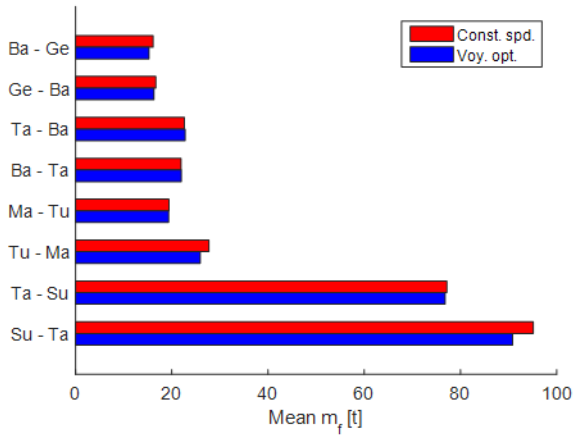


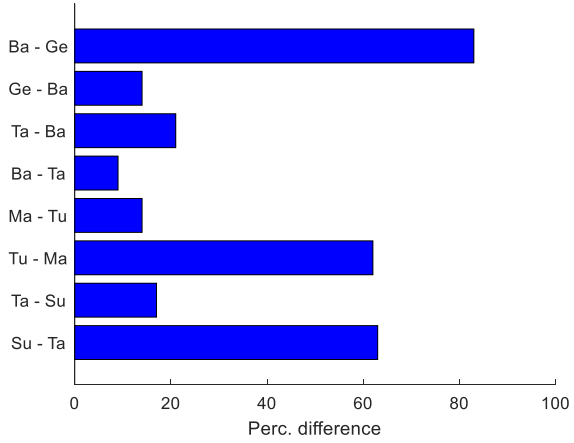
Tunis - Marseille

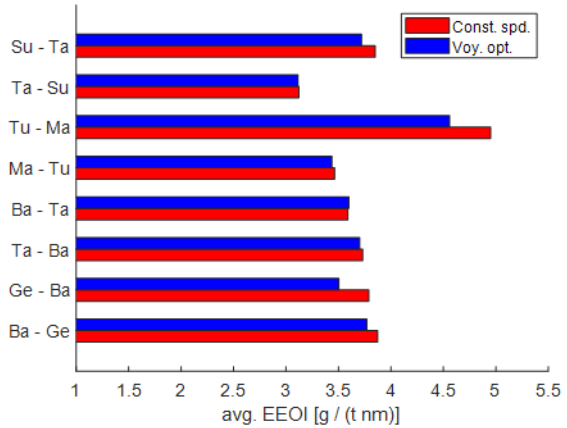




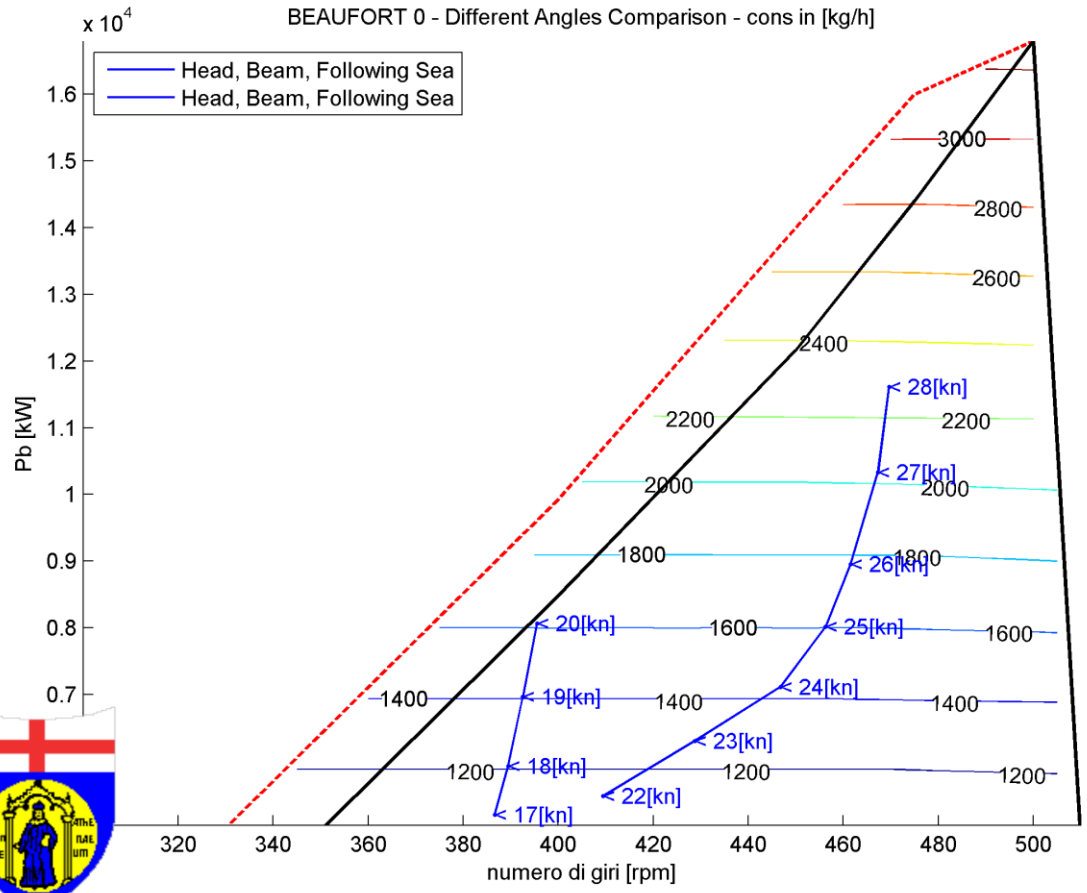
Fuel consumption & EEOI

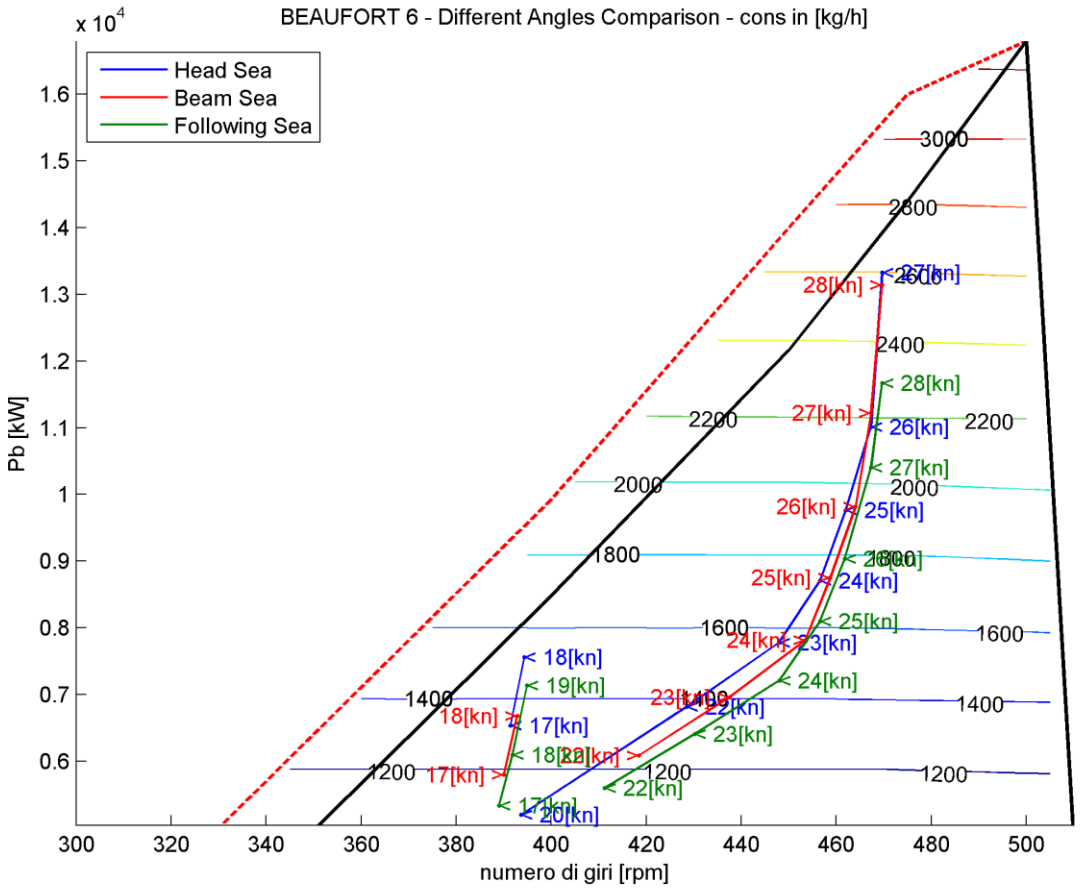




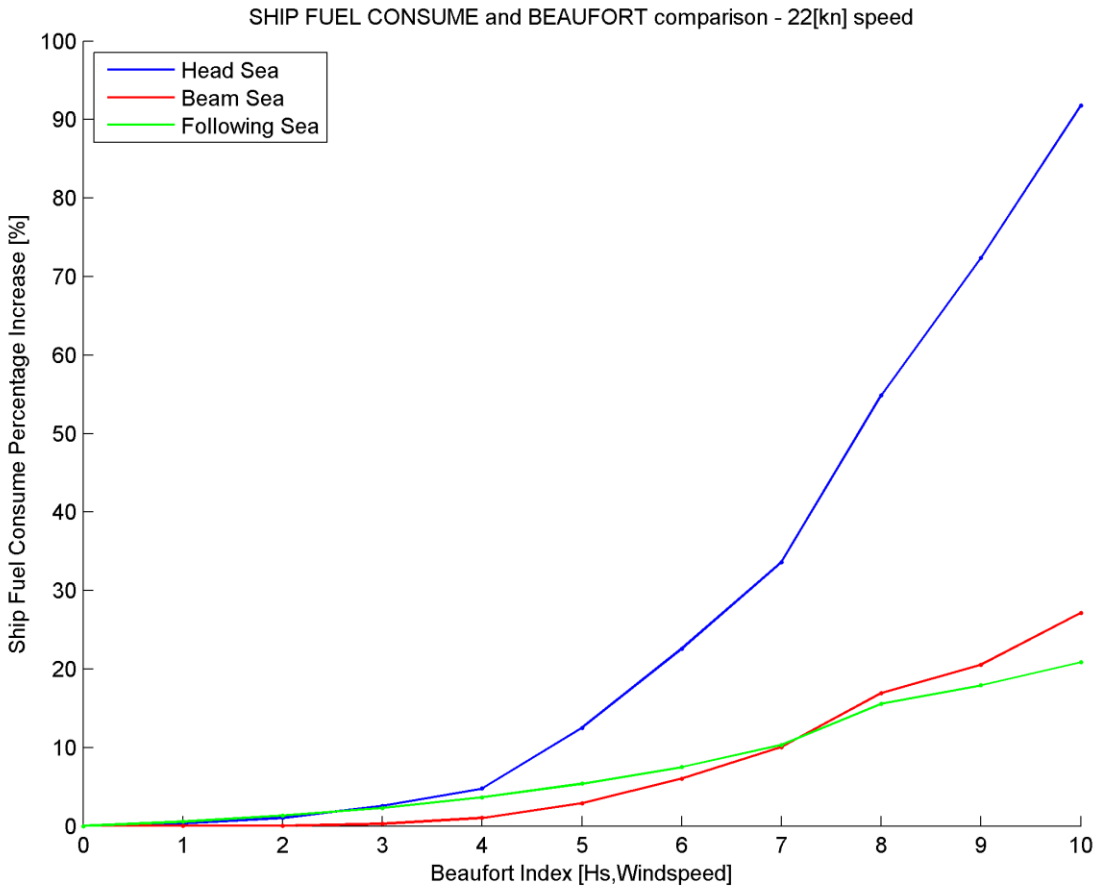


