Deliverable D7.1

Proceedings of 1st Public Workshop:

“Introduction of the Project to Key Stakeholders”

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CA as CO plus Advisory Committee members
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Document History

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Title: Proceedings of 1st Public Workshop: “Introduction of the project to key stakeholders”

Abstract
The first public SHOPERA workshop “Introduction of the Project to Key Stakeholders” was organised by GL with the assistance of NTUA on October 30, 2014, in Hamburg, to communicate the objectives of the project to the wider scientific and technical community and to the various stakeholders. The workshop included presentations by external speakers, representing views of industry and research groups and by SHOPERA partners, describing problems addressed and proposed way ahead. Discussions were lively and most valuable in the substance. The workshop greatly contributed to the understanding of some controversial matters and clarified the view of how to proceed in the next years.

Summary Report:
Introduction. The first public SHOPERA Workshop “Introduction of the Project to Key Stakeholders” was organised by GL with the assistance of NTUA on October 30, 2014, in Hamburg, to communicate the objectives of the project to the wider scientific and technical community and to the various stakeholders. The workshop included presentations by external speakers, representing the majority of views of industry and industry research groups in the subject area and by SHOPERA partners described problems addressed along with the state of work and proposed way ahead. Discussions were very valuable in the substance.

State of the Art. SoA was presented by external speakers from industry research in the subject area, overseas research and background information on IACS work on the 2013 Guidelines.

Value added to SHOPERA. The main output from this workshop is the awareness of the key stakeholders of the project and facilitation of the acceptance of the expected results. The feedback gathered from the external participants will be used to refine the objectives of the project and shape the way ahead.

Achievements. The workshop greatly contributed to the understanding of some controversial matters and clarified the view of how to proceed in the next years.

Not achieved. Not relevant

Input from other Deliverables. D1.1, D1.3, D1.5, D3.1, D4.1

Exploitation of results. Proceedings of the Workshop will be publicly available and widely distributed through project web page. The wishes of the key stakeholders, as well as the feedback gathered will be used to refine the objectives, fine-tune criteria and standards and shape the way ahead to meet the very high expectations about the outcome of the project regarding the future regulatory work on EEDI at IMO.

This executive summary may be published outside the SHOPERA consortium. YES

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1 Introduction

1.1 Background
The introduction of the Energy Efficiency Design Index (EEDI) was a major step towards improving energy efficiency of shipping and reducing GHG emissions. At the same time, it has raised concerns that ship designers and ship builders might choose to lower the installed power and ship’s speed to achieve the EEDI requirements, instead of putting effort to optimize ship’s speed-powering performance. This can lead to insufficient propulsion power to maintain manoeuvrability of ships under adverse weather conditions. The above concerns refer especially to Phase 3 of the EEDI implementation, from 2025-01-01, when the required EEDI is to be reduced by up to 30% compared to the present level. Following a proposal from the International Association of Classification Societies (IACS), the following requirement was added to the Reg. 21, Ch. 4 of MARPOL Annex VI: “For each ship to which this regulation applies, the installed propulsion power shall not be less than the propulsion power needed to maintain the manoeuvrability of the ship under adverse conditions as defined in the guidelines to be developed by the Organization.” Work carried out by IACS to develop such guidelines, see MEPC 64/4/13 and MEPC 64/INF.7, served as basis for the Interim Guidelines for Determining Minimum Propulsion Power to Maintain the Manoeuvrability of Ship in Adverse Weather Conditions, MSC-MEPC.2/Circ.1 (2012) referring at first to bulk carriers, tankers and combination carriers. Discussions within the MEPC Correspondence Group and Working Group led to 2013 Interim Guidelines for Determining Minimum Propulsion Power to Maintain the Manoeuvrability of Ship in Adverse Weather Conditions, ref. MEPC 65/4/3, Annex 1 (2013), see IMO MEPC 232(65), valid for Phase 0 and Phase 1 of EEDI implementation (until 2020-01-01).

1.2 Project SHOPERA
To address the challenges of the problem of norming maneuvrability of ships in adverse conditions, an European research project called SHOPERA (Energy Efficient Safe SHip OPERAtion, see www.shopera.org), funded by the European Commission in the frame of FP7, was launched in October 2013, aiming at developing suitable methods and tools and systematic case studies which will enable the development of improved Guidelines and their submission for consideration to IMO-MEPC in 2016. A strong European RTD consortium was formed, representing the whole spectrum of the European maritime industry, including classification societies, universities, research organisations and model basins, ship designers, shipyards and ship operators. The project will:

- Validate the proposed adverse weather conditions using data from deep water and coastal areas as well as ship accident databases.

1 National Technical University of Athens (NTUA, coordinator), DNV-GL, Lloyds Register (LR), Marintek (MRTK), Instituto Superior Tecnico (IST), Univ. Duisburg-Essen (UDE), Registro Italiano (RINA), Flensburg Schiffbau Gesellschaft (FSG), Uljanik Shipyard (ULJ), VTT, Flanders Hydraulics Research (EVFH), CEHIPAR, Strathclyde University (SU), Denmark Technical University (DTU), Tech. Univ. Berlin (TUB), Delft University of Technology (DUT), Naval Architecture Progress (NAP), Danaos Shipping Company Ltd. (DANAOS), FOINIKAS Shipping Co., CALMAC Ferries Ltd.
• Develop and fine-tune existing high fidelity hydrodynamic simulation software tools for efficient analysis of the seakeeping and manoeuvring performance and safety of ships in complex environmental and adverse weather conditions (including the consideration of winds and waves).

• Perform seakeeping and manoeuvring model tests in seaway using a series of prototypes of different ship types to provide the required basis for the validation of employed software tools. Validated software tools for the manoeuvrability assessment of ships in adverse weather conditions will be integrated into a ship design software platform and combined with a multi-objective optimization procedure, looking for sufficient powering and steering requirements for safe ship operation in adverse weather conditions while keeping the right balance between ship economy, efficiency and safety of the ship and the environment.

• Put together design teams that comprise designers, shipyards, owners, classification societies and national administrations to conduct investigations on the impact of the proposed new Guidelines for minimum propulsion power and steering efficiency to maintain manoeuvrability in adverse conditions on the design and operational characteristics of various ship types. The impact of EEDI will be investigated in parallel by implementation of the developed holistic optimisation procedure in a series of case studies.

The work is organised into the following work packages:

• WP1 - Environmental Conditions and Requirements for Different Ships provides met-ocean data to validate the proposed adverse weather conditions, defines relevant ship types and sizes, conducts a risk analysis of marine accidents related to manoeuvring in adverse weather conditions and proposes safety criteria to be addressed by the project.

• WP2 - Development and Refinement of Numerical Hydrodynamic Tools performs development and refinement of numerical hydrodynamic tools. It is expected to significantly improve the current state-of-the art in the scientific field of manoeuvring in adverse weather conditions by improving the capabilities of a series of numerical methods.

• WP3 - Experimental Studies provides experimental data for validation of the tools by performing seakeeping and manoeuvring model tests for a series of prototypes of different ship types to provide the required basis for the validation of numerical methods.

• WP4 - Validation, Sensitivity Studies and Level 1 Methods validates numerical tools using model test data. Selected test cases will be used for an open international benchmark study to evaluate the present state-of-the-art of numerical methods. Simple models of propulsion and steering devices and engine will be developed for the implementation in the numerical simulation tools. Simplified assessment methods (referred to as Level 1 methods) will be developed to reveal the safety margins of ship designs. Intact stability problems will be addressed in a coupled way with manoeuvrability in adverse weather conditions.

• WP5 - Adaptation/Integration of Tools - Multi-objective Optimisation Platform integrates software tools for hydrodynamic assessment of ships in adverse weather conditions into a ship design software platform and sets up multi-objective optimisation procedures to assess ship’s performance holistically, looking for the manoeuvrability requirements in adverse weather conditions while keeping balance between economy, efficiency and safety.
• WP6 - Application – Case Studies conducts investigations on the impact of the proposed new guidelines on the design and operational characteristics of various ship types, by implementation of the developed integrated holistic optimisation procedure in a series of case studies. This will be achieved by putting together teams that comprise designers, classification societies, yards and universities, while operators and ports will provide expertise and data.

• WP7 - Dissemination, Exploitation, Submission to IMO disseminates the results of the project to the public, provides for exploitation of the results through submission to IMO of new guidelines for sufficient manoeuvrability in adverse weather conditions, including minimum power and steering performance requirements, and develops exploitation plan for resulting knowledge, numerical tools, software and design methods. Wide dissemination of the project results will be facilitated through technical publications in international scientific journals and conferences.

1.3 First Public SHOPERA Workshop
To exchange views with external experts in ship design, hydrodynamics, safety and operation, shipowners, regulators and other stakeholders on hydrodynamic, design and regulatory aspects of norming manoeuvrability in adverse conditions, fine-tune the objectives of the project and the way ahead and, at the same time, facilitate acceptance of the project outcomes by the key stakeholders, four public workshops are organised by the project.

The first workshop "Introduction of the Project to Key Stakeholders” was organised by GL with the assistance of NTUA on October 30, 2014, in Hamburg, to communicate the objectives of the project to the wider scientific and technical community and to the various stakeholders.

The first part of the workshop included presentations by external speakers, representing the majority of views of industry and experts at IMO (BIMCO, Greek and Danish Shipowners Associations, IACS, ITTC), industry research groups in the subject area (Common Research Ships), as well as overseas research views from Japan and India. Industry representatives underlined very high expectations about the outcome of the project regarding the future regulatory work on EEDI at IMO.

In the second part, SHOPERA partners presented problems addressed by SHOPERA along with the state of work and the proposed way ahead. Discussions were lively and most valuable in the substance. The common feeling was that the workshop greatly contributed to the understanding of some controversial matters and clarified the view of how to proceed in the next few years, even if the subject is politically very tricky and scientifically very demanding.

The main output from this workshop is the awareness of the key stakeholders of the project and facilitation of the acceptance of the expected results. The feedback from the external participants will be used to refine the objectives of the project and shape the way ahead.

1.4 Short Information about Future Public SHOPERA Workshops
The second Public SHOPERA Workshop, “Benchmarking of Numerical Tools for Manoeuvrability Simulations in Adverse Conditions”, is planned in October 2015 in Lisbon and will be organized by IST, UDE and NTUA. The objective of this workshop is to present the results of validation and benchmarking of the various numerical
tools for the analysis of the hydrodynamic performance of ships in comparison with the results from model tests. Along with the members of the Advisory Committee, experts in ship hydrodynamics will be specifically invited, as well as other experts in ship design, safety and operation, shipowners, regulators and other stakeholders. The output from this workshop will be evaluation of the world-wide state-of-the-art of numerical tools for maneouvrability assessment in adverse conditions, which will be taken into account in the developed updated Guidelines, and dissemination of the knowledge gained in the project to the wide scientific and technical community outside of the project.

The third Public SHOPERA Workshop “Criteria and Standards for Sufficient Maneouvrability under Adverse Conditions” is planned in March 2016 in London, and will be organized by LR, RINA and NTUA. During this workshop the developed criteria, standards and Guidelines for sufficient maneouvrability under adverse conditions will be presented and discussed, to ensure feedback from the experts in ship design and operation and regulators. The members of the Advisory Committee, external experts in ship design, ship hydrodynamics, safety and operations, ship owners, regulators and other stakeholders will be invited. The output from this workshop will be feedback from the experts in ship design and operation and regulators regarding the developed criteria, standards and guidelines, which will be used to fine-tune the results of the project in accordance with the expectation of the key stakeholders.

The fourth Public SHOPERA Workshop “Presentation of the Results to Key Stakeholders” is planned in October 2016 in Athens and will be organised by NTUA, GL, DNV, LR and RINA. This workshop will provide the overall presentation of the elaboration of the project, with emphasis on the set objectives, adopted procedures, major achievements, key results, conclusions and recommendations. In particular, the developed new Guidelines for the required minimum propulsion power and steering performance for various types of ships to maintain maneouvrability under adverse conditions will be presented and discussed with the scientific community and key stakeholders prior to their submission to IMO. The members of the Advisory Committee, external experts in ship design, ship hydrodynamics, safety and operations, ship owners, regulators and other stakeholders will be invited. The output from this workshop will be wide awareness of the key stakeholders, particularly IMO members, of the proposed updated Guidelines, and better acceptance of the project results, on the one hand, and the feedback received at the workshop on the other hand. The feedback will be used to refine the Guidelines and to develop strategy for the formal submission to IMO.

2 Workshop Participants

The list of workshop participants:

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DNVGL, SHOPERA consortium
3 List of Presentations

Jeppe Skovbakke Juhl (BIMCO) EEDI – Minimum power to ensure safe maneuvering in adverse conditions

George A. Gratsos (Hellenic Chamber of Shipping) Minimum power requirements for safe navigation

Hans Otto Kristensen (Danish Shipowners’ Association) Some thoughts about minimum power for safe maneuvering in adverse weather conditions

Torsten Mundt (IACS and DNVGL) IACS contribution on the minimum required power issue: A retrospection

Frans Quadvlieg (Cooperative Research Ships, Group on Maneuuvrability in Waves) Maneuuvrving in adverse weather

Reint Dallinga, Olav Rognebakke (Cooperative Research Ships, Added Resistance in Waves Group) Added resistance - physical insights. Cooperative Research Ships JIP results

Masaru Tsujimoto (National Maritime Research Institute) Japan’s research activities on minimum propulsion power requirement - Hydrodynamic approach
Apurba Ranjan Kar (Indian Register of Shipping) Ship Maneuverability: An overview of ongoing studies by Indian Register of Shipping

Anton Minchev (FORCE Technology) Maneuvering aspects at ultra-slow speeds

Apostolos Papanikolaou (SHOPERA, NTUA) Introduction: Overview SHOPERA

Elzbieta M. Bitner-Gregersen (SHOPERA, DNVGL) Met-ocean description

Koimtzoglou A., Louzis K., Eliopoulou E., Ventikos N.P. (SHOPERA, NTUA) Identification of ships and risk analysis of relevant marine accidents

Vladimir Shigunov (SHOPERA, DNVGL) Manoeuvrability criteria

Carlos Guedes Soares (SHOPERA, IST): Development and Refinement of Numerical Hydrodynamic Tools

Ould El Moctar (SHOPERA, UDE): Numerical Investigation of Added Resistance in Waves

Florian Sprenger (SHOPERA, MRTK) Experimental Studies
4 Workshop Presentations

4.1 Invited Lectures

4.1.1 Jeppe Skovbakke Juhl (BIMCO) EEDI – Minimum power to ensure safe maneuvering in adverse conditions
Background

MARPOL Annex VI, Chapter 4, Regulation 21, stating:

“For each ship to which this regulation applies, the installed propulsion power shall not be less than the propulsion power needed to maintain the maneuverability of the ship under adverse conditions as defined in the guidelines to be developed by the Organization”

Amendment to MARPOL, MEPC 61, 2011
Background

- IACS offered a draft first guideline for consideration in May 2011 (MEPC 62/5/19) as basis

- The verification should be carried out at three different levels:
  - Minimum Power Lines assessment
  - Simplified assessment
  - Comprehensive assessment

- The ship should have sufficient power to maintain the maneuverability in adverse conditions if it fulfilled any of these assessment levels.

IMO Guidelines

- MEPC implemented minimum power lines for tankers and bulk carriers for phase 0 of EEDI. Final “Interim Guidelines” were issued in Dec 2012 (MSC-MEPC.2/Circ.11).

- In May 2013 MEPC 65 adopted the "2013 interim guidelines for determining minimum propulsion power to maintain the maneuverability of ship in adverse conditions" for phase 0 - resolution MEPC.232(65).

- In Oct 2014, MEPC 67 decided that the 2013 Interim Guidelines should continue to the EEDI phase 1 period without modification for ships larger than 20,000 DWT.
What are the challenges?

• Today, no regulation exists on safe maneuvering in adverse conditions

• They may differ per ship type and ship size

• No definition of adverse weather conditions

• Are the “as built” power curves a proper measure for new ships?

• How to fulfil the EEDI regulation and the minimum power requirements at the same time?

Tank, World fleet

Source: IHS database
Tank, World fleet

Minimum power line
World fleet

Source: IHS database

Bulk, World fleet

Minimum power line
World fleet

Source: IHS database
Concern voiced

There seems to be two overarching obstacles related to the minimum power requirements:

• Mandatory requirements for EEDI has to be fulfilled for new ships

• Requirements for minimum power are mandatory

- And both requirements have to be fulfilled.

Bulk carrier, Handymax

Source: BIMCO EEDI calculator
EEDI or minimum power?

Three ways to fulfill:

• Develop a proper methodology for the “simplified assessment” which takes into account the hydrodynamic aspects (rudder, appendages, block coefficient,...)

• Make use of the option in the Annex Vi to allow for installation of excessive power without being punished by EEDI

• Enhance the general ship design!

Expectations - from a ship owner point of view

• Establish sound and reliable criteria for sufficient maneuverability in adverse conditions – for different ship types, ship sizes and weather conditions

• Perform necessary verification of the outcome from SHOPERA e.g. by use of model test or other simulation tools

• Develop robust and trustworthy input to the IMO Guidelines on minimum power – in due time
Conclusions
Please, keep in mind...

- Establish sound and robust scenarios e.g. related to ship speed and fuel prices
- Balancing safety with environmental protection is a key future challenge for regulators – and for owners
- Consistent regulation is necessary
- Level paly field – global regulation
- Collaborate with other R&D projects
- Disseminate the outcome among relevant stakeholders before submission to the IMO
- KISS approach!

THANK YOU FOR YOUR ATTENTION

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www.bimco.org
BIMCO briefly...

• 1905: The Baltic and White Sea Maritime Conference
• 1988: The Baltic and International Maritime Council
• Membership organization
  • 2500 members in 123 countries
  • Owners, brokers, port agents, insurers, clubs, lawyers, associations, universities, schools

Services
• Shipping contracts
• Front Office
• Technical knowledge
• Politics and Economics
• Maritime Security
• Shipping Education

About BIMCO

• BIMCO is the largest of the international shipping associations representing ship-owners controlling around 65 percent of the world’s tonnage and with members in more than 120 countries drawn from a broad range of stakeholders having a vested interest in the shipping industry, including managers, brokers and agents.

• The association’s main objective is to protect its global membership through the provision of quality information and advice, and while promoting fair business practices, facilitate harmonisation and standardization of commercial shipping practices and contracts.

• In support of its commitment to promote the development and application of global regulatory instruments, BIMCO is accredited as a Non-Governmental Organisation (NGO) with all relevant United Nations organs.

• In an effort to promote its agenda and objectives, the association maintains a close dialogue with Governments and diplomatic representations around the world including maritime administrations, regulatory institutions and other stakeholders within the areas of EU, the USA and Asia.
4.1.2 George A. Gratsos (Hellenic Chamber of Shipping) Minimum power requirements for safe navigation
"The Road to Hell is Paved with Good Intentions"
Saint Bernard of Clairvaux (c.1150)

The authors of the EEDI formula wanted to create the most efficient ships targeting a 75% MCR which coincides approximately with the best SFOC.

This is the root cause of the ship powering problem.

Efficiency of road transport is estimated on a driving cycle and has proved successful in increasing vehicle efficiency.

Why change the concept?
Legislating on flawed shipping assumptions

Second IMO GHG Study 2009, paragraph 5.25, page 47 says:

“…and it is particularly important that they do not have incentives to contribute to inefficient behavior. As an example of the latter, ship upgrades and major maintenance activities depend on the high-level strategies of the operating companies. In cases where ships are operated by a different company than the commercial operator, the technical operator may tend to minimize time in dry dock (to minimize off-hire cost) and other maintenance costs (e.g., painting costs) while at the same time handing the fuel bill to the commercial operator.”

This statement in the Study is incorrect and misleading.

Each ship is evaluated by the time charterer based on the speed and consumption warranties given by the shipowner and is offered a daily rate for a specific trip or period on this basis.

The higher the consumption the lower the T/C rate ceteris paribus.

No commercial operator will accept practices leading to inflated fuel bills above the ship’s speed/consumption warranties.

Charterers will successfully recoup ship overconsumption or under performance through legal means.

“An expert is a man who has made all the mistakes which can be made, in a narrow field”

(Niels Bohr (1885 - 1962), Danish Physicist)

A simple idea underpins science:

“Trust, but verify”

(The Economist Oct 19-25, 2013)

I hope by now we know better!!
Hull form is the most important
- A racing skiff does ~10 kn with 1 M-P
- A light rowboat does ~2.5 kn with 1 M-P

Slow speed engines and propellers
“Propeller efficiency usually increases with increasing diameter” … “A reduction of the RPM tends to be beneficial” “Muntjewerft in 1983 mentions a possible increase of propulsive efficiency of 10 to 15 pct” (PNA-1988)

In 1981 B&W produced their MKIII 65.000 tdw Panamax bulk carrier with a greatly improved hull, 12.600 BHP engine and a slow turning 6.9 m diameter propeller doing 82 RPM @75% MCR, thus creating a very energy efficient ship.

The ship at scantling draft traded at 13.5 kn consuming 26 t/day of H.F.O.

Its consumption was about 25% less than other ships built at the time.

The B&W MKIII eco Panamax was designed because of high fuel prices

No “EEDI” was necessary

Energy efficiency
“BACK TO THE FUTURE?”

The EEDI is the Energy Efficiency Design Index. Its purpose is to promote the design of energy efficient ships. That means improved Hulls (the platform) and of course Machinery and Propellers. The simplified formula is as follows:

\[ \frac{P \cdot SFC \cdot C_f}{d\dot{w} \cdot v} = EEDI \leq a \cdot d\dot{w}^{-C} \]

As formulated (at a V equivalent to P at 75% MCR) it has a bias to reduce power rather than improve the design.

In MEPC 62/5/6 of 11-15 July 2011, Greece proposed that the EEDI should instead of be linked to a specific speed for different types of vessels. This would directly link engine power to ship hull design and safe navigation.
The databases that produced the regressions which formulate the reference line are plagued with inconsistencies “GiGo”

Table from IMO MEPC 62/5/6 of May 5, 2011 submitted by Greece

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<tr>
<th>MO/YEAR</th>
<th>YARD</th>
<th>DWT (Ton)</th>
<th>Engine (HP)</th>
<th>Speed (kn)</th>
<th>EST EEDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb-95</td>
<td>YARD 1</td>
<td>68519</td>
<td>9799</td>
<td>15.00</td>
<td>3.386 (3.730)</td>
</tr>
<tr>
<td>Jun-94</td>
<td>YARD 1</td>
<td>68621</td>
<td>9800</td>
<td>13.90</td>
<td>3.652 (4.019)</td>
</tr>
<tr>
<td>Jul-81</td>
<td>YARD 2</td>
<td>65337</td>
<td>15200</td>
<td>15.50</td>
<td>5.334 (5.871)</td>
</tr>
<tr>
<td>Jul-81</td>
<td>YARD 2</td>
<td>65020</td>
<td>15202</td>
<td>16.80</td>
<td>4.946 (5.444)</td>
</tr>
<tr>
<td>Aug-99</td>
<td>YARD 3</td>
<td>73725</td>
<td>10281</td>
<td>14.00</td>
<td>3.533 (3.889)</td>
</tr>
<tr>
<td>Sep-99</td>
<td>YARD 3</td>
<td>73659</td>
<td>10281</td>
<td>15.50</td>
<td>3.194 (3.516)</td>
</tr>
</tbody>
</table>

The above 3 pairs of 2 sister ships built by the same yard within a few months of each other have 8%-10% differences in EEDI.

