MAKING SMART USE OF THE ENVIRONMENT IN SHIPPING

Guilhem Gaillarde
Head of Ships department – MARIN

Rogier Eggers, Rob Grin, Rien de Meij, Peter Boelens
• MARIN status and strategy
• Why can wind propulsion revive?
• Overview of latest trends and concepts
• Wind availability and voyage simulation
• Two examples of recent studies: Wind Hybrid Coaster and SAIL
• Upcoming challenges and perspectives
MARIN STATUS AND STRATEGY
Independent and innovative service provider for the maritime sector in hydrodynamic and nautical research
MARIN STATUS AND STRATEGY

Dual mission

- To provide industry with innovative design solutions
- To carry out advanced research for the benefit of the maritime sector as a whole
Simulation is the imitation of real-world operations. This broad definition fully applies to MARIN’s contribution to the maritime world as MARIN models many processes and systems. But why is this necessary? Because we need to:

- optimize performance
- design for safety
- design for operations
- train and educate

**Start design process**
It starts with an idea, or a concept of a ship, offshore structure, or an intended marine operation.

**Think tank with brain waves**
It is useful to share ideas with experienced experts and externally benefit from their independent feedback. MARIN offers multidisciplinary teams to challenge and improve your ideas. Right from the start, this provides an integrated approach, which is focusing on your future operations.

**Performance exploration**
The use of database tools allows you to concept with available statistics to identify the performance that can be achieved. Robust, test and sufficiently accurate methods provide a quick assessment of the various performance aspects of a given design.

**Full-scale verification**
Critical commissioning aspects, structures and operations often require full-scale verification within part of the contract or a Class (STM) requirement.

**Verification of training & operations**
The design and the operation is verified in a fully simulated environment, and further attention is given to human aspects. Simulator sessions of operations provide operational procedures and the limit communication protocols, the outline of necessary decision support tools and the required training programmes. "Training for operations" can be used for very complex and/or emergency response operations.

**Operational performance analysis**
Future designs require a multiple criteria optimization to account for the specific environment; they will be operating in and for their required mission capability. The analysis provides an assessment of the efficiency, safety and workability of a design. Real-time (quasi-real) simulation tools provide the answers on each aspect, and when needed, how they connect to one another.

**Simulation categories**

- Completeness of hydrodynamic models
- Completeness in dynamics
- Completeness of scope of the assessment

**Prediction and optimization of hydrodynamic characteristics**
As design constraints continue to tighten during this stage, the complexity design base continues. The identified optimal multi-disciplinary performance solutions provide data for further and ultimately final engineering. A set of flexible, accurate and coherent tools is needed in this phase.

**On-board monitoring & operational advice and training**
Throughout the design, data generated to improve the quality of operations and to generate feedback on in-service performance. Analysis of this data could lead to advice about how to improve operations (often higher efficiency or more effective) and training as a prerequisite for safe and efficient operations.

Various training tools, suitable for different levels are available, or specific tools can be developed.
SHIPS @ MARIN

Team Cruise & Ferry

Team Yacht

Team Navy
Team Specialised Vessels

Team Merchant Ships & Workboat

Team Inland Waterway Transport (IWT)
WHY CAN WIND PROPULSION REVIVE
WHY CAN WIND PROPULSION REVIVE?

• Ships hydrodynamic optimisation, propulsion systems and ESD

How far can we still go?

- Analyze original ship, locate problems and link to hull lines
- Define basic hull shapes
- Design knowledge
- Calculate flow for >100 hull shapes
- Analyze and determine optimal compromise between power and comfort
WHY CAN WIND PROPULSION REVIVE?

- Ships hydrodynamic optimization, propulsion systems and ESD

Pareto chart wave resistance

Wave resistance in kN @ 20kn

Wave resistance in kN @ 25.2kn

Pareto front from RAPIDExplorer at multiple draughts
WHY CAN WIND PROPULSION REVIVE?

- Ships hydrodynamic optimization, propulsion systems and ESD
WHY CAN WIND PROPULSION REVIVE?

• Ships hydrodynamic optimisation, propulsion systems and ESD

Expected long term future potential gain in power (for actual optimised designs) through:

• New type of hull form
• Designing for service conditions
• Reducing added resistance
• Propulsive / propeller efficiency
• Energy saving devices ESD
• Lowering resistance (air lubrication or paint/coating)

Within 2-8%
WHY CAN WIND PROPULSION REVIVE?