Engine working points vs beaufort scale





Fuel rate increment vs beaufort scale

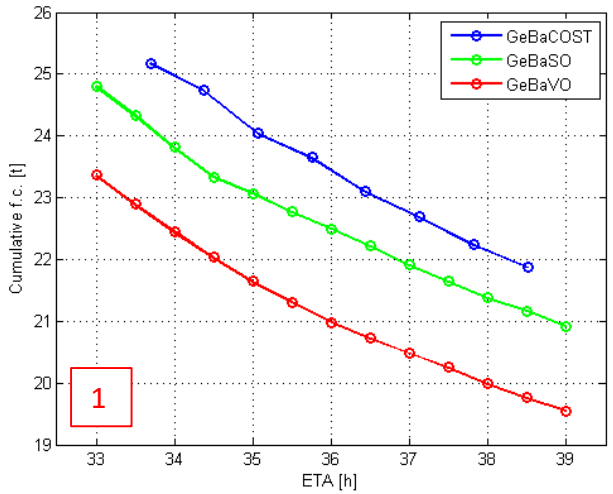


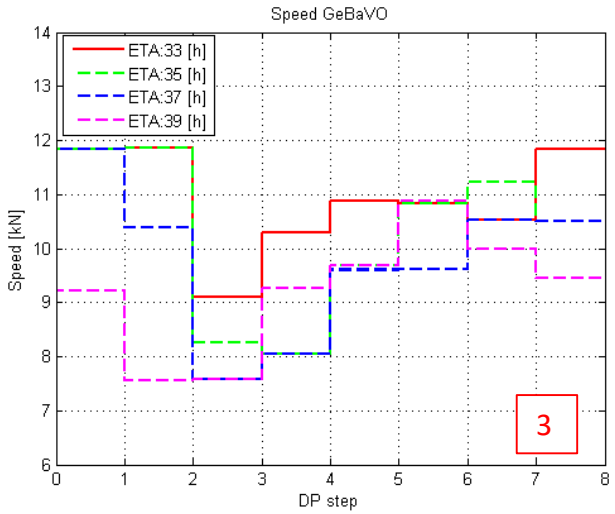
Voyage Optimization 1/2
Genova - Barcellona

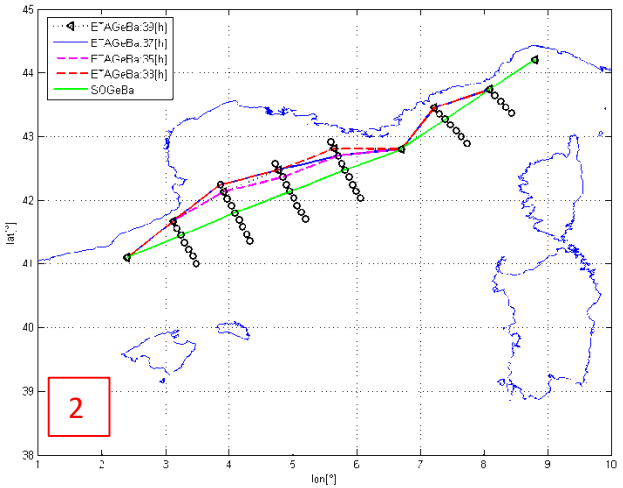
- **Distanza minima percorsa**: ca. 350 nm