You also see power reduction over time. The first pair with inadequate power hardly made headway in heavy weather.

Underpowered ships will have to travel greater distances in order to avoid weather. They will also burn more because they will also operate their engines at a higher SFOC.

Distances as per OCEAN PASSAGES OF THE WORLD, Hydrographic Department, Admiralty, (London 1950)

<table>
<thead>
<tr>
<th>San Francisco to Yokohama</th>
<th>Rio De Janeiro to Cape Town</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODERATE POWERED STEAMERS</td>
<td>MODERATE POWERED STEAMERS</td>
</tr>
<tr>
<td>June to September</td>
<td>All seasons</td>
</tr>
<tr>
<td>October to May</td>
<td>4535 miles</td>
</tr>
<tr>
<td>All seasons</td>
<td>3310 miles</td>
</tr>
<tr>
<td>LOW POWERED STEAMERS</td>
<td>LOW POWERED STEAMERS</td>
</tr>
<tr>
<td>All seasons</td>
<td>4840 miles</td>
</tr>
<tr>
<td>Increase in voyage length</td>
<td>Increase in voyage length</td>
</tr>
<tr>
<td>6.70%</td>
<td>6.04%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sunda Strait to Aden</th>
<th>New York to Gibraltar</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODERATE POWERED STEAMERS</td>
<td>MODERATE POWERED STEAMERS</td>
</tr>
<tr>
<td>May to September</td>
<td>July 1st to April 10th</td>
</tr>
<tr>
<td>3820 miles</td>
<td>3.180 miles</td>
</tr>
<tr>
<td>LOW POWERED STEAMERS</td>
<td>April 11th to June 30th</td>
</tr>
<tr>
<td>April to June</td>
<td>3.185 miles</td>
</tr>
<tr>
<td>September to October</td>
<td>April to May</td>
</tr>
<tr>
<td>4145 miles</td>
<td>3.645 miles</td>
</tr>
<tr>
<td>July to August</td>
<td>May to September</td>
</tr>
<tr>
<td>4000 miles</td>
<td>3.360 miles</td>
</tr>
<tr>
<td>Increase in voyage length</td>
<td>Increase in voyage length</td>
</tr>
<tr>
<td>8.51%</td>
<td>14.60%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rio De La Plata to Cape Town</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODERATE POWERED STEAMERS</td>
</tr>
<tr>
<td>All season</td>
</tr>
<tr>
<td>3590 miles</td>
</tr>
<tr>
<td>Increase in voyage length</td>
</tr>
<tr>
<td>1.67%</td>
</tr>
</tbody>
</table>

LOW POWERED STEAMERS
All seasons
3650 miles
Increase in voyage length 1.67%

Over the last 60 years weather patterns have deteriorated. The necessary deviations for the Low Powered Steamers, in all probability, have increased causing higher CO₂ emissions.
Survivability and maneuvering requirements

With the EEDI as formulated, minimum powering requirements should be established for each ship.

Criteria:
The IMO minimum speed requirement for maneuvering in heavy weather, works out from about 7 kn for Handysize ships to about 10 knots for Capesize ships. From studies carried out at NTUA for 5 ships, present powering is marginal particularly so for the smaller ships. Any reduction will create underpowered ships which will need to follow longer, fair weather routes thus causing more emissions.

The IMO Stability Code Severe Wind criterion requires testing in winds of 26m/sec plus gusts (10+B and 8 m waves).

<table>
<thead>
<tr>
<th>Event</th>
<th>Speed</th>
<th>Waves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan typhoon Vongfong</td>
<td>71.4 m/sec</td>
<td>257 km/hr</td>
</tr>
<tr>
<td>October 2013 UK wind speeds</td>
<td>31.1 m/sec</td>
<td>70 mph</td>
</tr>
<tr>
<td>Denmark</td>
<td>52.8 m/sec</td>
<td>190 km/hr</td>
</tr>
<tr>
<td>October 1987 UK wind speeds</td>
<td>51.1 m/sec</td>
<td>115 mph</td>
</tr>
<tr>
<td>Top wind speeds Hurricanes</td>
<td>Katrina 2005</td>
<td>77.8 m/sec, gusts 95.6 m/sec</td>
</tr>
<tr>
<td>Sandy 2012</td>
<td>41.7 m/sec, gusts 62.1 m/sec</td>
<td></td>
</tr>
</tbody>
</table>

Ships often meet such weather conditions and must survive.

Any powering requirements to meet lesser weather conditions would result in the ship grounding in an upright position in bad weather!

MEPC 64 and MSF Dec 2012 decided on: 19m/sec (8 Beaufort and 6 m waves)
MEPC 65 May 2013 reduced the above to: 15.7 m/sec and 4 m waves for ships <200m and 19.0 m/sec and 5.5 waves for ships >250m!!

In view of the above does this represent safe thinking? No

Underpowered ships are dangerous

Greece has submitted to IMO MSC 93/inf.13 of 11th March 2014 the paper “Minimum Power Requirements for Ship’s Safe Operation in Adverse Weather Conditions”, a study prepared by the National Technical University of Athens (NTUA) suggesting that the proposed powering criteria were inappropriate for the weather likely to be encountered. The study proposes that the minimum power should be increased by 15%-20%.

Greece’s views at IMO were supported by:
1. The Royal Institution of Naval Architects (RINA)
2. The International Federation of Shipmasters’ Associations (IFSMA)

Press comments:
“…mariners and marine engineers alike ought to welcome the important intervention of Greece at this month’s International Maritime Organization’s maritime safety committee, raising the subject of the safety evaluation of the interim guidelines for determining minimum propulsion power to maintain the maneuverability of ships in bad weather.”

Michael Grey “The need for speed” – Lloyd’s List May 2nd, 2014:
Underpowered ships continued:

At the MEPC 67, Greece made an interim compromise proposal to ensure adequate power until the SHOPERA study was completed.

Whereas it was supported by about 15 Nations and Associations it was not passed.

More significantly, it was supported by:
• The Nautical Institute and
• The ITF

Both are Associations whose members sail ships, not desks.

Power is an Incorrect Metric for Operational Performance

The Correct one is Speed

Speed encapsulates safety and forces ship designers to compete on hull lines, displacement to consumption trade-offs, energy saving devices etc.

The EEDI Legislators did not Account for the Human Element.

The EEDI, as formulated, considers lower powered ships with the same hull as “eco”. Shipyards immediately complied, by installing smaller engines, as it was cheaper than redesigning a new hull.

Result: A Lost Generation of Underpowered Ships

To avoid more such ships being built, IMO should adopt an Interim Minimum Speed Requirement for ocean going ships of, say, 14-15 knots at full draft, irrespective of their installed power. Such ships would probably have sufficient power for “adverse weather” conditions. They would also generally operate at a lower SFOC.
M.R.V.-An exercise in futility

Trade expands in line with the world economy therefore ship emissions will always increase *ceteris paribus*.

Ships operate in an environment producing many variables most of which are not controlled by the shipowner. All affect speed, resistance and consumption. These are:

- **Condition of load**: full load, part load, light ballast, heavy ballast, trim etc., which create greater or lesser resistance and powering requirements.
- **Consumption and emissions vary with speed**: The speed at which profit is maximized varies with the ratio of freight rate to bunker price if there are no other constraints. It also varies with weather conditions.
- **Water surface currents**: Over the year they may vary from 1 kn to 3 kn on the prevalent axis.
- **Wind speed and direction**
- **Hull and propeller fouling**
- **Hull deformation/damages/groundings**

No amount of data analysis can be meaningful when trying to assess the recorded speed and consumption of about 50,000 ships, operating with the above variables, particularly if one tries to take averages over extended periods. Even identical sister ships in different trades and trading areas have recorded different consumptions.

Larger ships are more energy efficient. Over the last 31 years energy efficiency of the average ship in the dry bulk fleet improved 39% *ceteris paribus* or 1.26% PA from the increase in average ship size alone from 35,500 tdw to 70,600 tdw.

Technological improvements increase efficiency further.
A practical suggestion for rating ship efficiency
“Columbus’s egg”

All owners create warranted time charter speed and consumption descriptions for their ships at various speeds and conditions of load which they update from time to time based on the ship’s observed performance.

Charterers monitor a ship’s speed/consumption performance daily using routing companies. This way they calculate overconsumption or underperformance, if any.

Since these speed and consumption descriptions are legally binding there is no reason to ask for third party verifications. A ship’s recent speed and consumption warranties are known on the market and verified by the fact that both owners and charterers accept them.

This is (and has been) how ships are rated on a daily basis.

Shipping reacts to cost inputs and profitability criteria

To improve shipping’s already very good environmental performance we must think clearly, free of ideological constraints and avoid meaningless, unnecessary complications.

Ships trade at the speed at which they maximize earnings for any given freight rate and bunker price. Ship emissions vary with the cube (or more) of the speed. Ships operate in an environment producing many variables most of which are not controlled by the shipowner.

All affect speed, resistance and consumption.
Ships will proceed at the speed at which they maximize earnings. This speed is a function of the ratio of the freight market to the bunker price.

The above shows that increasing the bunker price will predictably reduce the fleet’s profitable operating speed, therefore its emissions.

The only practical solution for reducing emission is a fixed bunker levy

A bunker Levy alone could act as both:
- A ship design improvement mechanism, and
- An automatic speed regulating mechanism with a bias for slow steaming

It would do this while reducing emissions, increasing ship profitability, eliminating unnecessary complexities and uncertainty.

A bunker Levy will not create underpowered ships.

Because of its simplicity the Levy is also 2 to 5 times more cost efficient from ETS (USA CBO) thus increasing environmental benefits at a lower overall cost to society.
“Any intelligent fool can make things bigger, more complex and more violent. It takes a touch of genius - and a lot of courage – to move in the opposite direction.”

Albert Einstein

I hope SHOPERA shows “a touch of genius and a lot of courage” to simplify this unrealistically complicated exercise.

Life is not one dimensional. Try some lateral thinking.

Thank you

G.A.Gratsos
4.1.3  Hans Otto Kristensen (Danish Shipowners’ Association) Some thoughts about minimum power for safe manoeuvring in adverse weather conditions
HANS OTTO KRISTENSEN  
SENIOR ADVISER, DANISH SHIPOWNERS´ ASSOCIATION  
HOK@SHIPOWNERS.DK

SHOPERA PRESENTATION  
HAMBURG 30. OCTOBER 2014

SOME THOUGHTS ABOUT MINIMUM POWER FOR SAFE MANOEUVRING IN ADVERSE WEATHER CONDITIONS

Relevant questions

• What is safe manoeuvring?

  1. The ability to carry out some standard manoeuvres in bad weather?
  2. The ability to keep steering speed in an adverse head sea condition?

• What is adverse weather conditions?

  1. Is it a condition defined by a specific sea state and wind speed? And which sea state should it be?
  2. Is it a sailing condition in a critical area such as a near coastal area? or close to a harbor entrance?
Propulsion points of a 57,000 DWT bulk carrier in full load condition
Propulsion points of 79,000 DWT bulk carrier in ballast condition

Propulsion points of 306,000 DWT VLCC in full load condition
Conclusions based on MSC93/INF.13

• The IS Code weather criteria (Hs = 8 m and Vwind = 26 m/s) are very severe and nearly impossible to fulfill for ships with normal machinery power.

• If the IS Code criteria should be used all ships shall have 50 – 100 % more installed power than to days average power.

• It is unrealistic to install 50 – 100 % more power, i.e. the IS Code weather criterion is not the right criterion.

Wave height and wind statistics
Resistance for 57000 DWT bulk carrier

Design condition, calm water
Total resistance at \( V_w = 26 \, \text{m/s} \) and \( H_s = 8 \, \text{m} \)
Total resistance at \( V_w = 19 \, \text{m/s} \) and \( H_s = 6 \, \text{m} \)
EEDI condition, calm water

Engine power for 57000 DWT bulk carrier

Design condition, calm weather
\( V_w = 19 \, \text{m/s}, \ H_s = 6 \, \text{m} \)
\( V_w = 26 \, \text{m/s}, \ H_s = 8 \, \text{m} \)
EEDI condition, calm weather
Engine power for 57000 DWT bulk carrier

57000 DWT bulk carrier

- Design condition, calm weather
- $V_w = 19 \text{ m/s}, H_s = 6 \text{ m}$
- $V_w = 26 \text{ m/s}, H_s = 8 \text{ m}$
- EEDI condition, calm weather

Revolutions (RPM)

Engine power (kW)

Engine lay-out diagram and operation modes

- M Specified MCR point
- Line 1 Propeller curve through point M ($i = 3$) (engine layout curve)
- Line 2 Propeller curve, fouled hull and heavy weather
  - heavy running ($i = 3$)
- Line 3 Speed limit
- Line 4 Torque/speed limit ($i = 2$)
- Line 5 Mean effective pressure limit ($i = 1$)
- Line 6 Propeller curve, clean hull and calm weather
  - light running ($i = 3$), for propeller layout
- Line 7 Power limit for continuous running ($i = 0$)
- Line 8 Overload limit
- Line 9 Speed limit at sea trial
Engine power for 57000 DWT bulk carrier

57000 DWT bulk carrier - MCR = 7700 kW

- Design condition, calm weather
- Vw = 19 m/s, Hs = 6 m
- Vw = 26 m/s, Hs = 8 m
- EEDI condition, calm weather
- Engine lay-out diagram
- Power and speed limit
- Torque/speed limit
- MCR point
- EEDI power = 75 % MCR, Vref = 13.7 knots

57000 DWT bulk carrier - MCR = 8500 kW

- Design condition, calm weather
- Vw = 19 m/s, Hs = 6 m
- Vw = 26 m/s, Hs = 8 m
- EEDI condition, calm weather
- Engine lay-out diagram
- Power and speed limit
- Torque/speed limit
- MCR point
- EEDI power = 75 % MCR, Vref = 13.3 knots
Engine power for 57000 DWT bulk carrier

### EEDI calculations

<table>
<thead>
<tr>
<th>Deadweight (t)</th>
<th>57000</th>
<th>Main engine</th>
<th>Aux. engines</th>
<th>EEDI (g/t/nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCR (kW)</td>
<td>Vref (knots)</td>
<td>Aux. power (kW)</td>
<td>SFOC (g/kWh)</td>
<td>SFOC (g/kWh)</td>
</tr>
<tr>
<td>7700</td>
<td>13.3</td>
<td>385</td>
<td>165</td>
<td>190</td>
</tr>
<tr>
<td>8500</td>
<td>13.7</td>
<td>425</td>
<td>165</td>
<td>190</td>
</tr>
<tr>
<td>11000</td>
<td>14.5</td>
<td>525</td>
<td>165</td>
<td>190</td>
</tr>
</tbody>
</table>

Max allowable EEDI 2013 (g/t/nm) 5.18
Max allowable EEDI 2015 (g/t/nm) 4.66
Max allowable EEDI 2020 (g/t/nm) 4.15
Max allowable EEDI 2025 (g/t/nm) 3.63

Power requirement at calm sea at max. draught at 14.5 knots (kW) 6000

<table>
<thead>
<tr>
<th>MCR (kW)</th>
<th>Engine margin (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7700</td>
<td>28</td>
</tr>
<tr>
<td>8500</td>
<td>42</td>
</tr>
<tr>
<td>11000</td>
<td>83</td>
</tr>
</tbody>
</table>

Minimum power according to IMO guidelines level 1 (kW) 7649
Conclusions

- The IS Code weather criteria (Hs = 8 m and Vwind = 26 m/s) are very severe and cannot be fulfilled taking into account the EEDI demands (2013)

- The present IMO minimum power demands according to level 2 (Hs = 6 m and Vw = 19 m/s) can only be fulfilled marginally while fulfilling the EDDI demands in 2015

- The present IMO minimum power demands according to level 1 can be fulfilled while still fulfilling the EDDI requirement in 2015, but on the limit to fulfill the EEDI requirements in 2020

- Normally a light running margin of the propeller of 3 % are recommended, but in order to gain a higher adverse weather sea margin the propeller light running margin has to be increased to more than 10 %

Wave height and wind statistics

Thank you!

A total program package including documentation can be obtained at: https://www.shipowners.dk/en/services/beregningsvaerktoejer/
4.1.4 Torsten Mundt (IACS and DNVGL) IACS contribution on the minimum required power issue: A retrospection
IACS contribution on the “min. req. Power issue”, a retrospection

T. Mundt
30. October 2014

1. Background on EEDI

2. Review of IACS contribution on the “Guidelines for Determining Minimum Propulsion Power to Maintain the Manoeuvrability of Ships in Adverse Conditions”

3. Conclusions
There are conditions overwhelming any ship

The EEDI as mandatory instrument

How EEDI will be used as efficiency criteria for new build ships in the future:

- existing ship data (last 10 years*) will set a “reference line”
- the required EEDI-line will be reduced further step wise
- Attained EEDI ≤ Required EEDI = (1-X/100) × Reference line

* 1999-01-01 to 2009-01-01

but “where” is the “natural end”?
The development of the “...min. req. power...” issue

- In 2010, safety implications of EEDI emerged:
  - the simple way to achieve required EEDI level is to reduce installed power
  - this may have negative effects on safety, perhaps “under-powered ships”
  
  Question: how to define the level for “under-powering of ships”

- Following an IACS proposal, a provision was added to the EEDI regulations (Regulation 21, Chapter 4 of MARPOL Annex VI):
  "For each ship to which this regulation applies, the installed propulsion power shall not be less than the propulsion power needed to maintain the manoeuvrability of the ship under adverse conditions as defined in the guidelines to be developed by the Organization."

- However, no Guidelines were available at that time...
  
  and technically sound ones are not foreseeable within next 2 years!

The development of “...min. req. power...” issue

- During the discussions in the Working Group on Energy Efficiency Measures for Ships during MEPC 60, it was proposed by the Bahamas that "... in the drive to make ships as environmentally efficient as possible, there will be an incentive to build underpowered or reduced strength ships. To avoid this, a minimum safety level based upon engine power and speed should be developed" 1)

- IACS was tasked to develop “Guidelines for Determining Minimum Propulsion Power to Enable Safe Manoeuvring under Adverse Weather Conditions”

1) paragraph 6.3 of MEPC 60/WP.9
The IACS Work on “min. req. Power”

IACS organised the work on developing the “Guidelines for Determining Minimum Propulsion Power to Enable Safe Manoeuvring under Adverse Weather Conditions” as follows:

- Project Teams (PT) were established:
  - PT4, PT5, PT6 & PT7 (2010-2013)
  - Each PT included 4 members of different Class Societies to solve a task within ~0.5 years
  - The following Classes participated: ABS, BV, DNV, GL, and LR
    for PT 7, IRS was appointed as IACS co-ordinator for the participation in the Correspondence Group
- The outcome of each PT were discussed IACS-internally after reaching consensus, the work was then submitted to IMO

IACS submissions to IMO on “min. req. Power”

- EE-WG 1/4 (2010) Minimum required speed to ensure safe navigation in adverse conditions, submitted by IACS
- MEPC 62/5/19 (2011) and
- MEPC 62/INF.21 (2011) Minimum propulsion power to ensure safe manoeuvring in adverse conditions, submitted by BIMCO, CESA, IACS, INTERCARGO, INTERTANKO and WSC
- MEPC 64/4/13 (2012) Minimum propulsion power to maintain the manoeuvrability in adverse conditions, submitted by IACS, BIMCO, INTERCARGO, INTERTANKO and OCIMF and
- MEPC 64/INF.7 (2012) Background information to document MEPC 64/4/13, submitted by IACS
IACS submissions/contribution to IMO on “min. req. Power”

- during MEPC 64, a Correspondence Group (CG) under the coordination of Japan was established for the purpose of further development of the guidelines (note: the CG was not limited to the “min.req power” issue)
- EE-WG 2/2/8 (2012) “Further improvement of guidelines for determining minimum propulsion power and speed to enable safe manoeuvring in adverse weather conditions”, submitted by IACS
- at EE-WG 2 (2012) IACS provided a presentation on "Minimum required speed to ensure safe navigation in adverse conditions”
- in MEPC 65/WP.10, ANNEX 5 (2013) “Interim Guidelines for Determining Minimum Propulsion Power to Maintain the Manoeuvrability of Ships in Adverse Conditions”, valid for Phase 0 (2013-01-01 to 2014-12-31) of the EEDI-framework were proposed on basis of the outcome of the Correspondence Group.
- After MEPC 65, IACS did not established further project teams as the validation of fluid dynamic calculation models could not be tackled by IACS alone. The classification societies which have been active PT-participants are now committed within the SHOPERA–Project together with further classes and partners

Initial Criteria & Environmental Conditions

- Acceptance criteria:
  - The ability to turn, or turning ability, defined as
    - time to complete a 180° turn is less than [15][30] minutes
    - displacement in the wave direction less than f*5L, with f = [1.2][1.5]
  - The ability to maintain a desired course at defined speed, or "course keeping and advance ability", defined as
    - Keeping minimum advance speed of [2][4] knots through water
    - Average deviation from the course is less than ± [5][10]°
- Verification procedures: verification may be achieved by model tests and/or numerical simulations
- Environmental conditions:
  (taking into account return periods and probability criteria)
Rational Evolvement of Criteria

- Manoeuvrability in the open sea is not a deciding factor in survivability situations, because the ship may drift and still remain safe due to the fulfilment of Weather Criterion of the “intact stability code”
- Manoeuvrability in coastal waters is much more important because of difficult navigational situation
- In coastal waters, the ship master cannot always select favourable course and heading because of navigational restrictions => all wave & wind directions with respect to course have to be considered
- In coastal waters, a ship cannot simply keep position, because the storm may escalate and the ship will start drifting => minimum advance speed is required
- Anchors are not designed for keeping position in true heavy weather

Actual Criteria

- The ship should be able to
  - (1) Keep speed through water of at least 4.0 knots in waves and wind from any direction
    - Reason: ship must be able to leave coastal area in sufficiently short time, before the weather conditions become so severe that the ship will not be able to sail in the open sea
    - Speed of 4.0 knots includes a margin for current to avoid taking current into account in the assessment
  - (2) Keep course in waves and wind from any direction
    - Course-keeping is used as a conservative criterion to ensure manoeuvrability: if the ship able to keep any course with respect to wind and waves, it is also able to keep track and to perform turning
- Aim of these simplifications was to ensure that criteria can be evaluated in practice – in experiments and in computations
Conclusion

- Balancing safety with environmental protection is a key future challenge for regulators.
- The EEDI requirements may call for reducing engine power and, at the same time, for minimum power criteria to ensure safe manoeuvring in adverse conditions.
- A consistent approach is needed.
- Current knowledge to define adverse conditions and capabilities to check the vessel's performance are investigated.
- The outcome of SHOPERCA is desperately awaited at IMO.