- Ships hydrodynamic optimisation, propulsion systems and ESD

When it becomes marginal to improve propulsive efficiency and reduce resistance, where can we find additional power and make the difference?

Something out of the box ...
WHY CAN WIND PROPULSION REVIVE?

- Ships hydrodynamic optimisation, propulsion systems and ESD

When it becomes marginal to improve propulsive efficiency and reduce resistance, where can we find additional power and make the difference?

IN THE AIR!
WHY CAN WIND PROPULSION REVIVE?
### WHY CAN WIND PROPULSION REVIVE?

#### Cumulative and annual offshore wind installation EU (MW)

<table>
<thead>
<tr>
<th>Year</th>
<th>Cumulative (MW)</th>
<th>Annual (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>0</td>
<td>2.00</td>
</tr>
<tr>
<td>1995</td>
<td>2.00</td>
<td>5.00</td>
</tr>
<tr>
<td>1996</td>
<td>7.00</td>
<td>10.8</td>
</tr>
<tr>
<td>1997</td>
<td>17.8</td>
<td>2.80</td>
</tr>
<tr>
<td>1998</td>
<td>20.6</td>
<td>4.00</td>
</tr>
<tr>
<td>1999</td>
<td>24.6</td>
<td>50.5</td>
</tr>
<tr>
<td>2000</td>
<td>75.1</td>
<td>170.0</td>
</tr>
<tr>
<td>2001</td>
<td>92.1</td>
<td>276.0</td>
</tr>
<tr>
<td>2002</td>
<td>119.1</td>
<td>85.7</td>
</tr>
<tr>
<td>2003</td>
<td>204.8</td>
<td>90.0</td>
</tr>
<tr>
<td>2004</td>
<td>314.8</td>
<td>92.5</td>
</tr>
<tr>
<td>2005</td>
<td>407.3</td>
<td>318.4</td>
</tr>
<tr>
<td>2006</td>
<td>725.7</td>
<td>373.5</td>
</tr>
<tr>
<td>2007</td>
<td>1,109.2</td>
<td>576.9</td>
</tr>
<tr>
<td>2008</td>
<td>1,686.1</td>
<td>882.7</td>
</tr>
<tr>
<td>2009</td>
<td>2,572.8</td>
<td>871.5</td>
</tr>
<tr>
<td>2010</td>
<td>3,454.4</td>
<td>1,163.5</td>
</tr>
<tr>
<td>2011</td>
<td>4,618.0</td>
<td>1,067.0</td>
</tr>
<tr>
<td>2012</td>
<td>6,035.6</td>
<td>1,446.0</td>
</tr>
<tr>
<td>2013</td>
<td>7,545.6</td>
<td>3,018.0</td>
</tr>
<tr>
<td>2014</td>
<td>11,027.7</td>
<td>4,984.4</td>
</tr>
<tr>
<td>2015</td>
<td>16,040.4</td>
<td>8,008.0</td>
</tr>
</tbody>
</table>

Note: The chart shows the cumulative and annual offshore wind installation in the EU from 1993 to 2015.
WHY CAN WIND PROPULSION REVIVE?

- IMO regulation, EEDI
- COP21
- Local CO2 and other reduction program

- Available and free energy that can be captured
- Always interesting to save fuel (whatever price level)

- Environmental concerns
- Clean tech trend and marketing

Tight regulation

Tight finance

Public awareness

Shipping Industry
OVERVIEW OF LATESTS TRENDS AND CONCEPTS
OVERVIEW OF LATESTS TRENDS AND CONCEPTS

- Wind propulsion devices (WPD) for shipping
- Markets (leisure, passengers, transport, support, ...)

Soft
Semi-rigid (Dynarig)
Rigid
Cylinder (Flettner or air suction)
OVERVIEW OF LATESTS TRENDS AND CONCEPTS

- Wind propulsion devices (WPD) for shipping
- Markets (leisure, passengers, transport, support, ...)

![Diagram showing various types of sails and their lift coefficients](image-url)
OVERVIEW OF LATESTS TRENDS AND CONCEPTS

- Wind propulsion devices (WPD) for shipping
- Markets (leisure, passengers, transport, support, ...)