- **Tempo di viaggio considerato**: 35 h (velocità media 10 Kn)
- **Differenti modalità di viaggio**:
  - Rotta a velocità costante
  - Ottimizzazione di velocità (S.O)
  - Ottimizzazione di rotta e velocità (V.O.)

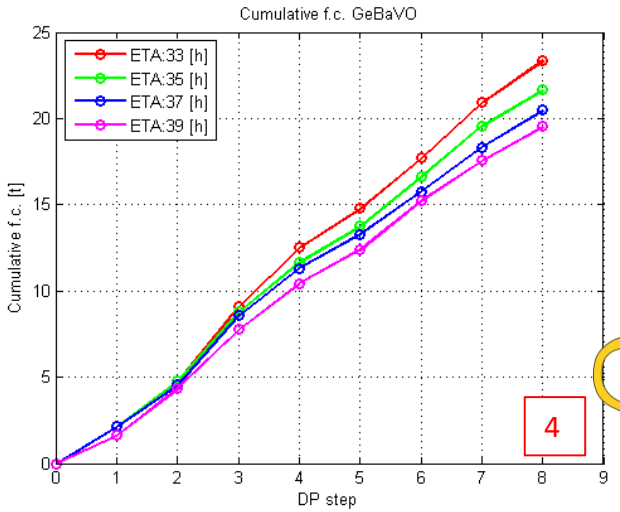
- **Risultati**:
  1. **Tempo di arrivo vs. consumo totale** nei casi considerati
  2. Confronto delle **traiettorie** nei casi considerati
  3. Confronto dei **profili di velocità** delle soluzioni **V.O.** a tempi di arrivo differenti
  4. Confronto dei **profili di consumo** (soluzioni **V.O**)