IACS contribution on the “min. req. Power issue”, a retrospection

Thank you for your Kind attention

Contact: Torsten.Mundt@dnvgl.com

www.dnvgl.com

SAFER, SMARTER, GREENER
BACK - UP
4.1.5 Frans Quadvlieg (Cooperative Research Ships, Group on Manoeuvrability in Waves)
Manoeuvring in adverse weather
Shopera workshop – manoeuvring in adverse weather

Frans Quadvlieg

FRANS QUADVLIEG

- Graduated Delft University – Naval Architecture (‘92)
- Manager of Manoeuvring departement of MARIN
- Knowledge coordinator – Ships – Manoeuvring
- ITTC Manoeuvring committee member 2005-2014
- CRS (Cooperative Research Ships) – Manoeuvring committee secretary 1998-present. Presently: manoeuvring in waves working group
- SIMMAN 2008 & SIMMAN 2014 workshops
• CRS = Cooperative Research Ships
• 30 members:
  - Shipyards: Damen, DCNS / SIREHNA, Fincantieri / CETENA, Navantia, STX Europe
  - Suppliers: ABB, Berg Propulsion, Wärtsilä
  - Operators: AP Møller – Maersk CMN/CMF
  - Class. Soc.: ABS, BV, DNV/GL, LR / MARTEC
  - R&D Org.: BEC, CEHIPAR, DRS, MARIN, QinetiQ, TNO

• Jointly performing research on applied hydrodynamic and related domains
• Simultaneously: 12 working groups
• CRS-MANWAV is one of the 12 working groups

INTRODUCTION

• At a workshop in the Far East, early this year...

  Frans, we did manoeuvring tests in waves! What do we need to do now? How do we analyse them?

• If “manoeuvring tests in waves” were the answer, what was the problem again?
1. Objectives of manoeuvring in waves
2. Stochastics
3. Physics
4. Methodologies
5. Conclusions / Overview

1. POSSIBLE OBJECTIVES OF MANOEUVRING IN WAVES

- Heading keeping in moderate (oblique) waves
- Effect of waves on a turning circle or a zigzag (trial corrections)
- Steering in harsh weather
- Low speed control in waves (mine sweeping, dynamic tracking)
- Description of broaching (loss of directional stability in stern (quartering) waves, in combination with loss of transverse stability)
- Stability at anchor / on a turret mooring
EXAMPLE: STEERING TOWARDS HEAD WAVES

- Steering towards head waves

EXAMPLE: COURSE KEEPING IN WAVES

Combinations of
- ship speed,
- wave direction and
- wave period
may excite the ship
### NAVAL MANOEUVRING REQUIREMENTS IN WAVES

<table>
<thead>
<tr>
<th>Requirement in calm water</th>
<th>Requirement in waves</th>
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<tbody>
<tr>
<td>TaP HM ASuW AAW MIW Vehicle Int</td>
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<td>Turning</td>
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<td>Initial turning</td>
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<td>Requirement in calm water</td>
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<td>SDNE</td>
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<tr>
<td>Requirement in waves</td>
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</tbody>
</table>

### FOR EVERY MISSION: MANOEUVRING ABILITIES

<table>
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<tr>
<td>Requirement in waves</td>
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</tr>
</tbody>
</table>

*More information:*

CONCLUSIONS

- “Manoeuvrability in waves” covers many issues.
- It is important to realise that every issue has its own approach tackling the answer.

2. STOCHASTICS

2 examples
- Trajectories of ships in waves
- Heading in stern quartering seas of a frigate
2. CONCLUSION ON STOCHASTICS

Many realisations are needed to “say something”

For turning related phenomena
- Approximately 1000 realisations would be desired if a 99% exceedence is to be quantified

For course keeping related phenomena
- In head waves, half hour seems sufficient
- In stern (quartering) waves, 3 hours is insufficient

3. PHYSICAL PHENOMENA

- Viscous forces on the hull (low frequent damping / manoeuvring forces)
- Frequency dependent (Potential flow) added mass & damping + viscous effects
- Wave forces (1st order and 2nd order)
- Propeller thrust & torque
- Propeller ventilation
- Rudder forces (lift & drag)
- Rudder ventilation
- Autopilot motions and reactions
- Engine reaction
- WIND
Classification of methodologies strived at in ITTC

- Free Running Model Tests
- Simulations using math models (perhaps partly based on model tests)
  - CFD (time domain)
  - Low frequency models
  - Unified models
  - Two time scale models

4 A) FREE RUNNING MODEL TESTS

Advantage
- Give complete picture: all physics (incl. rudder, engine, ...)
- Controlled environment

Disadvantage
- LONG and WIDE basin needed
- Many runs for statistics
4 B) SIMULATION METHODS

- Time domain CFD
  - Advantage
    - Seems a complete picture (engine model & autopilot...)
  - Disadvantage
    - Not practical at all for statistics (many runs)
    - Not practical at all for irregular seastates
    - Most complicated CFD is needed (running propeller with moving grids, ...)

4 B) SIMULATION METHODS; LOW FREQUENT MODELS

- Al models: time domain simulations
  \[ M \cdot \ddot{x} = F(t) \]

- 4dof State vector:
  \[ \ddot{x}^{-1} = [x \ y \ \phi \ \psi \ u \ v \ p \ r \ \delta] \]

- Low frequent force model:
  \[ X_T = X_H + X_{PR} + X_{RUD} + X_{WV}(\mu, H_S, T_P) + X_{wind} \]
  \[ Y_T = Y_H(u, v, r) + Y_{PR} + Y_{RUD} + Y_{WV}(\mu, H_S, T_P) + Y_{wind} \]
  \[ N_T = N_H(u, v, r, \phi) + N_{PR} + N_{RUD} + N_{WV}(\mu, H_S, T_P) + N_{wind} \]

2nd order wave drift forces,
Usually: based on diffraction(?) theory
4 B) SIMULATION METHODS; UNIFIED MODELS

- Use 6dof state vector: 
  \[ \ddot{x}^{-1} = [x \ y \ z \ \phi \ \theta \ \psi] \]

- Excitation force uses convolution integral:
  \[ \begin{align*}
  X_T &= \ldots \\
  Y_T &= Y_{PR} + Y_{RUD} + \int_{0}^{1} Y_v(\tau) \cdot v(t-\tau) \cdot d\tau \\
  Z_T &= \ldots \\
  K_T &= \ldots \\
  M_T &= \ldots \\
  N_T &= \ldots 
  \end{align*} \]

  Combination of encounter frequency dependent added mass & damping

- Challenge:
  - How to merge viscous forces in the convolution integral;
  - Non-linear manoeuvring forces. (may work for linear ships, but for tankers: to be investigated)

- Hooft&Pieffers [1994], Bailey [1998]

4 B) SIMULATION METHODS; EXAMPLE OF UNIFIED MODEL

Turning towards head waves using a unified model (Fredyn)


Bailey, P.A.; W.G. Price and P. Temarel; A unified mathematical model describing the manoeuvring of a ship travelling in a seaway. RINA 1997
4 B) SIMULATION METHODS; TWO-TIME-SCALE MODELS

- Separates high frequent & low frequent motions. The sum of motions is the total.
- Uses 12 dof state vector: \( \ddot{\mathbf{x}} = \begin{bmatrix} \ddot{x}_{\text{MAN}} & \ddot{x}_{\text{WF}} \end{bmatrix} \)

\[ M \cdot (\dddot{x}_{\text{MAN}} + \dddot{x}_{\text{WF}}) = F_{\text{MAN}}(\ldots) + F_{\text{WF}}(\ldots) \]

- Challenges:
  - stern quartering seas: low frequent and wave frequent are not separable.

CONCLUSIONS ON METHODOLOGIES

- There are numerous methodologies (any many more dialects)
- Choice of methodology should depend on the objective of the study
5. SUMMARY

- We gave an umbrella to classify methodologies
- Pros and cons of methods are given
- Every “issue” has a different preferred “methodology” (incl. hybrid methods)
- Free running model tests will be a good source for many more years.

- *One set* of benchmark model tests is available (ITTC) on manoeuvring in waves (Prof. Yasukawa, Hiroshima University)
4.1.6 Reint Dallinga, Olav Rognebakke (Cooperative Research Ships, Added Resistance in Waves Group) Added resistance - physical insights. Cooperative Research Ships JIP results
MARITIME

Added resistance - physical insights
Cooperative Research Ships JIP results
SHOPERA 1st public workshop Hamburg

Reint Dallinga and Olav Rognebakke
30th October 2014

Overview

- Cooperative Research Ships
- Objective of RAW+
- Scope of work
- Model tests
- Fatima
- CFD case studies

Maersk J-Class tests at MARIN
Cooperative Research Ships

- all members pay a fee → research fund
- all members decide → research projects
- not about joint finance, but about joint research: members ...
  - perform tasks in research projects
  - participate actively in working group meetings
  - combine knowledge and experience
  - form a network of specialists

Cooperative Research Ships

- applied hydrodynamic research
  - desk studies
  - model tests and full scale tests
  - software development
- provide hydrodynamic knowledge base for members
- focus on hydrodynamics and related domains:
  - structure, economy, design, operations ...
- about 12 Working Groups
CRS Objectives

Cooperative Research Ships
- ships with a navy & European shipyard focus
- provide knowledge base, improve design technology and operational performance
- practical tools and guidance
- balance of sea-keeping, manoeuvring, resistance, propulsion, structure and loads

CRS Members
- 7 shipyards: BAE Systems Surface Ships, Damen Shipyards, DCNS, Fincantieri, Navantia, STX France, Meyer Turku
- 3 suppliers: ABB, Caterpillar Propulsion, Wärtsilä Netherlands
- 2 operators: AP Møller-Maersk, CMA CGM
- 5 navies: Royal Netherlands Navy, Bundeswehr, Defence R&D Canada, US Coast Guard, US Navy
- 4 class. soc.: ABS, Bureau Veritas, DNV GL, Lloyd’s Register
- 6 R&D org.: CEHIPAR, DGA Hydrodynamics, DRS, MARIN, QinetiQ, TNO
CRS MEMBERS – geographical distribution

- Europe (22)
- North America (5)
- France (5)
- The Netherlands (5)
- United Kingdom (3)
- Finland (2)
- Spain (2)
- Denmark (1)
- Germany (1)
- Italy (1)
- Norway (1)
- Sweden (1)
- United States (4)
- Canada (1)

CRS Organization – general principles

- organization steered by Members
- small overhead and administration
- results exclusive property of Members
- all results available for all Members
  - reports (1600+)
  - data
  - software
**Objective of RAW+**

There are two main objectives

1. Explore the characteristics of added resistance for different ship types by use of Fatima
   - Other tools are also investigated

2. Investigate validity and specific aspects of the physics of added resistance which are not accounted for in Fatima
   - Breaking bow wave causing spray
   - Water line contribution
   - Suction below surface

**Means:** Experiments and CFD
Scope of work

Total budget EUR 600,000
The project runs until December 2015

Five main tasks
1. Fatima case studies
2. Fatima and related tools and methods
3. CFD case studies
4. Experiments
5. Validation

- Model test scope includes container vessel, fast patrol boat and tanker

Model test program
Experiments

- Phase I – Maersk J-Class
- Phase II – Fast patrol boat
- Phase III – 115k DWT tanker – blunt bow ship

Task 4.1 - Phase I model test J-Class container vessel

Note: No bilge keels and no bow thruster openings
**Test set-up**

- Partly self-propelled
  - Avoid stern-flow separation
  - Obtain info on effect of ship motions on hull efficiency
- Towed to enforce a constant (carriage) speed
  - Enables a direct comparison of a run in calm water and a run in waves

![Test set-up diagram](image)

**Test program and measurements**

**Test program**

- Calm water
  - 2 speeds
  - 2 speeds x 3 drift/helm angles (pulling the bow transversely)
  - 2 speeds x 5 helm angles (no drift angle)
  - 4 pulling (propeller over-load) tests
- Regular waves
  - 2 speeds x 3 headings x 12 combinations of wave frequency & amplitude
- Irregular waves
  - 2 speeds x 3 headings x 3 irregular waves (4 runs each)

**Measurements**

- Resistance and propeller thrust
- Motions and accelerations
- Detailed pressure measurements
- Local load contributions
Results – Added resistance in regular head waves

- Results with correction for drift in tow-force transducer sensitivity
- Results with a single reference for all tests

Video from J-Class tests, 1.5m bow quartering wave, 21knot
Results – Added resistance in regular beam waves

- Substantial contribution of mean helm and drift angle
- Estimated helm & drift contribution exceeds the total in some cases

Added resistance in irregular waves

Observations
- Correlation is best in head waves
- Less good in bow quartering
- Poor in beam seas

Explanations
- Statistics of mean RAW from short sample in irregular waves
- Varying part of helm and drift angle
- The ship-bound longitudinal component of the centrifugal force \( m \cdot v^2/R \cdot \sin(\text{drift angle}) \)
- Wave breaking?
Validation at component level

Water-line contribution

Pressure measurements yield
- Mean value in calm water
- Mean value in waves

Difference reflects
- Waterline contribution
- Mean pressure drop over the submerged part of the hull

Problems: Resolution of pressure gauges
- Values in calm water obtained by averaging over several runs
- All results were corrected for the reference values at the start of each run
- After these measures the results look qualitatively ok but “erratic” in some places

Conclusions

- The tests yield quantitative information on the added resistance with a fair idea of the accuracy
- Waves from forward direction: Radiated and reflected waves dominate the added resistance
- The contribution of a helm and drift angle become important in the lower added resistance in waves from abeam and from the stern-quarter
Task 4.2 - Phase II model test
Fast patrol boat

- Maersk J-Class
  - 100m Lpp
  - 13.36m B
  - 3.125m T
  - High speed capability
- Nice “straight” flare
- 6.6m 1:15 model was shared with FAST JIP
  - Bilge keels

Objectives

- Accurate validation data with a known accuracy
- Insight at component level
  - Effects of wave breaking
- Check superposition with runs in irregular waves

Model
Test Set-Up

- Partly self-propelled
- Obtain info on effect of ship motions on hull efficiency
- Towed to enforce a constant (carriage) speed
- Enables a direct comparison of a run in calm water and a run in waves (also at pressure level)

Instrumentation – General

- Incident wave (2)
- Model position & speed
- Motions and accelerations (6)
- Propeller thrust & torque
- Rudder angle, lift & drag
- Towing force
- Relative wave elevation (6)
Instrumentation
76 Pressures sensors and 1 local force

- Waterline contribution
  - 76 in total, mostly WW
  - St 16, 17, 18, 18¾, 19½
- Heave excit. x pitch contribution
  - 5 below the keel
  - 1 fwd, 1 aft, 3 (PS, CL, SB) St 10
- Force acting on the stem
- Propeller thrust & torque
- Rudder lift & drag

Visualization
- 1 camera from the bow quarter (ww)
- 1 camera from the stern quarter (ww)
- 1 high-speed camera with a zoom on the relative wave elevation in the bow area

Test program

- Tests in calm water to quantify:
  - the reference resistance
  - the propulsive characteristics
- Tests in regular waves for 3 speeds for:
  - a range of frequencies to obtain the quadratic transfer function
  - a range of wave heights at 2 frequencies
  - waves from ahead and from the bow quarter
- Tests in irregular waves for 3 speeds for:
  - 2 irregular waves
  - the above 2 headings
Added Resistance

- Results follow 1980’s (towed) results very well

- Considerable reduction in added resistance at high speeds (presumably due to wave breaking, to be analyzed)
Task 4.3 - Phase III model test blunt bow vessel 115k DWT tanker

- Experiments with a large (1:27, 8.85m, 6tons model of a 115kDWT single screw tanker)
- Model is made available to CRS
  - Lines not free to wider public
  - In exchange for measured data

Model and test set-up

- Partly self propelled to obtain an unambiguous stern flow
- High damping in the position (speed) feedback towing arrangement
- Low tow-point inside the model
- Model was self-steering to represent the natural drift angle
- Relatively high yaw-rate gain was required to obtain a course-stable ship

Objectives

- Accurate measurement of added resistance in waves for a blunt bow vessel
- Obtain information at component level
Instrumentation and visualization

- Measurements
  - The tow force
  - Propeller thrust and torque
  - Rudder lift and drag
  - The ship motions
  - The pressures at 70 locations in the bow area
  - The relative wave elevation at 6 locations by means of “silver strips” and conventional probes at the locations where the straight wires follow the hull sufficiently close

- Video
  - Standard dual video camera
  - High speed shots

Test program

- Head seas
  - Regular waves at 2 speeds
    - 8 wave frequencies x 1 height
    - 2 wave frequencies x 3 additional heights
  - Irregular waves
    - 4 combinations of speed and irregular waves

- Beam seas
  - Regular waves at 2 speeds
    - 8 wave frequencies x 1 height
    - 2 wave frequencies x 3 additional heights
  - Irregular waves
    - 4 combinations of speed and irregular waves

- Waves from the bow quarter
  - Regular waves at 2 speeds
    - 8 wave frequencies x 1 height
    - 2 wave frequencies x 3 additional heights
  - Irregular waves
    - 4 combinations of speed and irregular waves

- Waves from the stern quarter
  - Regular waves at 2 speeds
    - 8 wave frequencies x 1 height
    - 2 wave frequencies x 3 additional heights
  - Irregular waves
    - 4 combinations of speed and irregular waves
Calm water references

- 9 drift angles x 2 speeds (rudder amidships)
- 5 helm angles x 2 speeds x 3 drift angles (among which sailing straight)
- Propeller over-load tests and speed variations to derive the propulsion characteristics
- 20 repeat runs in calm water

- The rms of all calm water reference values is:
  - 2.3% at 15knots and
  - 6.3% at 10knots
- Removing clear trend:
  - 1% at 15knots (similar to the J-Class)
  - 2% at 10knots

Conclusions

- Full block ships are indeed more difficult to run in a towing tank
- Issue with reflected wave in measured incident wave
- Using local reference for the calm water resistance a “fair” accuracy is achieved
- The motions and added resistance look good
FATIMA program developed by MARIN

The Fatima code

- Rankine source based potential flow solver
- Nonlinear calculation of the steady flow
  - Accounts for sinkage and trim
  - Changes restoring terms
  - Important for predicted relative motion
- Oscillatory flow solved in frequency domain
- Linearization around steady flow
- Calculation of linear and quadratic transfer functions
Extensive testing and validation done by MARIN for various ship types and sizes

- Fair over-all agreement
- Substantial scatter
  - Possible reasons are test procedures and related accuracy, numerical details and physical issues not covered by the theory like breaking waves

Fatima and model tests

- Overall good predictions in head waves for expected Froude number range
- Container vessel
  - Good agreement in bow quartering waves
  - Despite substantial flare and spray
- Tanker
  - Less good predictions at lower speeds for waves from bow quarter
  - Not so good in beam seas
  - Poor predictions for stern quartering waves
- FDS results (fast patrol boat)
  - Good agreement up to Fn 0.285
  - Increasing discrepancy beyond that speed
- Helm and drift angle effects affect stern and beam wave results
Various case studies with Fatima and other tools have been carried out.

Detailed results FDS and Navantia patrol boat variations.
Term-by-term comparison of added resistance contributions

- Task undertaken by Bureau Veritas
- Objectives:
  - Identification of the most dominant terms contributing to the added resistance through a numerical study
  - Testing of FATIMA and Precal_R

![Graph showing total drift force in the x-direction for different models](image)

### Theory

- Drift force composed of:

  - Squared velocity component
  - First order motion times gradient of pressure
  - Relative wave height contribution
  - Rotation of first-order forces and moments
  - Rotation of steady pressure gradient

\[
\left\langle \vec{F}^{(2)} \right\rangle = \frac{-2}{2} \rho \int_{H_0} \nabla \phi^{(1)} \cdot \nabla \phi^{(1)} \nabla \phi^{(0)} \cdot \nabla \phi^{(0)} \, dS
\]
**Comparison of Numerical Results with experimental data**

**KVLCC2: 0 knots, Fn 0, 180 degrees heading**

<table>
<thead>
<tr>
<th>Wave Frequency [rad/s]</th>
<th>Added Resistance in Waves [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>0</td>
</tr>
<tr>
<td>0.200</td>
<td>50000</td>
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<tr>
<td>0.400</td>
<td>100000</td>
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<td>150000</td>
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</tr>
<tr>
<td>1.600</td>
<td>400000</td>
</tr>
<tr>
<td>1.800</td>
<td>450000</td>
</tr>
<tr>
<td>2.000</td>
<td>500000</td>
</tr>
</tbody>
</table>

**Experimental**

**PRECAL_R**

**ABS_WAMIT**

**BV_HydroStar**

**DNV_WASIM**

**LR_WaveLoad**

**Empirical Formulations**

---

**Fn = 0.0: Comparisons with the Experimental data**

- **Peak magnitude & its location**:
  - Good, Good
  - Higher, Upward
- **Magnitude and trend at Higher freq. (upward similar to the exp. data or downward)**:
  - PRECAL, R: Higher, Upward
  - FATIMA: Higher, left
  - WAMIT: Lower, Flat
  - HydroStar: Higher, flat

**Fn = 0.142: Comparisons with the Experimental data**

- **Peak magnitude & its location**:
  - Slightly lower, Right
  - Higher, Right
  - Very High, Right
- **Magnitude and trend at Higher freq. (upward similar to the exp. data or downward)**:
  - PRECAL, R: Higher, left
  - FATIMA: Lower, Flat
  - WAMIT: Very High, left
  - HydroStar: Very Low, Downward
  - WaveLoad: Lower, Right

**Empirical Formulations**

- **Fatima**: Slightly lower, Right
- **WAMIT**: Higher, Right
- **PRECAL and PRECAL_R**: Very High, Right
- **Fatima**: Varying, Downward
- **Empirical Formulations**: Varying, Nearly flat

---

**Damen Naval buoy laying vessel**

- Calculation of heave, pitch and added resistance in waves using different methods
  - Strip theory (Shipmo) with three methods
    - Boese
    - Gerritsma Beukelman
    - Havelock
  - PRECAL and PRECAL_R
  - Fatima
  - Use of ships own wave system from RAPID calculations in Shipmo and PRECAL

---
Evaluation of ship speed loss and RPM in waves

- Reversed process of state-of-the-art speed trial analysis
- ISO 15016:2002
- Thorough walk-through of proposed methodology

Method used for L160 containership

<table>
<thead>
<tr>
<th>Table 4.1 Main data of the subject containership L160</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship ID</td>
</tr>
<tr>
<td>Length between perpendiculars [m]</td>
</tr>
<tr>
<td>Breadth [m]</td>
</tr>
<tr>
<td>Draft [m]</td>
</tr>
<tr>
<td>Displacement volume [m$^3$]</td>
</tr>
<tr>
<td>Wetted surface area bare hull [m$^2$]</td>
</tr>
<tr>
<td>Wetted surface area with appendages [m$^2$]</td>
</tr>
<tr>
<td>Block coefficient [-]</td>
</tr>
<tr>
<td>Propeller Diameter [m]</td>
</tr>
<tr>
<td>Wind load coefficient [-]</td>
</tr>
</tbody>
</table>

Fatima analysis tool

- Scripting in Python
- Process the input and output data from a Rapid / Fatima run
- Provides layered HTML report
- Includes warnings if pre-defined criteria are not met
- Finished initial scripts
- Preliminary testing carried out by MARIN
- Now rolled out for testing
- Some budget left to accommodate future needs of members
CFD case studies

CFD case study – DNV GL Maersk J-Class

- Regular wave cases in head- and oblique waves
- Result analysis on component level
- Challenges
  - Processing of model test results
  - Filtering of signals to get smooth input to CFD
  - Understanding conventions of sign and rotations
  - Inconsistency of zero levels or reference levels
  - Implementing motions to Star-CCM+
    - Information about definition of rotations was wrong
    - Synchronisation of motions and incident wave
    - Fairly long simulation time
- Original plan to use prescribed motions based on measurements
- Changed to free model
- Simulations proceeding well
Two more CFD studies awarded

- Tanker
- Study identical cases as tested in the laboratory
- Focus on physical insights
- Regular and irregular waves
- Solve for vessel motions
- Similar measurements as in tests
- Results by March 2015

Validation studies
Deterministic reproduction of irregular raw time traces - background

- CRS RAW+ container ship added resistance tests finished successfully
- High quality dataset is obtained
- Tests in regular head waves show good agreement with FATIMA calculations
- Results in irregular waves differ from what might be expected from regular wave results.