![Wind propulsion devices](image1.jpg)  
![Wind propulsion devices](image2.jpg)  
![Wind propulsion devices](image3.jpg)
WIND AVAILABILITY AND VOYAGE SIMULATIONS
Driving factors for the availability are:

- Route, which determines the distribution of true wind speed and direction
- Vessel speed
Several tools are available to obtain the wind climate. Within Marin we use so-called voyage simulations.
WIND AVAILABILITY AND VOYAGE SIMULATION

Southampton to NY
- Vs = 20 kn
- Availability: 15%

NY to Southampton
- Vs = 20 kn
- Availability: 40%

Southampton to NY
- Vs = 10 kn
- Availability: 34%

NY to Southampton
- Vs = 10 kn
- Availability: 68%
Scatter diagram of apparent wind direction and speed for Southampton to New York sailing at 10 kn
RECENT STUDIES
RECENT STUDY: WIND HYBRID COASTER

- Sub project of MARITIM
- Main objective was to develop a Flettner rotor for coasters
- MARIN delivered design advice, model tests, performance predictions and voyage simulations
- Vessel not in build; scope for improvement
- Development continuing under the banner of “ECO FLETTNER”
RECENT STUDY: SAIL (ECOLINER)

- Broad scope; large group of participants
- In principle independent from any specific design
- Ecoliner, developed by Dykstra Naval Architects (DNA), used as main reference
- MARIN provided voyage simulations for the Ecoliner
- Design development ongoing at DNA
• Voyage simulations using GULLIVER (Scensim) are used at MARIN to evaluate the actual environment a ship is sailing in.

• Intended for the design phase.

• To study e.g.:
  • Complete operational profile
  • Involuntary speed loss due to wave and wind added resistance
  • Voluntary speed loss due to accelerations, slamming, green water (“Caption Decision Mimic” criteria)
  • Actual speed, power, emissions
  • The certainty of arrival time versus engine power (Sea Margin)
  • The fuel consumption of wind assisted ships!
RECENT STUDY: VOYAGE SIMULATIONS

- $U_{\text{wind}}$ [kts] vs. $t$ [w/k]
- $\min=0.27$, $\max=47.13$, $\text{mean}=12.36$, $\text{stdev}=6.75$
- $x_{10\%}=21.77$, $x_{1\%}=31.19$, $x_{0.1\%}=38.37$

Distribution of $U_{\text{wind}}$ [kts] and $P(U_{\text{wind}} > x)$ [%]
RECENT STUDY: VOYAGE SIMULATIONS

• Hydrodynamic forces (towing tank or CFD)
  • Parasitic resistance
  • Lift and lift induced resistance
• Aerodynamic forces (wind tunnel or CFD)
• Propulsion installation performance
  • Specific fuel consumption map
    (versus engine power and speed)
  • Losses along the propulsion line
• Seakeeping
  • Motions and accelerations, relative wave height
  • Added resistance
### Wind Hybrid Coaster
- Conventional hull, adjusted for speed range
- Partial load condition
- $L_{WL}, B_{WL}, T = 85.0, 14.0, 4.7$ m
- Displ. $= 4590$ t
- Speed $= 8$ kn
- GM $= 0.7$ m
- Single rudder

### SAIL - Ecoliner
- Dedicated hull shape for motor-sailing
- $L_{WL}, B_{WL}, T = 138.0, 18.0, 7.2$ m
- Displ. $= 11916$ t
- Speed $= 11$ kn
- GM $= 0.6$ m
- Single rudder
RECENT STUDY: SHIP CHARACTERISTICS (AERODYNAMIC)

Wind Hybrid Coaster
- Twin Flettner rotors side by side integrated with deck house
- L / D = 18 / 3 m
- Max. rot. rate = 280 RPM
- Max. $C_L$ = 10.1

SAIL - Ecoliner
- Three Dynarigs, spread along the length of the vessel
- 3 masts
- Mast height = 61 m
- Sail area = 3859 m$^2$
- Max. $C_L$ = 1.5

Additionally, each design is simulated without wind propulsor as “conventional”
RECENT STUDY: SHIP CHARACTERISTICS (PROPULSION)

Wind Hybrid Coaster
• Single diesel direct installation
• Installed power = 1520 kW
• Controllable pitch propeller

SAIL - Ecoliner
• Four generator sets (constant RPM) – an assumption
• Electric propulsion motor
• Installed power = 4x750 kW
• Controllable pitch propeller
## Recent Study: Gulliver Input Data