Massima riduzione dei consumi riscontrata: 11%





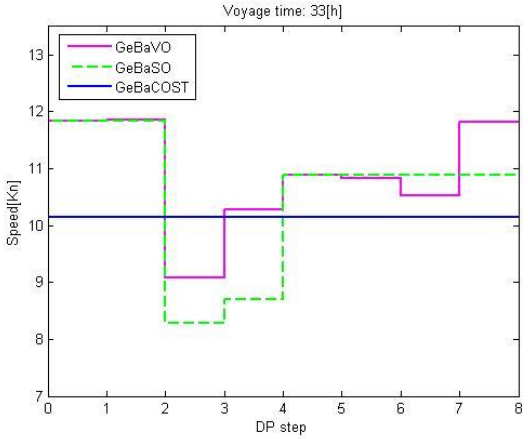


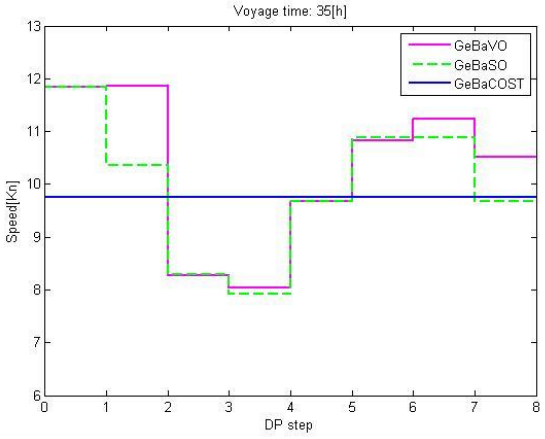


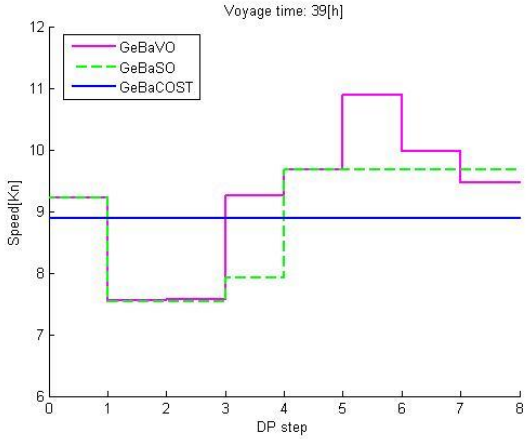
Voyage Optimization 2/2
V.O. vs. S.O. vs. velocità costante

Tempo di viaggio

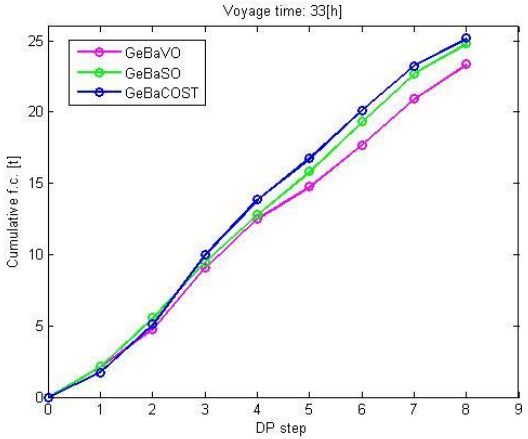
Profilo di velocità

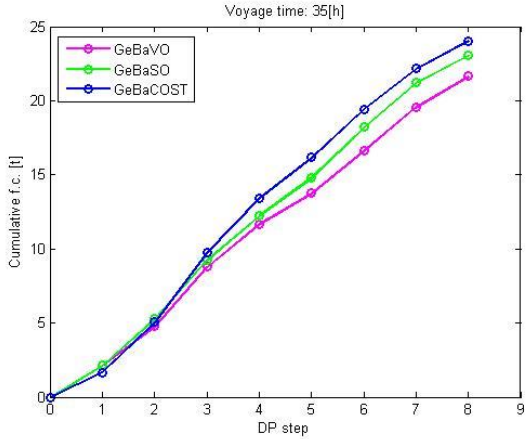


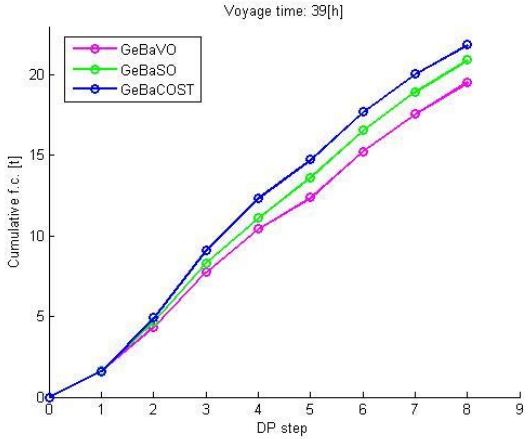




Profilo di consumo







APPLICATIONS

- MRV monitoring, reporting and verification of carbon dioxide emissions from maritime transport,
- EEOI assessment
- SAR vessel capability optimization
- Naval vessel platform capability assessment