![RAW Irregular Waves - 180deg - 15knots](image)

Background cont’ed

- Possible reasons for differences:
  - The statistical variation related to the limited run duration in irregular seas.
  - The, occasionally, higher temporal steepness of the individual waves in an irregular wave train the resulting reduction in added resistance.
  - The resistance associated with the dynamic components in the low-frequency course-keeping and steering (not accounted for in FATIMA results)

- Objective of the present project:
  - To deterministically determine RAW in irregular waves and reduce differences between measurements and predictions.
RESULTS

Some good cases

- Test 211001: $U=21$ kn, $\mu=180$ deg, $T_p=12$ s, $H_s=4$ m
- Test 208006: $U=21$ kn, $\mu=180$ deg, $T_p=12$ s, $H_s=2$ m

Some bad cases

- Test 218003: $U=21$ kn, $\mu=135$ deg, $T_p=12$ s, $H_s=2$ m
- Test 221002: $U=15$ kn, $\mu=135$ deg, $T_p=7.5$ s, $H_s=3$ m
CONCLUSIONS

Deterministic reproduction of RAW in irregular waves successfully implemented. The differences with the measurements are sometimes quite large. Explanations:

- Inaccuracies in the FATIMA QTF (main diagonal) due to the linearization principle (i.e. no breaking waves).
- The use of Newman’s approximation for the side diagonals.
- Inaccuracies in the inertia and damping correction.
- The resistance associated with the dynamic components in the low-frequency course-keeping and steering.

The effect of statistical uncertainty on the mean value seems small.
Pitch and heave motions reproduce well.

Maersk proposal for RAW+ validation study

Background:
- APMM uses an empirical formula to correct various performance calculations for added resistance in waves. The current model is linked to the available information that are reported during daily operations.

Expected outcome and corresponding tasks:
- The overall goal is to evaluate the newly derived RAW transfer functions for the j-class vessels using operational data.
- The evaluation will be done by comparing a calculated hull and propeller fouling (given through a SP%) using the newly obtained RAW transfer functions and the existing APMM method. Which of the methods will give the least amount of scatter?
- The evaluation will be done on basis of reported sea and weather data by the crew and if possible through hindcast data provided by METROGROUP.
Maersk proposal for RAW+ validation study

- Can we make more accurate performance evaluations by replacing existing correction method for added resistance in waves?
- Will we reduce scatter in our predictions of hull and propeller fouling?

Plot illustrates the development of hull and propeller fouling over time

Way forward
Collecting insights and new knowledge

- How do we best grab and share the new knowledge?
- Communicate main findings
- Report on accuracy and applicability
  - Measurements – validation cases for the future
  - Fatima and similar tools (GL Rankine)
  - CFD for unsteady wave structure interaction problems

- Input from SHOPERA 1st public workshop

Thank you for your attention

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SAFER, SMARTER, GREENER
Japan's Research Activities on Minimum Propulsion Power Requirement

_Hydrodynamic approach_

National Maritime Research Institute

Masaru Tsujimoto

2 CONTENTS

1. Japan's R&D Project
2. Numerical Simulation (NMRI)
3. Experimental Research (NMRI)
Concern that ships with excessively small propulsion power would be constructed just for the purpose of improving the EEDI value

The purpose of the interim guidelines is to verify that ships, complying with the EEDI requirements, have sufficient installed power to **maintain the maneuverability in adverse conditions**.

Application: Bulk Carrier, Tanker and Combination Carrier of 20,000DWT or above

Used for Phase 0 and **Phase 1** of EEDI regulation

---

**Japan's R&D Project on Minimum Propulsion Power**

In order to establish a "rational" assessment method from hydrodynamic approach, the Japan Society of Naval Architects and Ocean Engineers (JASNAOE) established a Strategy Research Committee on the Minimum Propulsion Power in **2014** in cooperation with ClassNK.

**Objective of R&D Project**

To develop technically rational methods to determine minimum propulsion power to maintain ship manoeuvrability under adverse weather conditions.
5 Japan's R&D Project on Minimum Propulsion Power

Objective

1) To develop and improve hydrodynamic simulation tools
   manoeuvring simulation in winds and waves considering engine characteristics

2) To develop model test procedure
   free-running model test operation scenario etc.

3) To validate the developed tools and the applicability to other ship types

4) To establish a rigorous methodology for the determination of minimum propulsion power.

Structure of R&D Project (2014)

JASNAOE
Japan Society of Naval Architects and Ocean Engineers

Universities
Research Institutes
Shipyards
Ship owners
Class

Chairman
Prof. H. Yasukawa (Hiroshima Univ.)

NMRI
NRIFE

Marine Dynamic Basin (NRIFE: 1993) having wave makers of 80 units
L=60m, B=25m, D=3.2m
7 Free-running model tests (NRIFE)

BF10, Long crested irregular waves
\(H=9\text{m}, U_{\text{wind}}=26.5\text{m/s for full scale ship}\)

Bulk carrier
\(L_{\text{ship}}=178\text{m}\)
\(L_{\text{model}}=2.9\text{m}\)

8 Japan's R&D Project on Minimum Propulsion Power

Outcomes

Process and final results of the R&D Project will be provided to stakeholders in both Japanese and English.

Research results of the R&D Project are expected to contribute to the discussions in IMO on consideration of the minimum propulsion power.

The results are expected to be utilized in ship design for the optimization of main engine output and ship speed taking both efficiency and safety into consideration.
9 Numerical Simulation (NMRI)

Estimation of wind forces

NMRI Empirical formulae (based on wind tunnel data base)

Standard error for wind tunnel test


10 Numerical Simulation (NMRI)

Estimation of wave forces

Added resistance in waves:

NMRI method (2D calculation with practical correction)

validated by round robin tests and onboard measurements
- tanker, bulker, container ship and PCC

Steady lateral force yaw moment:

NMRI database (3D calculation of zero forward speed)
Numerical Simulation (NMRI)

Estimation of wave forces

Added resistance in waves:

**NMRI method** (2D calculation with practical correction)

- resistance test in short waves
- *almost diffraction condition* coefficient of advance speed

Minimum number of the tests are 6.
(3 kinds of speed, 1 kind of wave length and 2 times each for the confirmation)


---

**12** Numerical Simulation (NMRI)

**in heading waves** **in oblique waves**

- $F_n = 0.247$
- $F_n = 0.200$

container ship (length 300m)
Numerical Simulation (NMRI)

Estimation of wave forces
Validation by onboard measurements

bulker (L=160m)

PCC (L=190m)


Numerical Simulation (NMRI)

Solving equilibrium equations in steady state

Considering engine characteristics (torque limit: MEP and OLP)

Engine operation: constant revolution mode by the governor

solutions: Ship speed (V), Drift angle (β) and Rudder angle (δ)
Numerical Simulation (BF8)

$N_E$ reduction is caused by torque limit

Large $\beta$ or $\delta$ should be rejected

Numerical Simulation (BF9)

$N_E$ reduction is caused by torque limit

From bow to beam waves, equilibrium conditions are not found.

Large $\beta$ or $\delta$ should be rejected
From the simulation, we can find the effect of MCR on ship operation.

The increase of rudder area shows little difference.

Evaluation for stable criteria in manouvrability is needed.

Using the method the application of Minimum Propulsion Power for ships of small size (below 20,000DWT) will be considered.

Maneuvering response in waves:
Free-running model test ≠ Full scale

modification of the propeller loads

Rudder forces and Speed response of free-running model are proportion to those of full scale ships

New free-running experimental method using RSC is proposed

To correct propeller load auxiliary thruster of duct fun type is used.

RSC: Rudder effectiveness and Speed Correction

Auxiliary thruster of duct fun type
Revolution ($N_p$) and force ($F_{ta}$) of the auxiliary thruster are controlled by two conditions:

**Conditions**

A) Similarity of Rudder effectiveness
   matching non-dimensional longitudinal effective inflow velocity to rudder with full scale

B) Similarity of Speed response
   matching non-dimensional longitudinal force with full scale

**Example of $N_p$ and $F_{ta}$**

---

**Simulation: winds and waves of BF8**

Tanker: Ship (L=320m), Model (L=2.91m) in short crested irregular waves

- Speed and rudder response on steady condition in waves is
  - "Model, RSC" is equivalent to "Full Scale Ship" for all wave direction
  - "Model, Ship Point" shows overestimate to "Full Scale Ship".

Full Scale Ship; Scale effect on hull resistance, wake fraction and propeller open characteristics are considered
RSC has a potential for an experimental validation tool in extreme adverse condition.

22 Advantages of RSC

Advantages

Direct evaluation by tank test
Experimental validation for Numerical tools

RSC can be applied for Evaluation of speed decrease and maneuvering response of full scale ships in adverse condition.

Validations of RSC

Model tests using RSC in winds and waves are planned in Actual Sea Model Basin

23 Summary

1. Japan’s R&D project has started by academic sector.
   The results will be provided to stakeholders and contributed to the discussions in IMO.

2. Numerical simulation tool in steady state is prepared for the practical examination: 1st step.

3. RSC is an applicable tool to validate numerical simulation of full scale ship in extreme severe seas.

Thank you for your kind attention.
4.1.8 Apurba Ranjan Kar (Indian Register of Shipping) Ship Maneuverability: An Overview of Ongoing Studies by Indian Register of Shipping
Ship Maneuverability
An Overview of Ongoing Studies by INDIAN REGISTER OF SHIPPING

At the 1st Public Workshop of EU-SHOPERA Project on 30 Oct-2014

Overview

- Estimation of Hydrodynamic derivatives
- Trajectory Simulation of the vessel in calm sea and rough sea conditions
- Effect of environmental loads on the Trajectory of the vessel
- Studying the Shallow water effects
Steady and Unsteady simulations

- Possible methods to determine hydrodynamic derivatives numerically
  - PMM: Unsteady Simulation
  - Captive Model Test: Unsteady/Steady Simulation

- Steady simulations: Duplicating the Captive Model test is explored and studied at the present stage to determine the derivatives

- Unsteady PMM simulations are another approach for prediction of the derivatives.
Simulation for Captive Model Tests

- Captive model tests are numerically simulated using a steady state RANS solver

- As preliminary estimation of maneuverability parameters the actual unsteady nature is simulated by quasi steady approach.

- Tests Simulated numerically
  - Straight line / Static Drift test
  - Rotating arm Test
    - Zero drift and non zero Rotation
    - Non zero drift and non zero Rotation

Case I: Straight Line test/Static Drift test

- The test duplicates the same numerically with the model held stationary and the flow approaching the model with constant velocity corresponding to the Froude number of the vessel.

- The flow is then oriented in such a way that it meets the vessel at variable drift angle’s ranging from 0° to 15° in steps of 2.5°, producing the effect i.e. equivalent to the case when the vessel is oriented at an angle to the flow.

- This test is used to determine five of the velocity dependent hydrodynamic derivatives.
Case2: Rotating Arm Test/Constant Rotation test

- The model is placed stationary as described in straight line test and the flow approaches the vessel with the angular velocity defined by the constant linear forward speed and the radius of rotation i.e.

\[
r = \frac{u}{R}
\]

where

- \( r \) - Angular velocity
- \( u \) - Linear forward speed
- \( R \) - Radius of Rotation

- The ratio of radius to length of the vessel is crucially chosen and based on these parameters i.e. the linear forward speed and the radius, the angular velocity is determined.

Continued...

- For the numerical rotating arm test the chosen value of (radius to length of the vessel) ratio ranges from 2 to 5. Higher the radius lesser the flow complexity observed.

- This test is a mean to determine five angular velocity dependent hydrodynamic derivatives.
Estimation of Hydrodynamic derivatives

Deep water: Calm Condition

- Study carried out for a Container (S175) and a Tanker (KVLCC2)

- Sixteen velocity dependent hydrodynamic derivatives obtained using the previously mentioned method
  - Linear Derivatives: $Y_v$, $N_v$, $Y_r$, $N_r$
  - Non Linear Derivatives: $Y_{vw}$, $N_{vw}$, $Y_{wr}$, $N_{wr}$, $X_{wu}$, $Y_{wv}$, $N_{wv}$, $N_{wv}$

- Derivatives are compared with the experimental values
Forces and Moments for S175

Forces and Moments for Tanker KVLCC2
Trajectory

- In house developed MATLAB code is used for generating the trajectory of the vessel
- The code requires hydrodynamic derivatives as input
- Integration of equations of Motion is carried out by Euler method
Deep water : Rough sea condition

- The Environmental Loads have been determined by means of published empirical relations.
- Numerical estimation of these loads using general purpose CFD solvers is under development.
- The external loads considered are Wave, Current and Wind.
- The cases for each load acting independently and all loads acting together can be analyzed by the in house developed tool.
- The results obtained for tanker vessel under the action of wave, current, wind and combinations are presented.
Effect of Wave / Current on Trajectory

Under wave action with $\lambda/L$ of 0.127 and a significant wave height of about 2.7 m

Under current speed of 0.7 m/s

Effect of wind and all the loads combined

Trajectory under wind speed of 11 m/s

Trajectory under all the loads acting together
Shallow water/Water Depth effects

- With encouraging results in deep water, the scope of exploring the efficacies of CFD in maneuvering has been extended to shallow waters.

- This project deals with the challenges involved in maneuvering the vessels in harbor areas.

- Change in water depth has a strong influence on a vessel’s maneuvering performance. The restricted water depth alters the flow lines around the ship, causing more flow along the sides of the vessel.

- This changes the side forces and the moments acting on the vessel, therefore a change in hydrodynamic derivatives and hence the maneuverability characteristics.

Continued...

- The vessel has to overcome higher forces and moments which makes it more sluggish and deteriorates its controllability.

- Numerically the confinement effects are replicated by changing the domain depth to a specific h/T ratio, this changes the nature of flow as observed in reality.

- Captive model tests described for deep water are duplicated in the modified domain, forces and moments are then obtained.

- Forces and moments are curve fitted and the coefficients are estimated.
Conclusion

- Hydrodynamic derivatives for simulation of maneuverability have been determined by numerical simulation i.e. numerical tanks.

- A steady state fluid flow solver has been used which replicates the model motions during captive model tests in a physical testing tank.

- The techniques have been developed to deal with/analyze any type of hull form using CFD techniques.

Continued…

- Trajectory simulation codes in standard maneuvers viz. turning circle and zig-zag maneuvers have also been developed. These codes require the calculated hydrodynamic derivatives as input and have been efficient enough in predicting the vessel trajectories accurately.

- Benchmarking studies have also indicated that the trajectory predicted are reasonably credible.
THANK YOU FOR YOUR KIND ATTENTION
4.1.9 Anton Minchev (FORCE Technology) Maneuvering aspects at ultra-slow speeds
Maneuvering Aspects at Ultra Slow Speeds
Anton Minchev, FORCE Technology

(Based on USYSES 2012 Summer School FT Presentation)

Inside the mathematical model...
Case study – Objective

The objective with the case study has been to evaluate a vessel with:
- Identical design
- Three different engine sizes

Under the influence of the weather (Wind and associated ocean waves (PM)).

We will analyze the vessel capability by means of performing the turning circle in increasing weather conditions.

We have used the turning circle as the criteria since a vessel needs to be able to recover from the situation where it has been forced off its course.

Case study – Description of vessel

Reference vessel – TORM Laura:
- Tanker in loaded condition
- Operating across the Atlantic

Mathematical model based on:
- Resistance and propulsion tests
- Planar Motion Mechanism (PMM) manoeuvring tests
- Detailed 3D Seakeeping calculation
- Wind tunnel tests data

Vessel particulars:

<table>
<thead>
<tr>
<th></th>
<th>Loaded Tanker – TORM Laura</th>
</tr>
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<tbody>
<tr>
<td>L (m)</td>
<td>183.00</td>
</tr>
<tr>
<td>Lpp (m)</td>
<td>174.50</td>
</tr>
<tr>
<td>B (m)</td>
<td>32.20</td>
</tr>
<tr>
<td>T (m)</td>
<td>12.00</td>
</tr>
<tr>
<td>Displ (m³)</td>
<td>54926</td>
</tr>
<tr>
<td>C⁰</td>
<td>0.815</td>
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</table>
Simulations of turning circle in calm weather based upon the following assumption:

- Hull remain unchanged
- Rudder & rudder turning rates remain unchanged
- Propeller remain unchanged
- Engine are changed (reduction of available power (handle setting) as shown in below table:

<table>
<thead>
<tr>
<th>Handle</th>
<th>Approx power available</th>
<th>Corresponding initial speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 % MCR</td>
<td>10,200 KW</td>
<td>14.9 kn</td>
</tr>
<tr>
<td>68 % MCR</td>
<td>7,650 KW</td>
<td>12.4 kn</td>
</tr>
<tr>
<td>45 % MCR</td>
<td>5,100 KW</td>
<td>9.8 kn</td>
</tr>
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</table>

20% MCR = 10.21 MW
0.75* 90% MCR = 7.65 MW
0.5 * 90% MCR = 5.10 MW
The vessel can also perform the turning circle in 20 m/s wind and associated waves.

Wind and Waves
5 m/s - $H_s = 0.87; T_p = 4.78$
7.5 m/s - $H_s = 1.96; T_p = 7.01$
10 m/s - $H_s = 3.44; T_p = 9.01$
20 m/s - $H_s = 9.95; T_p = 14.83$
Case study – Simulations - Wind & waves

Turning circle in wind and waves Handle=45%

| Wind and Waves | 5 m/s - Hs = 0.87; Tp = 4.78 | 7.5 m/s - Hs = 1.96; Tp = 7.01 | 10 m/s - Hs = 3.44; Tp = 9.01 | 20 m/s - Hs = 9.95; Tp = 14.83 |

Case study – Simulations – Course Keeping

Simulations of course keeping in wind of 10 m/s and corresponding waves:

Maximum rudder with autopilot is limited to +/- 20 deg
All engine sizes fulfil the IMO Resolution MSC.137(76) under ideal condition

Turning circles (transfer & advance) are nearly identical for the three engine sizes – time scale is naturally different.

As wind and waves increase the picture is changing and for the smallest engine the vessel can only handle 7.5 m/s wind and associated waves (approximately Hs=2.0m)

From the course keeping simulations it can clearly bee seen that the vessel is underpowered with respect to manoeuvring.

To survive with small main engines a vessel like the Torm Laura would need to be redesigned with larger rudder & propeller and/or emergency/alternative means of manoeuvring device like an azimuth thruster or similar. This setup should not be used for propulsion and thus not included in the EEDI calculation.
4.2 SHOPERA Partners

4.2.1 Apostolos Papanikolaou (SHOPERA, NTUA) Introduction: Overview SHOPERA
Introduction

Concerns after IMO-MEPC.212 (63) on EEDI

Project SHOPERA: objectives

Project SHOPERA: early results & plans
  o Accident Statistics
  o Criteria for Maneuverability in Adverse Conditions
  o Environmental Conditions
  o Numerical Hydrodynamic Tools
  o Experimental Studies
  o Validation Studies
  o Multi-objective Optimization
  o Case studies

Outlook
The 2012 guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships (MEPC.212(63)) represent a major step forward in implementing the REGULATIONS ON ENERGY EFFICIENCY OF SHIPS through the introduction of a series of specifications for calculating the EEDI for various types of ships.

There are, however, serious concerns regarding the sufficiency of propulsion power and of steering devices to maintain the manoeuvrability of ships in adverse conditions, hence the safety of ships, assuming that the ship marginally passes the relevant EEDI criterion. This gave reason for additional considerations and studies at IMO (IACS studies: MEPC 64/4/13 and MEPC 64/INF7).

This presentation outlines the objectives, the methodology of work and early results of the EU funded, FP7 project SHOPERA (Energy Efficient Safe Ship Operation, 2013-2016, www.shopera.org), which aims at addressing the above shortcomings by state of the art scientific methods and ultimately proposing a rational regulatory framework, properly accounting for the energy efficiency of ships, while keeping undisputed the safety of ships, their crew and people onboard and of the air-marine environment.

**Funding Framework:** European Commission, FP7, 4th call

**Project Type:** Medium Size Collaborative Project, Grant Agreement: 605221

**Evaluation:** Received highest score among three strongly competing major proposals

**Budget:** 6.594 Mio EUR, EU Funding: 4.384 Mio EUR

**Partnership:** 21 partners from 13 European Countries; 2 Yards, 3 Shipping companies, 4 Class societies, 4 Research institutes, 7 University Laboratories, 1 Design Company

**Start:** Oct. 1, 2013, End: September 30, 2016

**Coordinator / web access:** Prof. A. Papanikolaou, Ship Design Laboratory, NTUA [http://www.shopera.org](http://www.shopera.org)
### The Consortium

<table>
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<tr>
<th>Participant organisation name</th>
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<th>Country</th>
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<tr>
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<td>Det Norske Veritas AS (DNV)</td>
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### Geography of the SHOPERA Consortium

![Map of the SHOPERA Consortium Partnerships](image)
### The Advisory Committee

<table>
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<th>Contact name</th>
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<tr>
<td>HAPAG Lloyd</td>
<td>Captain W. Guntermann</td>
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<tr>
<td>FINCANTIERI</td>
<td>Dr. P. Guglia, Dr. A. Maccari</td>
<td>YARD</td>
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<td>Port of Rotterdam</td>
<td>Mr. Wim Hoebée</td>
<td>PORT</td>
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<td>Danish Shipowner Association</td>
<td>Mr. Hans Otto Kristensen</td>
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<td>Nat. Maritime Research Institute</td>
<td>Dr. Masaru Tsujimoto</td>
<td>RES</td>
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<tr>
<td>Maritime &amp; Coastguard Agency</td>
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<td>ADM</td>
<td>United Kingdom</td>
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<td>Indian Register of Shipping</td>
<td>Mr. Apurba Ranjan Kar</td>
<td>CLASS</td>
<td>India</td>
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<td>Malta Transport Centre</td>
<td>Mr. Ivan Sammut</td>
<td>ADM</td>
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<tr>
<td>MARAN Tankers Management Inc.</td>
<td>Mr. Stavros Hatzigrigoris</td>
<td>OPER</td>
<td>Greece</td>
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### Objectives of the SHOPERA research project

- **Verification of “adverse conditions”** introduced in IMO-MEPC 64/4/13 with respect to ship safety
- **Further development of high fidelity software tools** for the analysis of the seakeeping and maneuvering performance and safety of ships in adverse conditions
- **Model tests in combined seaway/wind environment** with a series of prototypes of different ship types
- **Integration of software tools, set-up of a multi-objective optimization procedure**, elaboration of optimization studies
- Investigation of the impact of the proposed guidelines for the minimum propulsion power to maintain maneuverability in adverse conditions on the design and operational characteristics of various ship types (**case studies**)
- **Development of guidelines** for the minimum propulsion power and steering performance to maintain maneuverability in adverse conditions.
- **Submission of results and recommendations to IMO for further consideration (2016)**.
SHOPERA: Environmental conditions and requirements for different ships (leader DNV-GL)

- Critical analysis of adverse conditions presented in EEDI documents and submissions to IMO. Seaway joint statistics for ship routes across the North Atlantic and in European coastal areas, relevant seaway spectra, critical sea states parameters and shallow-water aspects of wave dynamics, focusing on South North Sea, North-West Scotland, and one open sea scenario (North Atlantic).