<table>
<thead>
<tr>
<th>Wind Hybrid Coaster</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Model tests at MARIN</td>
</tr>
<tr>
<td>- TUHH Flettner wind tunnel tests</td>
</tr>
<tr>
<td>- Wageningen CD propeller series</td>
</tr>
<tr>
<td>- SHIPMO seakeeping calculations</td>
</tr>
<tr>
<td>- D3TAW added resistance</td>
</tr>
<tr>
<td>- Simplified specific fuel consumption map based on engine catalogue</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SAIL - Ecoliner</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Input Dykstra for hydrodynamic performance (bare hull model tests at TU Delft), excl. yaw balance</td>
</tr>
<tr>
<td>- Wolfson Unit wind tunnel tests</td>
</tr>
<tr>
<td>- Wageningen CD propeller series</td>
</tr>
<tr>
<td>- SHIPMO seakeeping calculations</td>
</tr>
<tr>
<td>- D3TAW added resistance</td>
</tr>
<tr>
<td>- Simplified specific fuel consumption map based on engine catalogue</td>
</tr>
</tbody>
</table>
Wind Hybrid Coaster

- Model tests at MARIN
- TUHH Flettner wind tunnel tests
- Wageningen CD propeller series
- SHIPMO seakeeping calculations
- D3TAW added resistance
- Simplified specific fuel consumption map based on engine catalogue

RECENT STUDY: GULLIVER INPUT DATA

- Large matrix with variations:
  - Leeway
  - Speed
  - Rudder angle
  - Thrust
- A detailed description of forces was derived to use in the voyage simulations
• Hindcast data for 1999 for WHC and 1995-1999 for the Ecoliner
  • Waves
  • Wind
  • Tidal or ocean current as appropriate for the route

• A ship leaving every 3 days -> favorable statistical uncertainty

• Ships are required to arrive in time (or early) according to a fixed speed on the shortest possible distance:
  • Wind Hybrid Coaster: 8 kn
  • Ecoliner: 11 kn
Recent Study: Routes Wind Hybrid Coaster

Reverse routes also, but without voyage optimization.
RECENT STUDY: ROUTES ECOLINER

- Trinidad
- Gibraltar
- Skagen
- Aberdeen
- Oostende
A grid for each route optimization for each trip:

<table>
<thead>
<tr>
<th>Grid</th>
<th># Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gibraltar-Izmir</td>
<td>256</td>
</tr>
<tr>
<td>Gibraltar-Skagen</td>
<td>11,111</td>
</tr>
<tr>
<td>Gibraltar-Trinidad</td>
<td>88,368</td>
</tr>
<tr>
<td>Oostende-Aberdeen</td>
<td>7,037</td>
</tr>
</tbody>
</table>
RECENT STUDY: ROUTE AND SPEED OPTIMIZATION

- Option to increase or decrease speed on each individual leg of the grid
- Combined with route optimization, this delivers quite a lot of options per route.....

<table>
<thead>
<tr>
<th>Grid</th>
<th>#Combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gibraltar-Izmir</td>
<td>8.7M</td>
</tr>
<tr>
<td>Gibraltar-Skagen</td>
<td>3,362M</td>
</tr>
<tr>
<td>Gibraltar-Trinidad</td>
<td>26,741M</td>
</tr>
<tr>
<td>Oostende-Aberdeen</td>
<td>239M</td>
</tr>
</tbody>
</table>

- Finally, for each departure, the single most efficient route and speed profile is selected and used for final analysis
RECENT STUDY: AN ANIMATION...

voyNo-002
WHC - Gibraltar to Izmir - 04-Jan-99 00:00 UTC

Wind Force (Beaufort)

Conventional
Windassisted

Speed Over Ground
Maximum Continuous Rating
Wind Induced Longitudinal Force

© MARIN 2014
Animation made with Weather Route Ani 1.85 - Updated: 23 October
Overall average fuel savings

- 10% on routes Gibraltar-Skagen and –Trinidad
- Small savings towards Izmir (very little wind)

Note: Only the power required for propulsion
Overall average fuel savings

- 10% on routes Gibraltar-Skagen and –Trinidad
- Small savings towards Izmir (very little wind)
Energy from wind only 2% of engine (input) power!