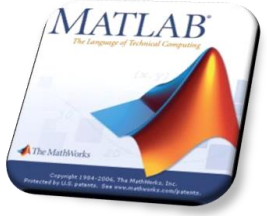
Thanks for your attention

Contacts: massimo.figari@unige.it
ennio.ottaviani@onairweb.com

Simulation Lab

Hardware

Working Environment



Prof. Marco Altosole (coordinator)
Prof. Giovanni Benvenuto*
Prof. Massimo Figari
Prof. Michele Martelli
Prof. Stefano Savio
Prof. Michele Viviani
Dr. Raphael Zaccone

Prof. Angelo Alessandri (DIME)
Prof. Ugo Campora (DIME)
Prof. Stefano Vignolo (DIME)

2 Ph.D. Students

Research streams

- **Propulsion plant dynamics**
  - Non linear models
- **Control logics simulation**
  - Propulsion controller
  - DP controller
  - Speed pilot
  - Autonomous navigation
- **Energy efficiency optimisation**
  - Weather routing
  - Power management
- **Condition based maintenance**
- **Alternative propulsion plants**
  - LNG
  - Hybrid Sail-Diesel-Electric Propulsion

SIMULATION MILESTONES

- 1994: diesel engine tabular model, propeller tabular model, fishing boat model
- 1996: shaft line model with torsion, thermodynamic diesel model, model of “San Giusto”
- 1998: water jet model, diesel engine model with EGR
- 2000: model “Nave EXCELSIOR” and measurement campaign

SIMULATION MILESTONES

- 2002: diesel engine model with sequential turbocharger, model of "**Comandante Bettica"** and **measurement campaign**

- 2003: manoeuvrability of planing hulls

SIMULATION MILESTONES

2004 - 2007: propulsion control system developed by simulation (RT-HIL) for "**Cavour**", and **measurement campaign**

2010 : low speed manoeuvrability model , model "**La Superba"** and **measurement campaign**

SIMULATION MILESTONES

2009 - 2012: propulsion control system for CODLAG and 6 DOF manoeuvrability model of “**FREMM**” with **measurement campaign**

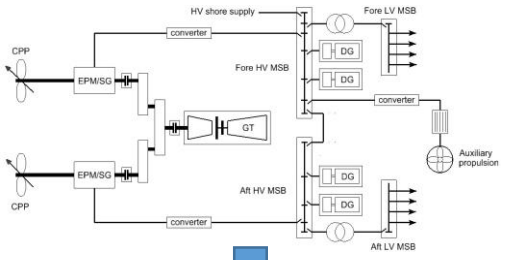
2013 : 4 DOF manoeuvrability model for planning hull

SIMULATION MILESTONES

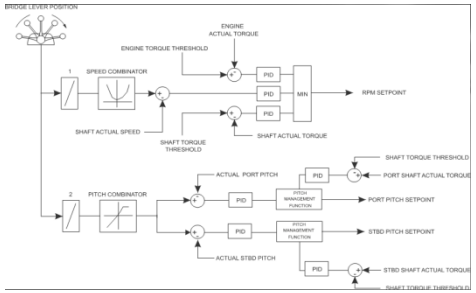
2013: **Amerigo Vespucci** : development of control system for combined sail and diesel propulsion

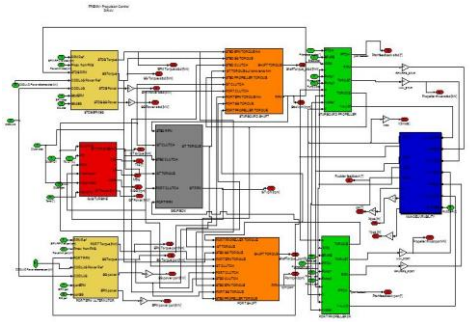
2013-2015 : Coast guard patrol vessel: **Diciotti** : 3 DOF low speed model for dynamic positioning application i

MODEL BASED DESIGN PROCEDURE

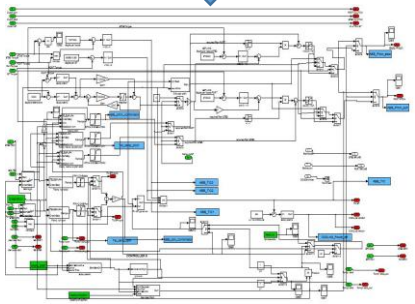


DESIGN





MODELLING



OPTIMIZE

TEST

REAL SYSTEM