- Identification of relevant ship types & sizes, especially those most affected by EEDI.

- Collection of data and analysis of operational experience from ship operators and ports.

- Setup of a database of ship types and sizes with all required ship characteristics.

- Risk analysis of marine accidents related to maneuvering in adverse weather conditions.

- Proposal of safety criteria and standards.

SHOPERA Year 1, 30 Oct 2014

SHOPERA: Environmental conditions and requirements for different ships (leader DNV-GL)

- Further development and refinement of numerical hydrodynamic tools available to the participants.

- The objective is to significantly improve the current state of the art in the field of maneuvering in adverse weather conditions by improving the capabilities of a series of numerical methods and computer codes differing with respect to the governing first principles (potential theory and field RANSE methods), computational speed, complexity and accuracy.

- Some of the employed methods are of universal nature, whereas others focusing on specific situations such as loss of stability in waves, maneuvering in waves, aerodynamic loads, and hydrodynamic interaction in confined waters.
Experimental Studies (Leader MRTK)

- Test matrix comprises
  - Added resistance / drift forces in regular and irregular waves
  - Propulsion & speed loss in waves
  - Manoeuvring in waves
  - Rudder forces in waves

  ➢ Parameters of variation
    - Loading condition
    - Water depth
    - Wave height and length
    - Forward speed
    - Heading
    - Propeller revolution
    - Rudder angle

Drift force tests in MARINTEK’s Ocean Basin to determine quadratic RAOs in steep regular waves (heading 60°)

Validation, Sensitivity Studies and Level 1 Methods (leader UDE)

- Validation of developed/available numerical simulation tools using conducted model test data.

- Moreover, selected test cases will be used in an open benchmarking with external participants to evaluate the available state-of-the-art of numerical methods for the proposal of new regulations (spring to summer 2015).

- Simple models of propulsion, steering devices and engine dynamics are not available for the implementation in the numerical simulation tools.

- The development of simplified assessment methods (Level 1 methods) for the assessment of ship maneuverability and intact stability in adverse conditions is an essential part of this project, in view of later proposal to IMO.
**Validated Numerical Methods**

- **Potential flow methods**
  - Drift forces in regular and irregular waves
  - Fast and robust
  - Challenges: Nonlinear effects (e.g. viscosity) may not always be satisfactorily captured

- **Field Methods:** Euler, Reynolds averaged Navier Stokes (RANS), Detached Eddy Simulation (DES), Large Eddy Simulation (LES)
  - Drift forces in regular and irregular waves. Nonlinearities can be captured
  - Propulsion in regular and irregular waves: Nonlinearities and engine dynamics can be modeled
  - Challenges: high computational effort, numerical diffusion to be considered

UDE (El Moctar): RANS code COMET
Grid: 3 Million cells
Time step: 0.01 sec
Inlet boundary: Stokes 2\(^{\text{nd}}\) order

13,000 TEU containership

---

**Validation: Quadratic RAO Added Resistance (UDE)**

![Graph of Added Resistance Coefficient](image)

\[ L = \text{ship length, } B = \text{ship breadth, } \rho = \text{water density, } g = \text{gravity acceleration, } \zeta_a = \text{wave amplitude and } \lambda_w = \text{wave length.} \]
Integration of validated software tools for the hydrodynamic & maneuverability assessment of ships in adverse seaway/weather conditions into a ship design software platform.

Set-up of a multi-objective optimization procedure in which ship’s performance is assessed holistically, thus, looking for the minimum powering requirement to ensure safe ship operation in adverse seaway/weather conditions, while keeping the right balance between ship economy, efficiency and safety of the ship and the marine/air environment.

Conduct of global and refined optimization studies for selected ship types and sizes.

Objectives:
To identify/minimize the powering required to ensure safe ship operation in adverse seaway/weather conditions, while keeping the right balance between ship economy, efficiency and safety of the ship and the marine/air environment.

Ship types to be addressed:
bulk carriers, containers, tankers, cruise ships, Ro-Ro ferries, general cargo ships and LNG carriers.

The optimization studies will be implemented in two phases:
- Global optimization, aiming to identify most favourable combinations of main dimensions, form parameters and other integrated characteristics of the ship, including powering and manoeuvring devices, for the selected operational profile. These studies should be carried out applying as far as possible simplified models (level 1 methods).
- Detailed optimization, including hullform details. These studies should be carried out applying as far as possible medium accuracy models (level 2 methods). Heavy-refined models (level 3, CFD type methods) could also be applied if necessary, but their use will be kept at minimum as possible.
Generic procedure for ship design optimization of NTUA-SDL

Owner's Requirements and/or Parent Hull

Knowledge Base
Technical & Economical Databases, Regulations

VARIATION OF DESIGN PARAMETERS

Design Optimization

Concurrent Evaluation of Multiple Objectives

External Shape
Resistance, Propulsion, Space, Stability

Internal Arrangement
Weights, Machinery Layout

Global Properties
Cost

Design Pool

Has the Pareto Frontier Formed?

Selection of the Best Compromise

Optimisation Criteria
EVALUATION OF MULTIOBJECTIVE FUNCTION

Detailed Design

Control of Constraints

NPV History diagram (first 10 generations)

SHP History diagram (first 10 generations)

Building Cost History diagram

Scatter Diagram of NPV vs. SHP

Optimization of a small ROPAX (NTUA)
Formed design teams that comprise designers, shipyards, owners and class societies will:

- Investigate the impact of the proposed guidelines for the assessment of the minimum propulsion power to maintain maneuverability in adverse conditions (MEPC 64/4/13) on the design and operational characteristics of various ship types.

- Investigate in parallel the impact on EEDI by implementation of the developed integrated/holistic optimization procedure in a series of case studies.

---

**Application / Case Studies (leader LR)**

The main objectives of undertaking cases studies
- Investigate the impact of the proposed new guidelines
- Assess additional ship types currently not covered by the EEDI provisions

<table>
<thead>
<tr>
<th>Subtask</th>
<th>DoW</th>
<th>Proposed</th>
<th>Within current EEDI frame work</th>
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<td>6.2.4</td>
<td>Cruise ships</td>
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<tr>
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<td>Ro–Ro ferries</td>
<td>Ro–Ro ferries</td>
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</tr>
<tr>
<td>6.2.6</td>
<td>OSVs</td>
<td>Ro–Ro cargo ships</td>
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<td>Tugs</td>
<td>Car carriers</td>
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<td>6.2.10</td>
<td>LPG carriers</td>
<td>Refrigerated cargo carrier</td>
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</table>

- Analyse results from all other work packages to develop improved guidelines
- Establish likely new EEDI requirements ensuring safe operation
Conclusions

- **Balancing safety with environmental protection** is a key future challenge for regulators.
- **New EEDI requirements** call for reducing engine power and, at the same time, for minimum power to ensure safe manoeuvring in adverse conditions.
- A **consistent** regulation is needed.
- **Current knowledge** to define adverse conditions and capabilities to check the vessel’s performance is in research-stage. **SHOPERA** addresses this challenge.

---

**Outlook: Planned Public workshops**

1. **Introduction of the project to key stakeholders** (30 October 2014, organisers GL-DNV, NTUA) Hamburg
   
   To present the problems addressed by SHOPERA, the state of the art and the proposed way ahead. First results will be presented. Feedback from the external participants will be used to refine the objectives of the project and shape the way ahead.

2. **Benchmarking of numerical tools for manoeuvrability simulations in adverse conditions** (Sep. 2015, organisers IST, UDE, NTUA) Lisbon
   
   To present the results of validation of numerical tools in comparison with model tests. To obtain knowledge on the world-wide state-of-the-art of numerical tools for manoeuvrability assessment in adverse conditions, and to disseminate the knowledge gained in the project.

3. **Criteria and standards for sufficient manoeuvrability under adverse conditions** (April 2016, organisers LR, RINA, NTUA) London/ Southampton
   
   The developed criteria, standards and guidelines for sufficient manoeuvrability under adverse conditions will be presented and discussed, to ensure feedback from external experts in ship design and operation and regulators regarding the developed criteria, standards and guidelines.

4. **Presentation of the results to key stakeholders** (Sep 2016, organisers NTUA, GL, DNV, LR, RINA) Athens
   
   Overall presentation of the project, with emphasis on the set objectives, adopted procedures, major achievements, conclusions and recommendations. The developed guidelines for the minimum propulsion power and steering performance of ships to maintain manoeuvrability under adverse conditions will be discussed with the scientific community and key stakeholders prior to their submission to IMO. The feedback will be used to refine the guideline and to develop strategy for the formal submission to IMO.
Energy Efficient Safe SHip OPERAition

SHOPER A Year 1 Public Workshop
Hamburg, 30 October 2014

SHOPER A web site: www.shopera.org
Contact (coordinator):
Prof. A. Papanikolaou, papa@deslab.ntua.gr
4.2.2 Elżbieta M. Bitner-Gregersen (SHOPERA, DNVGL) Met-ocean description
WP 1
Environmental conditions and requirements for different ships

Task 1.1 Met-ocean description

Elzbieta M. Bitner-Gregersen

WP1: Objectives

- Provide **met-ocean description** for the project
- Define **ship sizes** for ship types considered in the project
- Conduct **risk analysis of marine accidents** related to manoeuvring in adverse weather conditions
- Propose **safety criteria** to be addressed by the project based on a critical review of the current EEDI as well as operational experience from ship operators and other project partners.
Introduction of Energy Efficiency Design Index (EEDI) represents a major step forward in implementing the regulations on energy efficiency of ships.

It has brought serious concerns regarding the sufficiency of propulsion power and of steering devices to maintain the manoeuvrability of ships in the adverse conditions.

Ship designers might choose to lower the installed power to achieve EEDI requirements.

Implementation of EEDI two phases:
- Phase 0 – interim assessment procedures to be applied (1 Jan. 2013 - 31 Dec. 2014) within Phase 0 of the EEDI implementation.
- Phase 1 and later
To avoid negative effects, such as under-powered ships, a provision was added to regulation 21 in Chapter 4 of MARPOL Annex VI, stating:

“For each ship to which this regulation applies, the installed propulsion power shall not be less than the propulsion power needed to maintain the manoeuvrability of the ship under adverse conditions as defined in the guidelines to be developed by the Organization.”

At MEPC 65 the “2013 Interim Guidelines for determining minimum power to maintain the manoeuvrability of ships in adverse conditions” were adopted (17 May 2013).

For 2013 Interim Guidelines
- Possibility for 2 levels assessment
- Definition of adverse condition
- Definition of “minimum power lines” (assessment level 1) for bulk carriers and tankers (including combination carriers)
- Definition of “required ship speed of advance” (for assessment level 2)
  - Minimum navigational speed (4.0 knots)
  - Minimum course-keeping speed (defined as function of rudder area, ship length, breadth and draft, ship frontal windage area and lateral windage area)

For final guidelines (to be defined)
- Applicability to other ship types
- Verification and possible redefinition of adverse conditions
- Redefinition of “minimum power lines”
- Definition of safety criteria and standards

Task 1.0. Technical Management (DNV)
Task 1.1. Met-ocean description (DNV, IST, GL, EVFH)
Task 1.2. Identification of ships and risk analysis of relevant marine accidents (NTUA, GL, DNV, LR, IST, RINA, DAN, FNK, CAL)
Task 1.3. EEDI and safety criteria (GL, DNV, NTUA, LR, IST, UDE, RINA, DAN, FNK, CAL)

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</table>
Task 1.1. Met-ocean description
Adverse Conditions - Definition

1.1 "Adverse conditions" mean sea conditions with the following parameters:

<table>
<thead>
<tr>
<th>Significant wave height $h_s$, m</th>
<th>Peak wave period $T_P$, s</th>
<th>Mean wind speed $V_w$, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5</td>
<td>7.0 to 15.0</td>
<td>19.0</td>
</tr>
</tbody>
</table>

JONSWAP sea spectrum with the peak parameter of 3.3 is to be considered for coastal waters.

1.2 The following adverse condition should be applied to ships defined as the following threshold value of ship size.

<table>
<thead>
<tr>
<th>Ship length, m</th>
<th>Significant wave height $h_s$, m</th>
<th>Peak wave period $T_P$, s</th>
<th>Mean wind speed $V_w$, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 200</td>
<td>4.0</td>
<td>7.0 to 15.0</td>
<td>15.7</td>
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<tr>
<td>$200 \leq L_{pp} \leq 250$</td>
<td>Parameters linearly interpolated depending on ship's length</td>
<td>7.0 to 15.0</td>
<td>15.7</td>
</tr>
<tr>
<td>More than $L_{pp} = 250$</td>
<td>Refer to paragraph 1.1</td>
<td>7.0 to 15.0</td>
<td>15.7</td>
</tr>
</tbody>
</table>

30 Oct. 2014

SHOPERA. WP1.1

Task 1.1. Met-ocean description
Adverse Conditions - Definition

- Adverse conditions to be analysed from three perspectives:
  - Met-ocean description
  - Ship accident statistics
  - Interviews of ship masters

- Adverse conditions - met-ocean description
  - Developed for coastal waters
  - Deep water
  - Include wind and waves. Current is not included.

- How adverse conditions relate to field data?
- What ship accident statistics is showing?
- Do numerical calculations and model tests confirm these conditions?
Objectives:

- Critical review of adverse conditions in EEDI documents & IMO submissions.
- Effects of ship type and size will be considered.
- Seaway statistics for North Atlantic ship routes (open sea scenario) and in European coastal areas (entranceways to the ports of Rotterdam and Antwerp; North-West Scotland scenario).
- Critical sea state parameters (e.g. spectra) and shallow-water aspects (e.g. topological issues).

- Determined adverse conditions for numerical simulations, model tests and in the case studies, will be revisited based on results and interactions with WP2, WP3, WP6.

Coastal waters

Shipping channels – access to Antwerp

Measuring network:
wind, waves, tide, current

Meetnet Vlaamse Banken

Wave statistics (example)

<table>
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<tr>
<th>$H_s$ (m)</th>
<th>0-2.5</th>
<th>2.5-3.5</th>
<th>3.5-4.5</th>
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<th>5.5-6.5</th>
<th>6.5-7.5</th>
<th>7.5-8.5</th>
<th>8.5-9.5</th>
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</table>

TOTAAL: 4.85 35.35 39.40 27.23 3.08 0.16 0.01 - - 100.00

Wind statistics (example)

Source:
http://www.vlaamsehydrografie.be/hydrometepatlas.htm
Correlation
wind speed – wave height

Shallow water conditions correspond well to the adverse conditions

Source:
http://www.vlaamsehydrografie.be/hydrometeoatlas.htm

Average wave spectra

(Truijens, 1992)

Different classes:
• Significant wave height
• Tidal level
• Wind direction

Example:
2.50 m < Hs < 3.00 m
3 water level classes
Task 1.1. Met-ocean description
(DNV, IST, GL, EVFH)

- Wave design database for ships, BMT (1986) visual observations, the PM spectrum, IACS 34 Recommendations (2000).

- Operational conditions, visual observations BMT (1986), other data sources, JONSWAP, PM spectrum

Joint probabilities, wind

CMA – marginal distribution and series of conditional density functions

\[ f_{H_{\infty}T_{p}\Theta V_{U}U_{W}W_{1}W_{2}}(h, t, \theta, v, u, w_{1}, w_{2}) = f_{H_{\infty}T_{p}V_{U}U_{W}1\Theta}(h, t, v, u, w_{1} | \theta) f_{\Theta}(\theta) f_{W_{2}}(w_{2}) \]

- Significant wave height – 3-par. Weibull

\[ f_{H_{\infty}}(h) = \frac{\beta}{\alpha} \left( \frac{h - \gamma}{\alpha} \right)^{\beta - 1} \exp \left\{ - \left( \frac{h - \gamma}{\alpha} \right) ^{\beta} \right\} \]

- Wave period – log-normal conditional on Hs

\[ f_{T_{p} | H_{\infty}}(t | h) = \frac{1}{\sigma(h) t \sqrt{2\pi}} \exp \left\{ - \frac{(\ln t - \mu(h))^{2}}{2\sigma(h)^{2}} \right\} \]

log-mean and std. are functions of Hs; \( \mu = a_{1} + a_{2} h^{\alpha} \), \( \sigma = b_{1} + b_{2} e^{\beta h} \).
Task 1.1. Met-ocean description
(DNV, IST, GL, EVF)

- Wind speed - 2-par. Weibull distribution

\[ f_{u,h}(u|h) = k \frac{u^{k-1}}{U_c^k} \exp \left( -\frac{u}{U_c} \right)^k \]

Where \( k = c_1 + c_2 h_s \)

\[ U_c = c_5 + c_7 h_s \]

West Shetland

Adverse conditions seem to be more conservative regarding wind.

Task 1.1. Met-ocean description
FUGRO - OCEANOR database - WORLDWAVES

- Position 1 (54.0°N, 45°W)

Sea states with \( H_s \geq 4 \) m more often than in coastal areas.
### Task 1.1. Met-ocean description (DNV, IST, GL, EVFH)

- Wave design database for ships, BMT (1986) visual observations, the PM spectrum, IACS 34 Recommendations (2000).
- Sea state steepness, IACS scatter diagram, IACS 34

#### Table 1.1.1

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<tr>
<th>Hs (m)</th>
<th>Tz (s)</th>
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<th>3.5</th>
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**SUM:** 0 0 1 165 2091 9280 19922 24879 20870 12898 6245 2479 837 247 66 16 3 1 10000

*Adverse conditions*, Uw=19m/s, for coastal areas JONSWAP gam=3.3

*Adverse conditions* – depending of ship size, ship length below 200 m, Uw=15.7m/s
Task 1.1. Met-ocean description
(DNV, IST, GL, EVFH)

- JONSWAP spectrum, gamma parameter, DNV–RP–C205

\[ \frac{H_s}{T_z} \]

- High steepness and a narrow wave spectrum can trigger modulational instability → rogue waves

Wave Steepness, DNV–RP–C205
- \( H_s = 5.5m, T_p = 7\text{–}15s, Lpp > 250m \)
- \( H_s = 4.0m, T_p = 7\text{–}15s, Lpp \leq 200m \)

Field data
Task 1.1. Met-ocean description
(DNV, IST, GL, EVFH)

- Two peak spectra; e.g. Strekalov & Massel (1971); Ochi (1967), Guedes Soares (1984)
- Two wave systems; total $H_s=5.5m$, $T_p=7-15s$ ($U_w=15.7m/s$), Torsethaugen spectrum (1987, 1993)

30 Oct. 2014

Task 1.1. Met-ocean description
(DNV, IST, GL, EVFH)

- Two wave systems; total $H_s=4m$, $T_p=7-15s$ ($U_w=15.7m/s$)
Task 1.1. Met-ocean description
Wave steepness

- Wave Steepness, DNV-RP-C205
- $H_s=5.5\,\text{m}$, $T_p=7\text{–}15\text{s}$, $L_{pp}>250\,\text{m}$
- $H_s=4.0\,\text{m}$, $T_p=7\text{–}15\text{s}$, $L_{pp}\leq200\,\text{m}$

![Average wave steepness graph](image)

The limiting values of $S_s$ may, in absence of other reliable sources, be taken as:

- $S_s = \frac{1}{10}$ for $T_p \leq 6\text{ s}$
- $S_s = \frac{1}{15}$ for $T_p \geq 12\text{ s}$

and interpolated linearly between the boundaries. The limiting values of $S_p$ may be taken as:

- $S_p = \frac{1}{15}$ for $T_p \leq 8\text{ s}$
- $S_p = \frac{1}{25}$ for $T_p \geq 15\text{ s}$

and interpolated linearly between the boundaries.

Density of VOS reports on the considered area

Vettor & Guedes Soares (2014).

Accuracy of the VOS data; bad weather avoidance

HIPOCAS data base

28 Oct. 2014

SHOPERA WP1.1
Background of SOLAS:
- HARDER: collisions happen mostly in calm water, and very rare at $H_s > 4.0$ m
- Groundings were not taken into account – note however that adverse weather conditions are more relevant to groundings than to collisions
- Therefore, further databases should be evaluated (GOALDS?)

Accident investigation: grounding in heavy weather of bulk carrier *Pasha Bulker*:
- Figure: number of ships at anchor vs. $H_s$: 80% of ships at $H_s=4.5$ m and 20% of ships at $H_s=6.0$ m

Accident investigation reports of MAIB (Marine Accidents Investigation Branch): in work
- Interviews with ship masters (container ships and bulk carriers): in work
- ANEP-79 (2007) Controllability and Safety in a Seaway:
  - Operability for most operations: Bft6, $H_s=4.0$ to $6.0$ m
  - Rescue and patrol: no weather limitations

MEPC 65/4/3, Annex 1 (2013), *Minimum Power Guideline*: $H_s=4.0$ to $5.5$ m

SOLAS (HARDER): $H_s < 4.0$ m

Grounding of bulk carrier *Pasha Bulker*: $H_s=6.0$ m

ANEP-79 (2007) Controllability and Safety in a Seaway $H_s=4.0$ to $6.0$ m (operability) up to maximum wave heights (rescue and patrol)

Ongoing work:
- Accident investigation reports by MAIB (Marine Accidents Investigation Branch)
- Interviews with ship masters (container ships and bulk carriers)

- Masters of about 50 container ships, bulk carriers and tankers have been questioned.
The first-phase validation of the adverse conditions has been carried out using data from deep water and coastal area as well as ship accident statistics and interviews of ship masters.

The next phase of Task 1.1 will provide, between others, assessment of the probability of occurrence of the adverse conditions along the main North Atlantic routes. Therefore some conclusions presented herein maybe revised in the second phase of Task 1.1.

The occurrence of sea states being in the range of adverse conditions varies significantly in deep and coastal waters.