Fuel Input Power 997.7 [kW] 98.3 [%]

Main Engine Loss 62.1 [%]

Required fuel reduced by 10%

Calm Water Resistance 206 [kW] 20.3 [%]
Main resistance components:
- Calm water (parasitic) resistance
- Added wave resistance
- Leeway induced resistance small (larger in more upwind conditions or when using more Flettner power)

Total thrust by rotors \(\sim 19\%\) of total
Loads tend to be very low, also for the conventional vessel.
But, go down even further for the wind assisted vessel, leading to a reduction of engine efficiency.
• Benefits are small on average on chosen routes
• Similar small benefits are achieved for the “conventional” vessel

Gibraltar-Trinidad

- Shortest
- Course Only
- Speed Only
- Course, then Speed
- Optimum

Fuel Consumption [t/d]
WIND HYBRID COASTER - MAIN OBSERVATIONS

- Conventional hull shape not a big problem for this magnitude of wind propulsion
  - Special appendages not required
  - Except at low ship speed and high wind speed
- Propeller efficiency stays constant or slightly improves
- Contribution in thrust about 20% (favorable routes)
- Small losses due to:
  - Interaction effects of Flettner rotors
  - Required power for Flettner rotation
  - Low engine loads (engine manufacturer data preferred!)
  - Lift induced resistance
- Resulting in an effective saving of about 10% (favorable routes)
RECENT STUDY: AN ANIMATION...
Overall average fuel savings:

- 10%: Trinidad-Gibraltar (unfavorable route)
- 25%: Most routes
- 40%: Oostende-Aberdeen and vice-versa

Note: Only the power required for propulsion
Overall average fuel savings:

- 10%: Trinidad-Gibraltar (unfavorable route)
- 25%: Most routes
- 40%: Oostende-Aberdeen and vice-versa

Note: Only the power required for propulsion
Energy from wind also only 12% of engine (input) power!

Required fuel reduced by 25%

Fuel Input Power
2491.3 [kW] 89.1 [%]

Main Engine Loss
51.0 [%]

Dynarig Wind Power
304.9 [kW] 10.9 [%]

Calm Water Resistance
855 [kW] 30.6 [%]
Main resistance component:
- Calm water (parasitic) resistance!

Total thrust by sails ~30% of total
Almost no benefit from speed and route optimization for “conventional” vessel as added resistance is proportionally low.

Benefit for wind assisted vessel very much dependent on route:
- Favorable routes with little variability benefit hardly
- Unfavorable routes benefit the most

Trinidad-Gibraltar
Gibraltar-Trinidad

<table>
<thead>
<tr>
<th>Route Combination</th>
<th>Trinidad-Gibraltar</th>
<th>Gibraltar-Trinidad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>7.5</td>
<td>7.0</td>
</tr>
<tr>
<td>Wind-Assisted</td>
<td>7.0</td>
<td>6.5</td>
</tr>
<tr>
<td>Shortest</td>
<td>6.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Course Only</td>
<td>6.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Speed Only</td>
<td>6.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Course, then Speed</td>
<td>5.5</td>
<td>5.0</td>
</tr>
<tr>
<td>Optimum</td>
<td>5.0</td>
<td>4.5</td>
</tr>
</tbody>
</table>
UPCOMING CHALLENGES AND PERSPECTIVES
- Operational profile and service conditions need to be put forward on specifications. Ship speed, routes and loading conditions combinations will provide information on:
  - Potential resources (wind availability)
  - Simulations of options with operational constraints included (type of system)
  - Expected return on investment (costs + CO2 & emission saving)

- Integration of the systems needs to be engineered at large scale
  - Fully integrated devices in the superstructure
  - Appendages similar to ESD (easy to refit or remove)

- Costs (investment and maintenance) will hopefully decrease with volume of solutions available on the market and produced

- The market needs several investors who will dare to invest a large scale and dare to take the risk
UPCOMING CHALLENGES AND PERSPECTIVES

- A new area is going to grow between hydrodynamics and aerodynamics: natural propulsion systems and their integration within the propulsion train (control, safety, ...).

- Making a smarter use of the available resources and environment is technically possible. Step towards a generalized use is in front of us for wind. Other energy recovery systems from ship motions (at anchor or transit) is still unexplored.

- Main players not yet known and all niche markets not yet explored. Who will take the lead and create new chances of business? Anybody in this room?
5th BLUE WEEK
MAKING SMART USE OF THE ENVIRONMENT AT SEA

NATURAL PROPULSION SEMINAR
Wind Propulsion Technology Presentations and Workshop
Organised by International Wind Ships Association

BlueWeek is an independent, dedicated and free event where the industry, academics and institutions come together to discuss the latest R&D initiatives, regulations and projects.

Location:
Hotel de Wageningsche Berg
http://hoteldewageningscheberg.nl/

Registration required:
http://www.blueforum.org

Naturally powered by  MARIN  Deltarces  IWSA