The suggested sea states may include combined wave systems (wind sea and swell), particularly in deep water. Also wind conditions seem to be different in deep water and coastal areas. Further, current has impact on ships’ manoeuvrability; this effect is still not sufficiently investigated.

Some of the proposed sea states in the adverse conditions are very steep and can trigger very steep abnormal waves. The deep water and coastal data confirm existence of such steep sea states. They are recommended to be investigated further in numerical simulations and model tests as they may impact ships’ manoeuvrability.

It is also recommended to apply in WP 2 and WP 3 both the PM as well as JONSWAP spectrum with different parameter gamma (e.g. 3.3 and 6.0). The calculations planned to be carried out in WP 2 could also include a two-peak spectrum. The results should be compared with ones obtained by using the proposed adverse conditions.

Further investigations will need to combine environmental description based on an analysis of new data sets with an analysis of ship accident statistics, especially groundings and strandings in heavy weather, and results from interviews of ship masters.
Conclusions and way ahead

- So far, **masters of about 50 container ships, bulk carriers and tankers have been questioned**. Questioning of the masters, especially of the ship types not considered so far, is an important activity for the identification of manoeuvrability criteria and environmental conditions.

- **Distinguishing between coastal areas and open sea** needs to continue to the second phase of Task 1.1. It is proposed that to investigate effects of increase of storm intensity with respect to wave steepness and wave height, on ships’ manoeuvrability. **For low-speed manoeuvrability criteria, both the wind speed and current speed are recommended to be studied.**

- **Gustiness factor** for ship manoeuvrability in wind and in combined waves and wind is to be defined. Wind conditions are the same. Relation between wind speed and wave height is different.

Task 1.1: Met-ocean conditions

Thank you for your attention
4.2.3  Koimtzoglou A., Louzis K., Eliopoulou E., Ventikos N.P. (SHOPERA, NTUA)  
Identification of ships and risk analysis of relevant marine accidents
Introduction

Research Goal
Accidents in adverse weather conditions in locales where the maneuvering capabilities of ships play a key role (e.g. port approaches, restricted waters)

• The aim is to come up with metrics suitable to project trends and identify ship types of interest: statistics, rates, risk
Roadmap to achieving our target

• How our analysis is implemented?

• What comes out of a more detailed study with respect to the involved ships?

• How bad the weather needs to be? What if include hurricanes?

• How often these accidents occur and what the consequences are?

• What is the difference between ship types in terms of risk?

What type of data has been acquired?

Database inclusion criteria

– Ship Types:
  Container, Cruise, Ro-Ro Ferry, Ro-Ro Cargo, Pure Car Carriers, Tankers, Gas Carriers, Bulk Carriers, General Cargo

– GT ≥ 400 gt
– Built Date ≥ 1/1980
– Accident Date ≥ 1/1990 – 11/2013
– Heavy weather conditions

1666 accidents collected

Further analysis of accidents

– Based on accident reports and web search for details
– Human factor and tug assistance taken into consideration

Data source: IHS Sea-Web
What type of data has been acquired?

Data Fields
- Ship Details (Name, Type, GT...)
- Ship Dimensions (L, B, D...)
- Machinery (Installed power, service speed...)
- Accident Details (Date, location, type...)

Example of included accidents:
- General Cargo – **CARRIER** - 3/4/2012
  Strong winds and large waves overwhelmed the ship while it was maneuvering

- Bulk Carrier – **PASHA BULKER** – 8/6/2007
  Ship was rapidly approaching shore due to strong winds. Master attempted maneuver to avoid grounding which failed due to weather conditions

What type of accidents is relevant?

Initial exclusion criteria for accidents
- Hull/Machinery damage
- Fire and explosion
- Extreme weather conditions (e.g. hurricanes)
- Anchored/Berthed ships
- Foundered at sea (e.g. capsized, cargo shift)
- High Speed Crafts (Fr > 0.5)

Example of excluded accidents:
- Ro-Ro Cargo – **CAMILLA** – 23/1/2003
  Sustained M/E breakdown and developed list

- LPG Carrier – **BENEGAS** – 13/7/2006
  Caught fire while discharging cargo

1427 accidents were excluded
How is our sample distributed?

### Retained Accidents

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<tr>
<th>Type</th>
<th>Percent (%)</th>
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<tr>
<td>Cruise Ships</td>
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<tr>
<td>Ro-Ro Ferries</td>
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<td>Ro-Ro Cargo</td>
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<td>Pure Car Carriers</td>
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<td>Gas Carriers</td>
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<tr>
<td>General Cargo</td>
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### Fleet at Risk (1990-2012)

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<td>Cruise Ships</td>
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**Location Type**

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Fleet at Risk Source: NTUA SDL / Clarkson’s Shipping Intelligence Network

1st SHOPERA Workshop
Hamburg, 30 Nov. 2014

‘Identification of ships and risk analysis of relevant marine accidents’
How is our sample distributed?

[Bar chart showing the distribution of accident types and location types.]

1st SHOPERA Workshop
Hamburg, 30 Nov. 2014
‘Identification of ships and risk analysis of relevant marine accidents’
How do accidents fit in a timeline?

Statistically significant increasing trend
Kendall’s Tau = 0.662, p<0.0001

How does our sample compare to the fleet?

Container Ships

FLEET 2013 Source: IHS Sea-Web
How does our sample compare to the fleet?

Tankers

Which are the ships of interest?

Identification of size classes per ship type of interest

1. Define size classes (e.g. Panamax tanker, Capesize bulk carrier)
   - Distributions of size per ship type in accident sample
2. Select classes with highest accident frequency
3. Determine measure of size: DWT, GRT or TEU
   - Focus on characteristic value for size in each class
4. Determine characteristic MCR and LBP corresponding to each size class
5. Define ship of interest per size class based on Size, MCR, LBP
Which are the ships of interest?

### Container Ships

#### Feedermax Handysize Panamax

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<td>3900</td>
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#### Tankers

#### Small Panamax Aframax

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<td>$L_{bp}$ [m]</td>
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<td>219</td>
<td>230</td>
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</table>

**FLEET 2013 Source: IHS Sea-Web**
What happens if we include hurricanes?

- **Extended dataset** included accidents in extreme weather conditions (e.g. hurricane and freak seas)
- **277** accidents vs. **239** in initial sample

**Extended dataset**

- Accidents in extreme weather conditions involved in average smaller ships compared to those in the initial sample
- In general the ships of interest were not altered due to the added accidents

Comparison of **Tanker ships** of interest between the initial and extended datasets
Which were the weather conditions?

- Data validated where possible from available **accident reports**

  Wave height available for **59%** of accident cases (142)
  Wind speed available for **54%** of accident cases (130)

Data sources: **DANAOS Corporation, Instituto Superior Tecnico (IST), Accident Reports**

Outlier Analysis

Cut-off limits determined by extreme value analysis and Z scores

Wave height and wind speed distributions after removal of outliers
Weather Data by Accident Type

<table>
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<tr>
<th></th>
<th>WAVE HEIGHT (m)</th>
<th>WIND SPEED (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision</td>
<td>Mean 1.98</td>
<td>11.07</td>
</tr>
<tr>
<td></td>
<td>25th 0.75</td>
<td>8.47</td>
</tr>
<tr>
<td></td>
<td>50th 1.42</td>
<td>11.44</td>
</tr>
<tr>
<td></td>
<td>75th 3.18</td>
<td>14.16</td>
</tr>
<tr>
<td>Contact</td>
<td>Mean 1.51</td>
<td>9.61</td>
</tr>
<tr>
<td></td>
<td>25th 0.33</td>
<td>5.36</td>
</tr>
<tr>
<td></td>
<td>50th 0.77</td>
<td>8.42</td>
</tr>
<tr>
<td></td>
<td>75th 3.00</td>
<td>13.33</td>
</tr>
<tr>
<td>Grounding</td>
<td>Mean 1.28</td>
<td>9.44</td>
</tr>
<tr>
<td></td>
<td>25th 0.30</td>
<td>6.39</td>
</tr>
<tr>
<td></td>
<td>50th 0.85</td>
<td>8.86</td>
</tr>
<tr>
<td></td>
<td>75th 2.03</td>
<td>12.58</td>
</tr>
</tbody>
</table>

Global Average

Weather Data by Ship Type

- Statistically significant differences in wave heights per ship type
- Ship types with **lower means** are more affected by wave height

Non parametric test **Kruskal – Wallis**

\[ X^2 = 16.527, p = 0.035 \]

level of significance \( p = 0.05 \)
Risk Analysis - Methodology

Risk Triplet = (Scenario, Frequency, Consequences)

Kaplan, S., & Garrick, B. J. (1981)

- **Risk triplets** were used to produce (risk) curves per ship type
- Accident cases categorized into scenarios with specific parameters

Each scenario was described in terms of:

- Ship type
- Size class
- Accident type
- Installed Power

**Scenario Example**

(Bulk Carrier, Handysize, Collision, 8000 kW)

---

Risk Analysis - Methodology

**Accident Sub-Sample**

- Accidents that occurred in the same time period for which the rate has been calculated
- Accidents for which consequence data were available

Risk analysis sub-sample consists of 100 accidents
### How often do these accidents occur?

<table>
<thead>
<tr>
<th>Ship Type</th>
<th>Fleet At Risk</th>
<th>Accidents</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container Ships</td>
<td>63594</td>
<td>8</td>
<td>1.26E-04</td>
</tr>
<tr>
<td>Cruise Ships</td>
<td>5252</td>
<td>11</td>
<td>2.09E-03</td>
</tr>
<tr>
<td>Ro-Ro</td>
<td>19173</td>
<td>56</td>
<td>2.92E-03</td>
</tr>
<tr>
<td>Pure Car Carriers</td>
<td>9814</td>
<td>8</td>
<td>8.15E-04</td>
</tr>
<tr>
<td>Gas Carriers</td>
<td>22195</td>
<td>6</td>
<td>2.70E-04</td>
</tr>
<tr>
<td>Tankers</td>
<td>145159</td>
<td>23</td>
<td>1.58E-04</td>
</tr>
<tr>
<td>Bulk Carriers</td>
<td>143158</td>
<td>49</td>
<td>3.42E-04</td>
</tr>
<tr>
<td>General Cargo</td>
<td>23462</td>
<td>74</td>
<td>3.15E-03</td>
</tr>
</tbody>
</table>

Frequencies above include collisions, contacts and groundings

Fleet At Risk Source: Clarkson’s Shipping Intelligence Network (1996-2013)
Which are the consequences?

Days Off-Hire, Injuries, Fatalities, Pollution, Hull Damage

- **Hull Damage** selected as the consequence variable
- Data classified into discrete categories

<table>
<thead>
<tr>
<th>Levels</th>
<th>Dummy Values</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO</td>
<td>0</td>
<td>No hull damage reported</td>
</tr>
<tr>
<td>YES</td>
<td>2</td>
<td>Hull damage reported</td>
</tr>
<tr>
<td>ABOVE WL</td>
<td>4</td>
<td>Minor hull damage reported above WL</td>
</tr>
<tr>
<td>BELOW WL</td>
<td>6</td>
<td>Hull damage reported below WL that led to Loss Of Watertight Integrity (LOWI)</td>
</tr>
<tr>
<td>TOTAL LOSS</td>
<td>8</td>
<td>Severe and extended hull damage that led to LOWI and resulted in the sinking of the ship</td>
</tr>
</tbody>
</table>

1st SHOPERA Workshop
Hamburg, 30 Nov. 2014

What is the risk of each ship type?
What is the risk of each ship type?

Risk Curves per ship type and size class (Group I)

Aversion-prone Zone

What is the risk of each ship type?

Risk Curves per ship type and size class (Group II)

Aversion-prone Zone
Conclusions

• **Groundings** and **collision/contacts in port** are the most frequent accidents of interest
• A statistically significant **increasing trend** in accidents of interest is observed (highly contributing up to 2007)
• Ship types with high accident frequency
  - Cruise, Ro-Ro Ships, Pure Car carriers: **large wind profile area**
  - General Cargo: **(frequent) port calls**
• Inclusion of extreme weather accidents **does not alter** the quality of the results

Conclusions

• Minimum median wave height / wind speed found in accidents in port
• Wave and wind important parameters in contacts and groundings
• Statistically significant difference in mean wave height per ship type
  - RoRo ships most affected
• Accident rates are in the range of \(10^{-4}\) to \(10^{-3}\) and are one order of magnitude lower compared to those in FSAs
• Ships of interest generally **smaller** compared to the (range of) Fleet 2013 ships
Thank you for your attention!
4.2.4 Vladimir Shigunov (SHOPERA, DNVGL) Manoeuvrability criteria
Overview

- Background
- Overview of existing criteria
- Sources: accident statistics, accident reports, interviews of ship masters
- Proposal for additional manoeuvrability criteria
- Assessment procedure and assessment examples
- Outlook
Background:
EEDI and Minimum Power Guidelines

• Energy Efficiency Design Index (EEDI) was introduced to improve energy efficiency of shipping and reduce GHG emissions
• Concerns: if EEDI fulfilled only by reducing installed power => insufficient manoeuvrability in adverse conditions
• Following IACS proposal following requirement was added to MARPOL: “For each ship to which this regulation applies, the installed propulsion power shall not be less than the propulsion power needed to maintain the manoeuvrability of the ship under adverse conditions as defined in the guidelines to be developed by the Organization.”
• Work of IACS Project Teams PT4-PT7 on Minimum Power Guidelines resulted in 2012 and 2013 Interim Guidelines for Determining Minimum Propulsion Power to Maintain the Manoeuvrability of Ship in Adverse Weather Conditions, IMO Res. MEPC.232(65)

Background:
EEDI and Minimum Power Guidelines: Concerns

• Only tankers, bulkers and combination carriers covered
• Level 3 assessment excluded from 2013 Guidelines (numerical tools not mature enough)
• Level 2 assessment requires model tests: too complex for Level 2
• Level 1 assessment does not take into account manoeuvrability characteristics
• Potential conflict between EEDI and Minimum Power regulations, especially in Phase 3 of EEDI implementation (after 1 January 2025)
• More general: how to combine EEDI & Min. Power Requirements in regulations, design and approval
Manoeuvrability Criteria: Sources

- IMO Standards for Ship Manoeuvrability
- Proposals in the literature
- NATO ANEP-79, 2007
- Requirements of Classification Societies to Redundancy or Duplication of Propulsion System
- Work of IACS Project Teams on minimum power requirements
- Accident reports
- Interviews of ship masters

Literature Studies:

IMO Standards for Ship Manoeuvrability, Res. MSC.137(76), 2002: ship’s manoeuvring abilities are evaluated in simple manoeuvres in calm-water:

- Turning
- Initial turning
- Yaw-checking
- Course-keeping
- Emergency stopping

Concerns: not addressing manoeuvrability (1) at low speed, (2) in restricted waters and (3) in wind, waves & current

How these concerns can be addressed:

1. Whether standards of existing criteria should be made stricter? – unclear yet, but it is not enough:
2. Whether additional criteria are required? – definitely:
   - One of the tasks of steering is withstanding environmental forces
   - Environmental forces are ship-specific
   - However, ship-specific ability to withstand environmental forces is not normed
Literature Studies:
Other Sources

- Wagner (1972): course-keeping in beam wind
- Quadvlieg & van Coevorden (2008):
  (1) leaving quay at low speed in wind 20 to 30 knots and (2) 180° course change at $h_s=6.0$ m
- NATO ANEP-79 (2007):
  requirements for frigatte/corvette: (1) fully operational up to sea state 6 and (2) survive and perform transit, search and rescue in worst likely storms
- IACS, EE-WG 1/4 (2010): Summary of requirements of Classification Societies to Redundancy and Duplication of Propulsion System:
  - GL: (1) weather-vaning (change and keep heading) at wind 21 m/s, $h_s=5.4$ m and (2) advance speed of at least 7 knots or 0.5 design speed at wind 11 m/s, $h_s=2.8$ m
  - ABS: weather-vaning without drifting at wind of 33 knots, $h_s=4.5$ m
  - DNV: weather-vaning at advance speed of at least 6 knots at wind of Bft 8, corresp. $h_s$
  - LR: steering ability & advance speed of at least 7.0 knots
  - BV: advance speed of at least 7 knots at wind of Bft 5 & corresponding $h_s$
- Work of IACS PTs on Minimum Power - resulting criteria:
  Ship should be able to (1) keep course in waves and wind from any direction and (2) keep advance speed of at least 4.0 knots in waves and wind from any direction

With exception of NATO requirements, the criteria can be summarised as:
- (1) Course change / course keeping, (2) minimum advance speed, (3) weather –vaning, (4) low speed

Other Sources of Criteria:
Detailed Accident Reports Concerning Grounding in Heavy Weather

- MV Willy: insufficient propulsion (advance speed): Bft 5-7, small waves (protected area)
- Tanker Astral: insufficient propulsion (advance speed): Bft 10
- Norcape: insufficient course-changing ability: wind 38-45 knots
- RoRo Riverdance: insufficient course-changing ability (1 of 2 engines failed): Bft 9-10, $h_s>10$ m
- RoRo Stena Challenger: insufficient course-changing ability: gale force wind, low waves
- Bulk carrier Carrier: Insufficient propulsion (advance speed): wind up to 40 knots, $h_{max}=4.0$ m
- Bulk carrier Pasha Bulker: insufficient propulsion (advance speed): wind 38-46 knots, $h_s=6.0$ to 6.6 m

Challenges:
- insufficient propulsion ability (advance speed)
- insufficient course-changing ability
Other Sources of Criteria:
Interviews of Ship Masters

- About 50 interviews: container ships, bulk carriers, tankers
- Manoeuvring in the open sea:
  - “If caught in violent weather, no engine power will help”
  - “It is enough to take position with enough room for drifting”
  - “Drifting is always possible for limited time”
- **Typical manoeuvre in extreme weather: weather-vaning**
- Usual weather-vaning practices in the open sea:
  - Container ships with high GM, all bulk carriers, all tankers: head waves to 30° off-bow (sometimes up to 60° off-bow)
  - Container ships with low GM: drifting in beam waves and wind
  - Extreme following and quartering seaways are always avoided
- Manoeuvring in coastal waters:
  - More challenging: any manoeuvre may be necessary
  - Environmental conditions are not severe: captains search for shelter or leave to open sea
  - Particular case: manoeuvring at low speed in strong wind when approaching ports, especially for ships with large windage area

Additional Functional Requirements

Three groups of requirements emerge:

- **Manoeuvrability in extreme weather in the open sea:**
  - Requirements to manoeuvring: weather-vaning ability
  - Weather conditions severe to extreme
- **Manoeuvrability in increasing storm in coastal waters:**
  - Any manoeuvre, in wind and waves from any direction
  - Weather conditions moderate
- **Manoeuvrability at low speed in restricted areas**
  - Reduced speed because of navigational restrictions
  - Strong wind, frequently strong current, no large waves
Criteria for Manoeuvrability in Extreme Weather in the Open Sea

- **Weather-vaning ability:** *the ship must be able to change and keep heading into seaway*

- Possible simplification for practical assessment:
  - *keep heading in bow to bow-quartering waves*

Criteria for Manoeuvrability in Coastal Waters

- **Any manoeuvre**, in wind and waves from any direction

- Criteria: the ship must be able to
  - *Change the course to the required one and keep it*
  - *Maintain some minimum advance speed*
  - Both criteria are required in waves and wind from any direction

- This was background behind 2012 and 2013 Interim Guidelines
• Manoeuvrability at **low speed** because of navigational restrictions (approaching ports)

• Such criteria will not lead to minimum power requirements => no potential conflict with EEDI

• Criteria: *course-keeping at specified reduced speed*
  - *in strong wind*
  - *in shallow water near channel wall or near bank* (4)
  - *in shallow water during overtaking by a quicker ship*

**Assessment Procedure:**

*Full Scale Trials / Model Tests / Numerical Simulations*

• *IMO Manoeuvrability Standards* are evaluated in full-scale trials; full-scale trials are impracticable in adverse weather conditions => Alternatives: model tests, numerical calculations

• Evaluation of criteria is possible in principle in transient model experiments with self-propelled models in irregular waves and wind

• Drawbacks:
  - Experimental methods are not mature enough: combination of waves and wind, scale effects on propulsion and steering forces => *is the achievable accuracy worth expenses?*
  - Statistical predictions in irregular waves require multiple seaway realisations × number of wave directions => *too expensive*
  - Only few facilities exist world-wide for such tests => *impractical for routine design*
  - Verification by the Administration is possible only by observation of the testing programm => *impractical for approval*
  - Result depends very much on steering time history => *too large variability of results, impossible to verify results in approval for marginal cases*
  - Alternative: numerical methods for direct simulation of manoeuvres in waves are *not mature enough* yet for routine design and approval
Assessment Procedure:
Possible Simplifications

- Oscillatory wave forces and moments can be neglected, because their time scale is much shorter than time scale of manoeuvres
  - Exception: broaching-to, which is not relevant for minimum power requirements
- Thus, only average in time forces, moments and other characteristics (thrust, torque, rotation rate, required power, available power, drift angle, rudder angle) need to be considered
- Second simplification: spectral method to compute drift forces and moments due to waves
- Thus, the problem reduces to solution of steady coupled equilibrium equations in the horizontal plane, taking into account time-average contributions due to wind, waves, manoeuvring, rudder, propeller etc.

\[
\begin{align*}
X_s + X_w + X_d + X_R + T &= 0 & \Rightarrow \text{thrust} \Rightarrow \text{power} \\
Y_s + Y_w + Y_d + Y_R &= 0 & \Rightarrow \text{drift angle} \\
N_s + N_w + N_d + N_R &= 0 & \Rightarrow \text{rudder angle}
\end{align*}
\]

Assessment Procedure:
Factors to be Taken into Account

<table>
<thead>
<tr>
<th>Factors</th>
<th>Evaluation Method</th>
<th>Possible Simplification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind forces and moment</td>
<td>Wind tunnel tests [CFD simulations]</td>
<td>Empirical data \textit{Simplified empirical formulae}</td>
</tr>
<tr>
<td>Wave drift forces and moment</td>
<td>Seakeeping basin model tests (regular waves) \textit{Numerical methods}</td>
<td>Empirical formulae</td>
</tr>
<tr>
<td>Calm-water forces and moment</td>
<td>Steady towing-tank tests [CFD simulations]</td>
<td>Empirical formulae</td>
</tr>
<tr>
<td>Rudder forces</td>
<td>Steady towing tank tests [CFD simulations]</td>
<td>Semi-empirical methods</td>
</tr>
<tr>
<td>Propeller: open-water curves</td>
<td>Steady towing-tank tests Numerical simulations</td>
<td>Propeller series \textit{Simplified empirical formulae}</td>
</tr>
<tr>
<td>Engine dynamics</td>
<td>\textit{Model to be developed}</td>
<td>Static model: engine diagram</td>
</tr>
<tr>
<td>Ship-ship interaction, bank &amp; shallow-water</td>
<td>Steady towing-tank tests Numerical simulations</td>
<td>Empirical formulae</td>
</tr>
<tr>
<td>Putting forces together</td>
<td>Steady model: 3 coupled equations</td>
<td>\textit{Further simplifications possible}</td>
</tr>
</tbody>
</table>

- Advantage: any contribution can be measured/computed/verified/re-evaluated individually, in a simple test or computation, or replaced with empirical formula
Example:
Typical Insufficient Manoeuvrability Cases

- Requirements: course-keeping & advance speed 4.0 knots
- In waves & wind from any direction

Example:
Influence of Rudder Area on Required Power
• Criteria & assessment procedure:
  – Validation & fine-tuning of criteria & assessment procedure, using
direct simulations of transient manoeuvres in time domain
    • adjust safety margins in the procedure: maximum rudder angle, available power
    • adjust environmental conditions
  – Add or remove criteria as necessary: the aim is to keep the number
    of new criteria to minimum

• Development of numerical methods:
  – drift forces (X, Y, Mz) due to waves
  – Simple empirical or semi-empirical formulae: drift forces due to
    waves, wind forces, calm-water forces, rudder forces, ship-ship
    interaction, shallow water and bank effects
4.2.5 Carlos Guedes Soares (SHOPERA, IST): Development and Refinement of Numerical Hydrodynamic Tools
Energy Efficient Safe SHip OPERAtion

Development and refinement of numerical hydrodynamic tools

WP2

Carlos Guedes Soares, Instituto Superior Técnico

WP 2 Objectives

- To perform further development and refinement of various numerical hydrodynamic tools available to the participants.
- The codes to be improved differ by their computational speed, complexity and accuracy, some are of universal nature, others focusing at specific situations such as loss of stability in waves, manoeuvring in waves, aerodynamic loads, and hydrodynamic interaction in confined waters.
- The models will be used to analyse the experimental results produced in WP3 and in the validation studies in WP 4.

WP2 - Tasks

- Task 2.0. Technical Management (IST)
- Task 2.1. Potential flow methods for seakeeping and loss of stability in extreme seas (IST, UU, NTUA, LR)
- Task 2.2. Potential flow methods for manoeuvring in waves (DNV, GL, IST, NTUA, RINA, LR, DTU)
- Task 2.3. Potential flow methods for manoeuvring in confined waters (IST, SU, LR)
- Task 2.4. Field methods to determine ship hydrodynamic characteristics (TUB, VTT, IST, SU, UDE, LR)
- Task 2.5. Field methods for direct predictions of ship motions (UDE, IST, LR)

Task 2.1. Potential flow methods for seakeeping and loss of stability in extreme seas

- IST and UR will extend a code for assessing the added resistance in waves and the associated emissions.
- IST and UR will work on an existing time domain code that predicts parametric rolling of ships to improve the accuracy of the computation of hydrodynamic loads on the hull and to extend it to include the effect of devices aimed at controlling the effect of parametric roll.
- NTUA will study parametric rolling. The codes will be used in Tasks 4.2, 4.3, 4.6 and WP 6.
2. Speed loss calculation

- Strip theory (Salvesen et al., 1970).
- Added resistance in waves (Faltinsen et al., 1980).
- Wind resistance (Isherwood or Blendermann model).

Fig. Scheme of the computations of ship speed in a given sea state

3. Numerical results

- To carry out improvement and refinement of two fast codes for manoeuvring in waves:
  - the strip-method semi-linear code dedicated to the wave manoeuvring (IST) and
  - the 3D nonlinear potential seakeeping code (GL). In the latter case the code will be fused to some database manoeuvring code.
- DNV also will improve its seakeeping-and-manoeuvring code with better modelling of diffraction-radiation forces and second-order wave loads and better model for propeller and rudder forces.
- NTUA will use the seakeeping code HYBRID with some manoeuvring model.
- RINA will also integrate its 3D potential seakeeping code with a proper manoeuvring model.
- DTU will further develop their OceanWave3D code for computing the seakeeping and added resistance of ships in waves.
- The codes will be used in Tasks 4.2, 4.3, 4.5 and WP 6.
DTU

- Code: OceanWave3D
- Steady wave computation on the KCS tanker hull using the immersed boundary code

Task 2.3. Potential flow methods for manoeuvring in confined waters

- A code for deep water existing at SU, will be extended to shallow water in order to study the stability and manoeuvring of vessels in waves in shallow water and the interaction between two vessels either overtaking or crossing in restricted waters.
- The hydrodynamic interaction code developed by IST will be improved by better approximation of the hull surface and better fulfilment of the body boundary condition. The code will be also augmented with dynamic account for the sinkage and trim of the ship.
- The codes will be used in Tasks 4.2, 4.3 and WP 6.

Mirror image vs Panelled moving patch

Ship-ship hydrodynamic interaction over horizontal flat seabed (overtaking, passing by, encountering, etc.)

Interaction involving Arbitrary bathymetry

Bank effect

Approach Channel

(La Quinta Channel, Texas, USA)
Results: Two ships travelling with the same speed in shallow water

Wave pattern: $\lambda/L_b=1.08$, $F_n=0.25$, $r=1.35$

Two ships travelling with same speed at different longitudinal distances

Scale: 1/75
$U = 0.238$ m/s

Task 2.4. Field methods to determine ship hydrodynamic characteristics

- UDE will use the in-house RANS solver to obtain off-line data bases for describing second-order wave forces, approximations of manoeuvring hull forces in shallow water, rudder forces behind the propeller in waves, simplified unsteady model for a screw propeller and peculiarities of hull-propeller interaction coefficients in waves.

- IST will use STAR CCM+ and OpenFoam codes to predict the hydrodynamic interaction in confined waters as well as the aerodynamic loads on the superstructure and proper hull hydrodynamic forces for specific vessels.

- SU will be using the ANSYS FLUENT CFD software to generate manoeuvring coefficients to be used for special vessel types.

- TUB will refine the in-house or OpenFoam codes to apply them to the following problems:
  1. carrying out virtual 400F captive model tests with account for the free-surface effects;
  2. development of a suitable body-force propeller model providing also correct rudder inflow data;
  3. determination of the propeller torque in curvilinear motion;
  4. estimation of forces and force on a rotating propeller in oblique flow;
  5. estimation of hull forces in regular and irregular waves;
  6. estimation of aerodynamic loads with account for the actual true wind profile;
  7. estimation of the influence of a current on hull forces.

Task 2.4. Field methods to determine ship hydrodynamic characteristics

- VTT will evaluate the hull-propeller-rudder (+all other appendices) interaction by field method (URANSE) in restricted waters.

- The free surface effects will be determined either with the field method or with the potential flow method. Special attention will be set on the determination of static surge, sway and yawing manoeuvring forces.

- The codes will be used in Tasks 2.2, 4.2, 4.3, 4.5 and WP 6.
Task 2.4: Field Methods
Waves with different encountering angles

RANS calculations:
- Encountering angle variation 0° - 180° in suitable steps
- Grid with 4.4 mio cells
- Calculations on one core
- Calculation time: one week

Task 2.4: Field Methods
Dependence on wave length

- Dependence on $\alpha$ (180°-$\mu$) modelled with Fourier coefficients
- Dependence on $\omega$ by polynomial approach of Fourier coefficients

\[ F'_Y(\alpha, \omega) = \sum_{k=1}^{m} \left( a_k(\omega) \cdot \cos(k \cdot \alpha) + b_k(\omega) \cdot \sin(k \cdot \alpha) \right) \]

Task 2.4: Field Methods
Rotating propeller in oblique flow

RANS calculations performed for body force database:
- Isolated stock propeller
- Variation of incident angle
- Variation of advance ratio

Pressure distribution on blades
\( \beta = 30^\circ \) and \( J = 0.7 \)

Task 2.5. Field methods for direct predictions of ship motions

- UDE will extend the in-house RANS solver coupled with the 6DOF ship motion simulator in the following respects:
  1. modelling of irregular sea waves;
  2. implementation of engine dynamics and automatic controllers;
  3. coupling with a simplified propeller model;
  4. implementation of a morphing algorithm.

- IST will extend the capability to predict hydrodynamic loads on the ship hull due to waves using the OpenFoam code coupled with his own ship motions code.

The codes will be used in Tasks 4.2, 4.3, 4.4 and WP 6.
Irregular Waves

- Modeling of irregular waves
- Implicit coupling of the volume fraction transport equation with the RANS Equations
- Refinement of existing implementation (No. of components, Boundary conditions, Discretization)
- Different wave theories

Energy Efficient Safe SHip OPERAtion

Development and refinement of numerical hydrodynamic tools

WP2

Carlos Guedes Soares, Instituto Superior Técnico

Body Force Model

- First application for a propeller behind a ship, including rudder
4.2.6 Ould El Moctar (SHOPERA, UDE): Numerical Investigation of Added Resistance in Waves
Energy Efficient Safe SHip OPERAtion

Numerical Investigation of Added Resistance in Waves

Prof. Bettar el Moctar, University of Duisburg-Essen

Content

1. Validation study based on available experimental data: How close are numerical results to experimental data?

2. Viscosity: How is added resistance affected by viscous effects?

3. Ship speed: How does it influence the added resistance?

4. Superposition of radiation and diffraction forces: Is this approach valid for the whole frequency range?
**Major Challenges**

- **Model tests**
  - Added resistance: free & suppressed motions at the same time, measurement of small values in short waves, free running models
  - Added power: Friction deduction is not applied (variable speed), engine dynamics,

- **Full scale Measurements**
  - Measurement of the environment conditions (waves, current..)

- **Potential flow methods**
  - Fast and robust: Nonlinear effects may not always be captured (short waves)

- **RANS based Field methods**
  - Computational effort, numerical diffusion to be considered, especially for short waves

**Objectives**

- Validate RANS based field methods

- Analysis of the flow and the force components of the added resistance based RANS

- Use RANS and experimental data to derive fast and simplified methods, which can be used in simulators
Transport equations for turbulence variables

Step 1: Computation of calm water resistance (RT)
Step 2: Computation of long. force in regul. waves (constant steepn.)
Step 3: Calculation of added resistance (aver. Fx – RT)
Test Cases/Added Resistance

Duisburg Test Case DTC (SHOPERA)
Cruise Ship (PerSee)
Wigley (Benchmark)

<table>
<thead>
<tr>
<th>Dim.</th>
<th>DTC</th>
<th>Cruise-Vessel</th>
<th>Wigley III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length $L = L_{pp}$ [m]</td>
<td>355.00</td>
<td>216.80</td>
<td>100.00</td>
</tr>
<tr>
<td>Breadth $B$ [m]</td>
<td>31.00</td>
<td>32.20</td>
<td>10.00</td>
</tr>
<tr>
<td>Draught $d$ [m]</td>
<td>14.50</td>
<td>7.20</td>
<td>6.26</td>
</tr>
<tr>
<td>Displacement $V$ [m$^3$]</td>
<td>17467.00</td>
<td>33219.10</td>
<td>2888.00</td>
</tr>
<tr>
<td>Inertia radius $k_{pp}$ [m]</td>
<td>88.75</td>
<td>59.58</td>
<td>25.00</td>
</tr>
<tr>
<td>Wettex surface $S_w$ [m$^2$]</td>
<td>22032.00</td>
<td>8011.90</td>
<td>1400.80</td>
</tr>
<tr>
<td>Vertical CoG [m]</td>
<td>9.68</td>
<td>15.1</td>
<td>5.66</td>
</tr>
<tr>
<td>Longitudinal CoG [m]</td>
<td>174.57</td>
<td>99.6</td>
<td>50.00</td>
</tr>
<tr>
<td>Froude number $Fn$ [-]</td>
<td>0.174</td>
<td>0.159</td>
<td>0.2 - 0.3</td>
</tr>
<tr>
<td>Model scale [-]</td>
<td>59.4</td>
<td>36.0</td>
<td>33.0</td>
</tr>
</tbody>
</table>

Source: Ley, Sigmund, el Moctar, OMAE 2014

Step 1: Calm Water Resistance: Wigley

Wigley III, Calm Water Resistance (model scale)

$\text{CFD 20.36 N (|\varepsilon|\leq 2.52\%)}$
$\text{EFD 19.86 N}$

Body Fixed: Coarse 890k
Body Fixed: Medium 1300k
Body Fixed: Fine 2200k
Free Dynamic Heave and Trim: Medium 1300k
Body Fixed at Dynamic Squat: Medium 1300k
EFD

Source: Ley, Sigmund, el Moctar, OMAE 2014
1. Validation Study

Calm water resistance can be reliably computed with SoA codes: Deviations less than 5%

Source: Ley, Sigmund, el Moctar, OMAE 2014

Step 2&3: Computed long. Force and added resistance

Simulations for many periods are necessary to reach a convergence solution

Source: el Moctar et al., paper in preparation 2015
Influence of Spatial Discretization on Ship Motions

Ship motions are not affected very much by discretization!

![Graph showing pitch angle vs. nondimensional wave frequency](image)

Source: Ley, Sigmund, el Moctar, OMAE 2014

Influence of Spatial Discretization on Added Resistance

Added resistance in short waves is affected by discretization!

![Graph showing added resistance vs. nondimensional wave frequency](image)

Source: Ley, Sigmund, el Moctar, OMAE 2014
**Measurements performed at TU Delft**

Source: Ley, Sigmund, el Moctar, OMAE 2014
1. Validation Study

Computed and Measured
Added Resistance: Wigley, Fn=0.3

![Graph showing computed and measured added resistance coefficients for Wigley, Fn=0.3. The graph plots nondimensional wave frequency against the non-dimensional added resistance coefficient, with data points showing the relationship between these variables.]

**Measurements performed at TU Delft**

Source: Ley, Sigmund, el Moctar, OMAE 2014

Computed and Measured
Added Resistance: Wigley, Fn=0.4

![Graph showing computed and measured added resistance coefficients for Wigley, Fn=0.4. The graph plots nondimensional wave frequency against the non-dimensional added resistance coefficient, with data points showing the relationship between these variables.]

**Measurements performed at TU Delft**

Source: Ley, Sigmund, el Moctar, OMAE 2014
**1. Validation Study**

Measurements performed by HSVA within PerSee Project

---

**2. Viscous Effects on Added Res.**

Friction part of the added resistance in short waves may be considerable!

---

Measurements performed by HSVA within PerSee Project
3. Ship Speed Effects

Speed effects are more pronounced for max RAO values

Source: Ley, Sigmund, el Moctar, OMAE 2014

4. Superposition?

Superposition of radiation and diffraction forces in short and long waves may not be accurate!

Source: Ley, Sigmund, el Moctar, OMAE 2014
Conclusions

- Results obtained from CFD (more details of the physics related to added resistance) may be used to improve fast potential flow and simplified methods
  - Nonlinearities related to short and steep waves etc.
  - Nonlinearities related to ship speed
  - Viscous effects
  - Behaviour of diffraction forces in short waves and radiation forces in long waves

- Future Work
  - Use MARINTEK and CEHIPAR data for Validation (Drift Forces)
  - Added resistance in irregular waves
  - Propulsion in Waves (wake distribution, propeller performance)
4.2.7 Florian Sprenger (SHOPERA, MARINTEK) Experimental Studies
WP3: Experimental Studies

Florian Sprenger
MARINTEK, CEHIPAR, Flanders Hydraulic Research, Technische Universität Berlin

Year 1 Workshop, Hamburg, 30th October 2014

Outline

• Task 3.1: Model Test Specification
  – Vessel Description
  – Test Matrix
  – Test Parameters

• Task 3.2 Model Testing and Analysis of Results
  – TK 3.2.1 Model testing at MARINTEK
  – TK 3.2.2 Model testing at CEHIPAR
  – TK 3.2.3 Model testing at TUB
  – TK 3.2.4 Model testing at EVFH
Vessel Description

KRISO VLCC (KVLCC2)

- Semi-Spade rudder with NACA 0018 profile
- fixed-pitch 4 bladed propeller of 9.86 m diameter and a pitch ratio of P/D = 0.721

<table>
<thead>
<tr>
<th>LPP [m]</th>
<th>BPP [m]</th>
<th>T [m]</th>
<th>V [m³]</th>
<th>S [m²]</th>
<th>CD [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>320.0</td>
<td>58.0</td>
<td>20.8</td>
<td>312622</td>
<td>27194</td>
<td>0.8098</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vessel Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 kn</td>
</tr>
<tr>
<td>6 kn</td>
</tr>
<tr>
<td>12 kn</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LC</th>
<th>T/Lp [m]</th>
<th>m [t]</th>
<th>LCG(m) [m]</th>
<th>VCG(m) [m]</th>
<th>GM [m]</th>
<th>r0 [m]</th>
<th>r10 [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC1</td>
<td>20.8/20.8</td>
<td>320438</td>
<td>171.1</td>
<td>TBD</td>
<td>5.71</td>
<td>23.2</td>
<td>80.0</td>
</tr>
<tr>
<td>LC2</td>
<td>8.2/11.5</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>21.4</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

(a) From aft perpendicular
(b) From baseline
(c) Alternative scantling condition with more realistic GM and radii of inertia compared to the original SIMMAN data

Year 1 Workshop,
Hamburg, 30th October 2014

Vessel Description

KVLCC2

- CEHIPAR: Scale 1:80, deep water
- EVFH: Scale 1:75, shallow water

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Deep Water (CEHIPAR)</th>
<th>Shallow Water (EVFH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance in calm water (+surge acceleration)</td>
<td>X(1)</td>
<td>X</td>
</tr>
<tr>
<td>Added resistance in regular waves</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Added resistance in irregular waves</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Drift forces in regular waves</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Propulsion in calm water</td>
<td>X(2)</td>
<td>X</td>
</tr>
<tr>
<td>Propulsion and speed loss in regular waves</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Propulsion and speed loss in irregular waves</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Bollard pull and rudder forces in calm water</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>Rudder forces in regular waves</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>PMM tests in calm water</td>
<td>X(1,a)</td>
<td>X</td>
</tr>
<tr>
<td>Circular motion tests in calm water</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Circular motion tests in regular waves</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Turning circle in calm water</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Turning circle in regular waves</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zig-Zag manoeuvre in calm water</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zig-Zag manoeuvre in regular waves</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(1) Data already available on the SHOPERA website
(2) Deep-water PMM tests are only available for full load; tests at intermediate/ballast load are desirable (UDE will provide the results, based on computations)

References: Stern et al. available on SHOPERA Website, SIMMAN Workshop

Year 1 Workshop,
Hamburg, 30th October 2014
Vessel Description

Duisburg Test Case (DTC)
(14k TEU Containership)

- Twisted rudder (5° around the shaft axis) with Costa bulb and a NACA 0018 base profile
- fixed-pitch five-bladed propeller of 8.911 m diameter, pitch ration P/D = 0.959.
- segmented bilge keel

<table>
<thead>
<tr>
<th>LC</th>
<th>$T_c/T_a$ [m]</th>
<th>$m$ [t]</th>
<th>$L_{CG}(b)$ [m]</th>
<th>$V_{CG}(b)$ [m]</th>
<th>$GM_c$ [m]</th>
<th>$r_{an}$ [m]</th>
<th>$r_{ag}$ [m]</th>
<th>$r_{ar}$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC1, Design</td>
<td>14.5/14.5</td>
<td>177804</td>
<td>174.6</td>
<td>9.68</td>
<td>5.1</td>
<td>20.3</td>
<td>87.3</td>
<td>87.4</td>
</tr>
<tr>
<td>LC2, Ballast</td>
<td>5.9/9.8</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>LC2, Intermediate(1)</td>
<td>7.8/11.0</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

(1) Optional
(2) From aft perpendicular
(3) From baseline
(4) UDE will provide the partners with the data

References: el Moctar et al. & Ley et al. available on SHOPERA Website
Vessel Description

ROPAX

<table>
<thead>
<tr>
<th>Lp[m]</th>
<th>Bwl[m]</th>
<th>T[m]</th>
<th>V[m³]</th>
<th>S[m²]</th>
<th>CB [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>90.00</td>
<td>17.82</td>
<td>4.19</td>
<td>3,752</td>
<td>1,763</td>
<td>0.56</td>
</tr>
</tbody>
</table>

- 2 rudders
- 2 four-bladed counter-rotating (inwards) propellers of 3.0 m full scale diameter
- Roll stabilization fins

<table>
<thead>
<tr>
<th>LC</th>
<th>T/Tc [m]</th>
<th>T [m]</th>
<th>LCG [m][a]</th>
<th>VCG [m][b]</th>
<th>GM [m]</th>
<th>rL [m][c]</th>
<th>rV [m][c]</th>
<th>rR [m][d]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC1, max load</td>
<td>4.089/4.296</td>
<td>3846</td>
<td>40,765</td>
<td>8.33</td>
<td>2,397</td>
<td>6.3</td>
<td>22.5</td>
<td>22.5</td>
</tr>
</tbody>
</table>

(a) From aft perpendicular
(b) From baseline
(c) Standard value 0.55B, since no other data is available
(d) Standard value 0.25L, since no other data is available
References: Stability Information Booklet Revision 1, provided by Caledonian MacBrayne

Year 1 Workshop,
Hamburg, 30th October 2014

Experimental Studies

Vessel Description

ROPAX

- MARINTEK: Scale 1:25, deep water

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Deep Water (MARINTEK)</th>
<th>Shallow Water [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance in calm water (+surge acceleration)</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Added resistance in regular waves</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Drift forces in regular waves</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Propulsion in calm water</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Propulsion and speed loss in regular waves</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Propulsion and speed loss in irregular waves</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bollard pull and rudder forces in calm water</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rudder forces in regular waves</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PMM tests in calm water</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Circular motion tests in calm water</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Circular motion tests in regular waves</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Turning circle in calm water</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Turning circle in regular waves</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zig Zag manoeuvre in calm water</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zig Zag manoeuvre in regular waves</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Year 1 Workshop,
Hamburg, 30th October 2014

Experimental Studies
Model production

DTC hull (1:63.65)

- Hull model
- 1 propeller
- 1 rudder
- Segmented bilge keels

<table>
<thead>
<tr>
<th></th>
<th>L网 [m]</th>
<th>B网 [m]</th>
<th>T [m]</th>
<th>V [m³]</th>
<th>S [m²]</th>
<th>CB [m]</th>
<th>d₅ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Scale</td>
<td>355.0</td>
<td>51.0</td>
<td>14.5</td>
<td>173467</td>
<td>22032</td>
<td>0.661</td>
<td>8.911</td>
</tr>
<tr>
<td>Model Scale</td>
<td>5.78</td>
<td>0.80</td>
<td>0.23</td>
<td>0.67</td>
<td>5.44</td>
<td>0.661</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Main particulars at DWL for full scale and model scale 1:63.65

Year 1 Workshop,
Hamburg, 30th October 2014

Model production

ROPAX appendages (1:25)

- 2x shaft, bossing, brackets etc
- 2x propeller
- 2x rudder
- 2x roll stabilization fins

Year 1 Workshop,
Hamburg, 30th October 2014
Tests in the Towing Tank  
(deep water conditions)

- Double flap wave maker for regular and irregular waves
- Towing carriage up to 10 m/s for traditional calm water tests
- Seakeeping carriage up to 5 m/s for tests with fixed or free-running models with 6DOF motion platform and autopilot

Length: 260 m   Width: 10.5 m   Depth: 5.6/10.0 m

<table>
<thead>
<tr>
<th>Tests</th>
<th>Test Parameters</th>
<th>No. of Tests</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTC, deep water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Resistance in calm water (surge acceleration)</td>
<td>Design draught, 6 and 16kn</td>
<td>2</td>
<td>100%</td>
</tr>
<tr>
<td>2. Added resistance in regular waves</td>
<td>Design draught, 0° and 180°, 6 – 16kn, 7 wave periods, 1 wave height (+ 2 additional wave heights for RAO peak and shortest wave)</td>
<td>44</td>
<td>50%</td>
</tr>
<tr>
<td>3. Added resistance in irregular waves</td>
<td>Design draught, 180°</td>
<td>3</td>
<td>In preparation</td>
</tr>
<tr>
<td>4. Propulsion in calm water</td>
<td>Design draught, 180°</td>
<td>1</td>
<td>In preparation</td>
</tr>
<tr>
<td>5. Propulsion and speed loss in regular waves</td>
<td>Design draught, 180°, 75% rpm, 3 irregular sea states (3h full scale duration)</td>
<td>10</td>
<td>In preparation</td>
</tr>
<tr>
<td>6. Propulsion and speed loss in irregular waves</td>
<td>Design draught, 180°, 75% rpm, 3 irregular sea states (3h full scale duration)</td>
<td>3</td>
<td>In preparation</td>
</tr>
<tr>
<td>7. Bollard pull and rudder forces in calm water</td>
<td>Design draught, continuous increase of rudder angle, 30% -75% - 100% rpm</td>
<td>3</td>
<td>In preparation</td>
</tr>
<tr>
<td>ROPAX, deep water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Resistance in calm water (surge acceleration)</td>
<td>Max Load, 5kn and 14kn</td>
<td>2</td>
<td>In preparation</td>
</tr>
<tr>
<td>9. Added resistance in regular waves</td>
<td>Max Load, 0° and 180°, 5 – 14kn, 7 wave periods, 1 wave height (+ 2 additional wave heights for RAO peak and shortest wave)</td>
<td>44</td>
<td>In preparation</td>
</tr>
<tr>
<td>10. Propulsion in calm water</td>
<td>Max Load, 75% rpm</td>
<td>1</td>
<td>In preparation</td>
</tr>
<tr>
<td>11. Propulsion and speed loss in regular waves</td>
<td>Max Load, 180°, 75% rpm, 5 wave periods, 2 wave heights</td>
<td>10</td>
<td>In preparation</td>
</tr>
<tr>
<td>Total in the Towing Tank</td>
<td></td>
<td>123</td>
<td>20%</td>
</tr>
</tbody>
</table>
Model Testing in the Towing Tank

Calm Water Resistance Test – Wave profile at 6kn (DTC)

Model testing in the Towing Tank

Calm Water Resistance Test – Wave profile at 16kn (DTC)
Model testing in the Towing Tank
Calm Water Resistance Test (DTC)

Model testing in the Towing Tank
Open Water Test (DTC)
Model testing in the Towing Tank
Regular waves for added resistance tests (DTC)

Following seas
6kn and 16kn

Head seas
16kn

Head seas
6kn

<table>
<thead>
<tr>
<th>$T_s$ [s]</th>
<th>$T_m$ [s]</th>
<th>$\lambda_s$ [m]</th>
<th>$\lambda_m$ [m]</th>
<th>$\lambda_s/\lambda_m$ [-]</th>
<th>$H_s$ [m]</th>
<th>$H_m$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.71</td>
<td>1.97</td>
<td>385.10</td>
<td>6.05</td>
<td>1.08</td>
<td>12.00</td>
<td>0.189</td>
</tr>
<tr>
<td>15.00</td>
<td>1.88</td>
<td>351.17</td>
<td>5.52</td>
<td>0.99</td>
<td>12.00</td>
<td>0.189</td>
</tr>
<tr>
<td>14.31</td>
<td>1.79</td>
<td>319.60</td>
<td>5.02</td>
<td>0.90</td>
<td>12.00</td>
<td>0.189</td>
</tr>
<tr>
<td>13.94</td>
<td>1.75</td>
<td>303.29</td>
<td>4.76</td>
<td>0.85</td>
<td>12.00</td>
<td>0.189</td>
</tr>
<tr>
<td>10.00</td>
<td>1.25</td>
<td>156.08</td>
<td>2.45</td>
<td>0.44</td>
<td>12.00</td>
<td>0.189</td>
</tr>
<tr>
<td>9.00</td>
<td>1.13</td>
<td>126.42</td>
<td>1.99</td>
<td>0.36</td>
<td>10.00</td>
<td>0.157</td>
</tr>
<tr>
<td>8.00</td>
<td>1.00</td>
<td>99.89</td>
<td>1.57</td>
<td>0.28</td>
<td>7.50</td>
<td>0.118</td>
</tr>
<tr>
<td>7.00</td>
<td>0.88</td>
<td>76.48</td>
<td>1.20</td>
<td>0.22</td>
<td>5.00</td>
<td>0.079</td>
</tr>
<tr>
<td>5.70</td>
<td>0.71</td>
<td>50.71</td>
<td>0.80</td>
<td>0.14</td>
<td>1.50</td>
<td>0.024</td>
</tr>
</tbody>
</table>

Following seas
6kn and 16kn

Head seas
16kn

Head seas
6kn
Model testing in the Towing Tank

Added Resistance Tests (DTC)

REG H12.0 T15.00 D0 V6

REG H12.0 T15.00 D0 V6
Model testing in the Towing Tank

Added Resistance Tests (DTC)

Preview of preliminary added resistance data for 6kn and 16 kn in head seas (0/180) deg

Please note: The presented raw data has been extracted during testing and has not been postprocessed. The actual wave in the tank has not been considered.

Irregular waves for added resistance tests (DTC)

3 JONSWAP spectra for head seas and 6kn:

<table>
<thead>
<tr>
<th>$T_p$ [s]</th>
<th>$T_m$ [s]</th>
<th>$H_s$ [m]</th>
<th>$H_{m0}$ [m]</th>
<th>$\gamma$ [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.50</td>
<td>0.81</td>
<td>2.00</td>
<td>0.031</td>
<td>1.59</td>
</tr>
<tr>
<td>9.50</td>
<td>1.19</td>
<td>3.00</td>
<td>0.047</td>
<td>1.00</td>
</tr>
<tr>
<td>11.50</td>
<td>1.44</td>
<td>7.50</td>
<td>0.157</td>
<td>2.51</td>
</tr>
</tbody>
</table>

IRREGULAR WAVES, BM2, Model scale

Wave height (m)

Wave period (s)
Tests in the Ocean Basin (deep water conditions)

- Double flap wave maker
- Multiflap wave maker, 144 individually controlled flaps for long and short crested spectra
- Carriage system with no constraints at speed up to 5 m/s
- Current and Wind

Length: 80 m  Width: 50 m  Depth: 0-10 m

---

Model testing in the Ocean Basin

<table>
<thead>
<tr>
<th>Tests, deep water</th>
<th>Test Parameters</th>
<th>No. of Tests</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>12. Drift forces in regular waves</td>
<td>Design draught, 0° - 30° - 60° - 90° - 120° - 150° - 180° for 0kn and 30° - 60° - 120° - 150° for 6kn; 7 wave periods, 1 wave height (+ 2 additional wave heights for RAO peak and shortest wave)</td>
<td>121</td>
<td>36%</td>
</tr>
<tr>
<td>13. Rudder forces in regular waves</td>
<td>Design draught, 75% rpm, 60° and 120°, 1 wave period, 1 wave height, continuous increase of rudder angle from 0° to 35°</td>
<td>2</td>
<td>In preparation</td>
</tr>
<tr>
<td>14. Turning circles in calm water</td>
<td>Design draught, 75% rpm, 35° rudder angle</td>
<td>1</td>
<td>In preparation</td>
</tr>
<tr>
<td>15. Turning circles in regular waves</td>
<td>a) Design draught, 75% rpm, 1 wave period, 1 wave height, continuous increase of rudder angle from 0° to 35° b) Design draught, 75% rpm, 1 wave period, 1 wave height, 1 wind</td>
<td>12</td>
<td>In preparation</td>
</tr>
<tr>
<td>16. Zig-Zag manoeuvre in calm water</td>
<td>Design draught, 75% rpm, 20°/20° rudder angle</td>
<td>1</td>
<td>In preparation</td>
</tr>
<tr>
<td>17. Zig-Zag manoeuvre in regular waves</td>
<td>Design draught, 180°, 75% rpm, 2 wave periods, 2 initial conditions (rudder turning in wave crest and wave trough), 20°/20° rudder angle</td>
<td>4</td>
<td>In preparation</td>
</tr>
</tbody>
</table>

Total in the Ocean Basin: 265

---

This test requires superstructure and container on deck

Preliminary schedule week 48/49 2014
Model testing in the Towing Tank

Regular waves for drift force tests (DTC)

### Table

<table>
<thead>
<tr>
<th>$T_h$ [s]</th>
<th>$T_m$ [s]</th>
<th>$\lambda_h$ [m]</th>
<th>$\lambda_m$ [m]</th>
<th>$\lambda/H_m$ [-]</th>
<th>$H_h$ [m]</th>
<th>$H_m$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.71</td>
<td>1.97</td>
<td>385.10</td>
<td>6.05</td>
<td>1.08</td>
<td>12.00</td>
<td>0.189</td>
</tr>
<tr>
<td>13.41</td>
<td>3.74</td>
<td>280.67</td>
<td>4.41</td>
<td>0.79</td>
<td>12.00</td>
<td>0.189</td>
</tr>
<tr>
<td>12.92</td>
<td>3.88</td>
<td>260.53</td>
<td>4.09</td>
<td>0.73</td>
<td>12.00</td>
<td>0.189</td>
</tr>
<tr>
<td>10.00</td>
<td>1.25</td>
<td>156.08</td>
<td>2.45</td>
<td>0.44</td>
<td>12.00</td>
<td>0.189</td>
</tr>
<tr>
<td>9.00</td>
<td>1.13</td>
<td>126.42</td>
<td>1.99</td>
<td>0.36</td>
<td>10.00</td>
<td>0.157</td>
</tr>
<tr>
<td>8.00</td>
<td>1.00</td>
<td>99.89</td>
<td>1.57</td>
<td>0.28</td>
<td>7.50</td>
<td>0.118</td>
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<tr>
<td>7.00</td>
<td>0.88</td>
<td>76.48</td>
<td>1.20</td>
<td>0.22</td>
<td>5.00</td>
<td>0.079</td>
</tr>
<tr>
<td>5.00</td>
<td>0.63</td>
<td>39.02</td>
<td>0.61</td>
<td>0.11</td>
<td>1.50</td>
<td>0.024</td>
</tr>
</tbody>
</table>

### Chart

**REGULAR WAVES, BM2, Model scale**

- **BM2 D=5.0m**
- **BM2 D=1.5m**
- **BM2 D=0.8m**
- **Client specified**

---

Model testing in the Ocean Basin

Regular waves for drift force tests (DTC)

Year 1 Workshop,
Hamburg, 30th October 2014

Experimental Studies
Model testing in the Ocean Basin
Drift Force Tests
Model testing in the Ocean Basin
Drift Force Tests (DTC)

Preview of preliminary drift force data for 0kn – 30 (150) deg

Please note: The presented raw data has been extracted during testing and has not been postprocessed. The actual wave in the basin has not been considered.

Model testing in the Ocean Basin
Drift Force Tests (DTC)

Preview of preliminary drift force data for 0kn – 60 (120) deg

Please note: The presented raw data has been extracted during testing and has not been postprocessed. The actual wave in the basin has not been considered.
Model testing in the Ocean Basin
Drift Force Tests (DTC)

Preview of preliminary drift force data for 0kn – 90 deg

Please note: The presented raw data has been extracted during testing and has not been postprocessed. The actual wave in the basin has not been considered.

---

Year 1 Workshop,
Hamburg, 30th October 2014

Model testing in the Ocean Basin
Drift Force Tests (DTC)

Preview of preliminary drift force data for 0kn – 120 (60) deg

Please note: The presented raw data has been extracted during testing and has not been postprocessed. The actual wave in the basin has not been considered.
Model production
KVLCC2 hull (1:80)

- Hull model
- 1 propeller
- 1 rudder
- Superstructure

| Main particulars at Scantling Draught for full scale and model scale 1:80 |
|-----------------|-------|-------|-------|-------|-------|-------|
|                  | Lₚₚ [m] | Bₚₚ [m] | T [m] | V [m³] | S [m²] | CB [-]       | dₛ [m] |
| Full Scale       | 320.0   | 58.0    | 20.8  | 312622 | 27194  | 0.8098       | 9.86   |
| Model Scale      | 4.0     | 0.725   | 0.26  | 0.61   | 4.25   | 0.8098       | 0.123  |

Year 1 Workshop,
Hamburg, 30th October 2014

Tests in the Ship Dynamics Laboratory
(deep water conditions)

- Inaugurated in 1992
- Dedicated to maneuvering, seakeeping and offshore tests

Main elements:
- Basin (150 x 30 x 5 m with 10 x 10 x 10 m pit)
- Computerized Planar Motion Carriage (CPMC) in 3 DOF for automatic or manual tracking
- Wave maker with 60 flaps, snake motion for regular waves and irregular 2D and 3D spectra
Model testing

Waves for added resistance and drift force tests (KVLCC2)

3 JONSWAP spectra for head seas and 6kn at scantling draught:

<table>
<thead>
<tr>
<th>$T_p$ [s]</th>
<th>$T_p$ [s]</th>
<th>$H_s$ [m]</th>
<th>$H_m$ [m]</th>
<th>$\gamma$ [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.50</td>
<td>0.73</td>
<td>2.00</td>
<td>0.025</td>
<td>1.59</td>
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<tr>
<td>9.50</td>
<td>1.06</td>
<td>5.00</td>
<td>0.063</td>
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<tr>
<td>12.50</td>
<td>1.40</td>
<td>10.00</td>
<td>0.125</td>
<td>3.33</td>
</tr>
</tbody>
</table>

Regular wave periods for drift forces at 0kn and scantling draught (under discussion):

<table>
<thead>
<tr>
<th>180°</th>
<th>150°</th>
<th>120°</th>
<th>90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.708</td>
<td>15.708</td>
<td>12.566</td>
<td>12.566</td>
</tr>
<tr>
<td>12.566</td>
<td>12.566</td>
<td>11.424</td>
<td>11.424</td>
</tr>
<tr>
<td>10.472</td>
<td>10.472</td>
<td>10.472</td>
<td>10.472</td>
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<tr>
<td>7.854</td>
<td>7.854</td>
<td>7.854</td>
<td>7.854</td>
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<tr>
<td>6.283</td>
<td>6.283</td>
<td>6.283</td>
<td>6.283</td>
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<tr>
<td>5.236</td>
<td>5.236</td>
<td>5.236</td>
<td>5.236</td>
</tr>
<tr>
<td>4.488</td>
<td>4.488</td>
<td>4.488</td>
<td>4.488</td>
</tr>
</tbody>
</table>
Model production

DTC hull (1:89.11)

- Hull model
- 1 propeller
- 1 rudder
- Segmented bilge keels

Main particulars at DWL for full scale and model scale 1:89.11

<table>
<thead>
<tr>
<th></th>
<th>Full Scale</th>
<th>Model Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyy [m]</td>
<td>355.0</td>
<td>3.98</td>
</tr>
<tr>
<td>Bxx [m]</td>
<td>51.0</td>
<td>0.57</td>
</tr>
<tr>
<td>T [m]</td>
<td>14.5</td>
<td>0.16</td>
</tr>
<tr>
<td>V [m³]</td>
<td>173467</td>
<td>0.25</td>
</tr>
<tr>
<td>S [m²]</td>
<td>22032</td>
<td>2.77</td>
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<tr>
<td>CB [-]</td>
<td>0.661</td>
<td>0.661</td>
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<tr>
<td>Dd [m]</td>
<td>8.911</td>
<td>0.10</td>
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</table>

Year 1 Workshop,
Hamburg, 30th October 2014

TUB

ROPAX hull (1:25)

- Hull model

Main particulars at Max Load for full scale and model scale 1:25

<table>
<thead>
<tr>
<th></th>
<th>Full Scale</th>
<th>Model Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyy [m]</td>
<td>90.0</td>
<td>3.60</td>
</tr>
<tr>
<td>Bxx [m]</td>
<td>17.82</td>
<td>0.71</td>
</tr>
<tr>
<td>T [m]</td>
<td>4.19</td>
<td>0.17</td>
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<tr>
<td>V [m³]</td>
<td>3756</td>
<td>0.24</td>
</tr>
<tr>
<td>S [m²]</td>
<td>1763</td>
<td>2.82</td>
</tr>
<tr>
<td>CB [-]</td>
<td>3.0</td>
<td>0.56</td>
</tr>
<tr>
<td>Dd [m]</td>
<td>3.0</td>
<td>0.12</td>
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</table>

Year 1 Workshop,
Hamburg, 30th October 2014
Tests in the Seakeeping Basin
(shallow water)

- Electrically driven wave maker with three boards, allowing flap type as well as piston type mode
- Electrically driven towing carriage with optical motion sensor system ($v_{\text{max}} = 4 \text{ m/s}$)

Length: 120 m  Width: 8 m  Depth: 1.1 m

Model testing

<table>
<thead>
<tr>
<th>Tests</th>
<th>Test Parameters</th>
<th>No. of Tests</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTC, shallow water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28. Resistance in calm water (+surge acceleration)</td>
<td>Design draught and Ballast, 6kn – 16kn</td>
<td>4</td>
<td>In preparation</td>
</tr>
<tr>
<td>29. Added resistance in regular waves</td>
<td>Design draught additional wave height (+2 wave height +2)</td>
<td>66</td>
<td>In preparation</td>
</tr>
<tr>
<td>30. Drift forces in regular waves</td>
<td>Design draught height (+2 additional wave height)</td>
<td>110</td>
<td>In preparation</td>
</tr>
<tr>
<td>31. Bollard pull and rudder forces in calm water</td>
<td>Design draught from 0° to 35°</td>
<td>3</td>
<td>In preparation</td>
</tr>
<tr>
<td>Total at TUB</td>
<td></td>
<td>183</td>
<td>In preparation</td>
</tr>
</tbody>
</table>

Preliminary schedule
December 2014
Development of a new measuring device for mean wave forces

- 2 Y-carriages held by tension springs
- 1 ΔX-carriage on each Y-carriage
- Connection to model via vertical shafts on ΔX-carriages
- 1 ΔX carriage with tension springs serves as towing post

Development of a data evaluation software

Model production

KVLCC2 hull (1:75)

- Existing hull model

| Main particulars at Scantling Draught for full scale and model scale 1:75 |
|-----------------|---------|------|-------------|-----|-----------------|-----|
|                 | $L_{pp}$ [m] | $B_{WS}$ [m] | $T$ [m] | $V$ [m$^3$] | $S$ [m$^2$] | $CB$ [-] | $d_p$ [m] |
| Full Scale      | 320.0     | 58.0  | 20.8     | 312622 | 27194 | 0.8098 | 9.86 |
| Model Scale     | 4.27      | 0.77  | 0.28     | 0.74  | 4.83  | 0.8098 | 0.13 |
Tests in the Towing Tank (shallow water)

- Planar motion carriage
- Electro-hydraulic wave generator
- Auxiliary devices for ship-ship interaction

Length: 87.5 m  Width: 7.0 m  Depth: 0.5 m

Model testing

<table>
<thead>
<tr>
<th>Tests</th>
<th>Test Parameters</th>
<th>No. of Tests</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>KVLCC2, shallow water</td>
<td>Scantling, 6kn and 12kn, 2 water depths</td>
<td>4</td>
<td>In preparation</td>
</tr>
<tr>
<td>32. Resistance in calm water (+surge acceleration)</td>
<td>Scantling, 180°, 0kn – 6kn – 12kn, 7 wave periods, 1 wave height (+2 additional wave heights for RAO peak and shortest wave), 2 water depths</td>
<td>66</td>
<td>In preparation</td>
</tr>
<tr>
<td>33. Added resistance in regular waves</td>
<td>Scantling, 180°, 0kn – 6kn – 12kn, 7 wave periods, 1 wave height (+2 additional wave heights for RAO peak and shortest wave), 1 water depth</td>
<td>110</td>
<td>In preparation</td>
</tr>
<tr>
<td>34. Drift forces in regular waves</td>
<td>Scantling and Heavy Ballast, 30° - 60° - 90° - 120° - 150°, 0kn, 7 wave periods, 1 wave height (+2 additional wave heights for RAO peak and shortest wave), 1 water depth</td>
<td>10</td>
<td>In preparation</td>
</tr>
<tr>
<td>35. Propulsion in calm water</td>
<td>Scantling, 30% - 40% - 65% - 75% - 85% - 100% rpm, 2 water depths</td>
<td>14</td>
<td>In preparation</td>
</tr>
<tr>
<td>36. Propulsion and speed loss in regular waves</td>
<td>Scantling, 180°, 30% - 75% - 100% rpm, 7 wave periods, 1 wave height, 2 water depths</td>
<td>42</td>
<td>In preparation</td>
</tr>
<tr>
<td>37. Bollard pull and rubber forces in calm water</td>
<td>Scantling, 30% - 75% - 100% rpm, slow continuous increase of rubber angle from 0° to 35°</td>
<td>3</td>
<td>In preparation</td>
</tr>
<tr>
<td>38. PMM tests in calm water</td>
<td>Scantling, 2 water depths</td>
<td>100</td>
<td>In preparation</td>
</tr>
<tr>
<td>DTC, shallow water</td>
<td>Design draught, 6kn and 16kn, 2 water depths</td>
<td>4</td>
<td>In preparation</td>
</tr>
<tr>
<td>39. Resistance tests in calm water</td>
<td>Design draught, 180°, 0kn – 16kn – 16kn, 7 wave periods, 1 wave height (+2 additional wave heights for RAO peak and shortest wave), 2 water depths</td>
<td>66</td>
<td>In preparation</td>
</tr>
<tr>
<td>40. Added resistance in regular waves</td>
<td>Design draught, 180°, 0kn – 16kn – 16kn, 7 wave periods, 1 wave height (+2 additional wave heights for RAO peak and shortest wave), 2 water depths</td>
<td>14</td>
<td>In preparation</td>
</tr>
<tr>
<td>41. Propulsion in calm water</td>
<td>Design draught, 30% - 40% - 65% - 75% - 85% - 100% rpm, 2 water depths</td>
<td>42</td>
<td>In preparation</td>
</tr>
<tr>
<td>42. Propulsion and speed loss in regular waves</td>
<td>Design draught, 180°, 30% - 75% - 100% rpm, 7 wave periods, 1 wave height, 2 water depths</td>
<td>42</td>
<td>In preparation</td>
</tr>
<tr>
<td>43. PMM tests in calm water</td>
<td>Design draught, 2 water depths</td>
<td>100</td>
<td>In preparation</td>
</tr>
<tr>
<td>Total at EVFH</td>
<td></td>
<td>565</td>
<td>In preparation</td>
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</tbody>
</table>
Thank you very much for your attention!
References


