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EVALUATION OF REQUIRED POWER IN ADVERSE CONDITIONS

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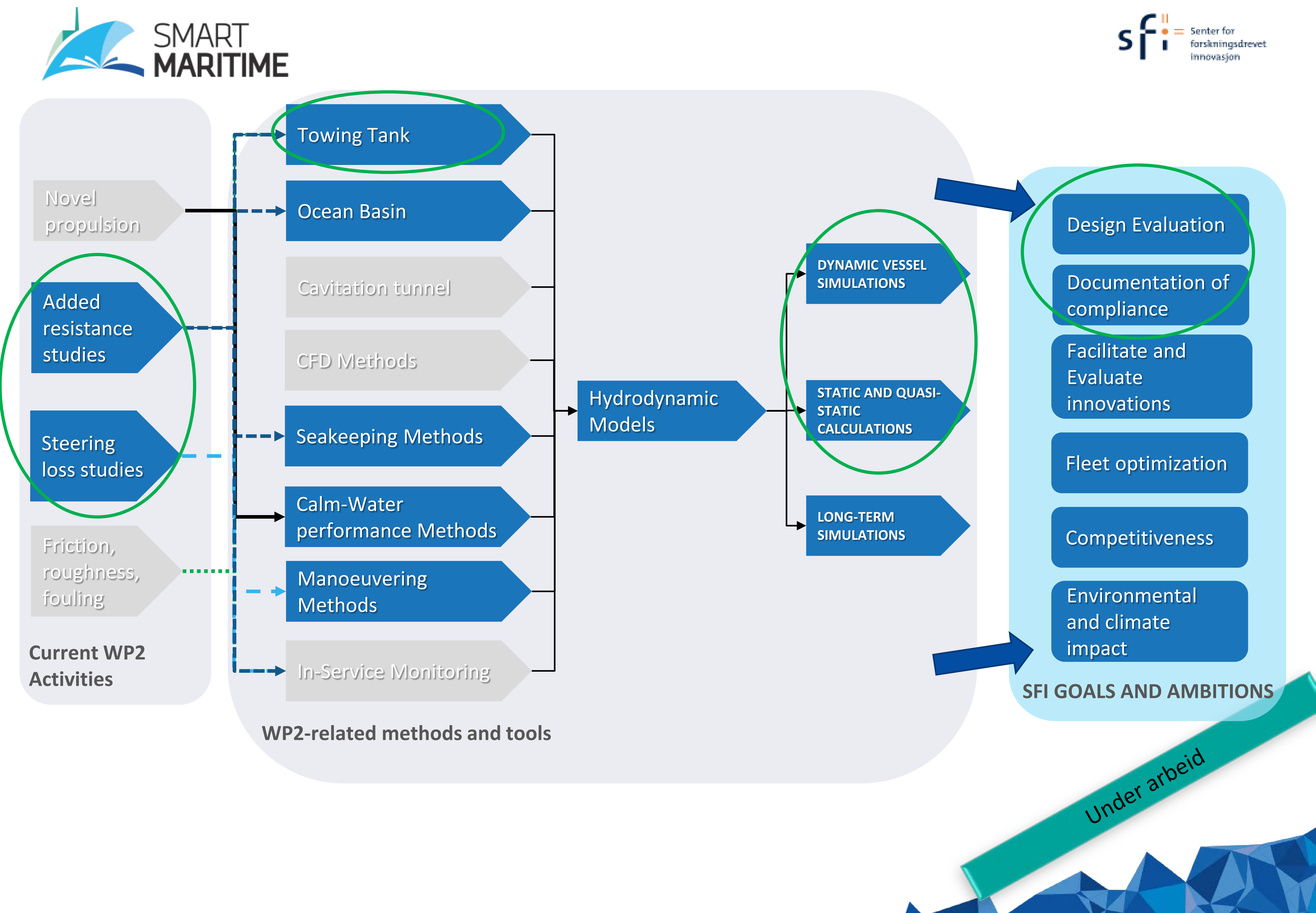
SAC MEETING 20-09-2018

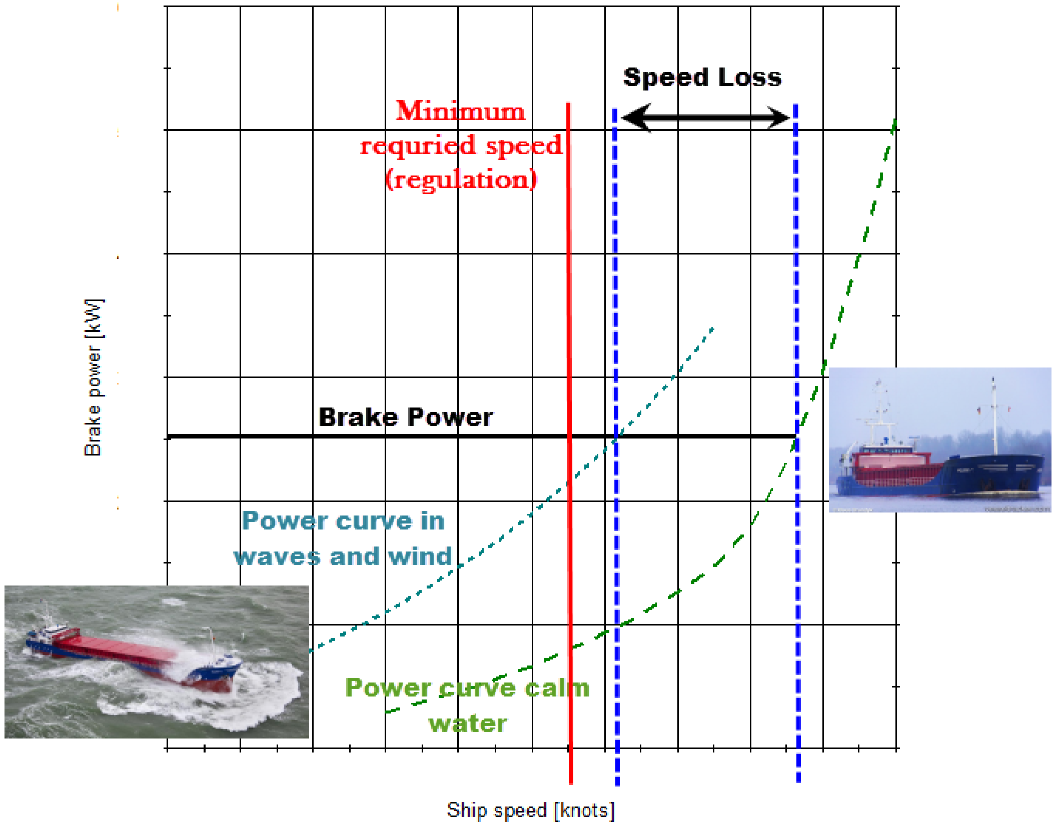
Background for the study and webinar

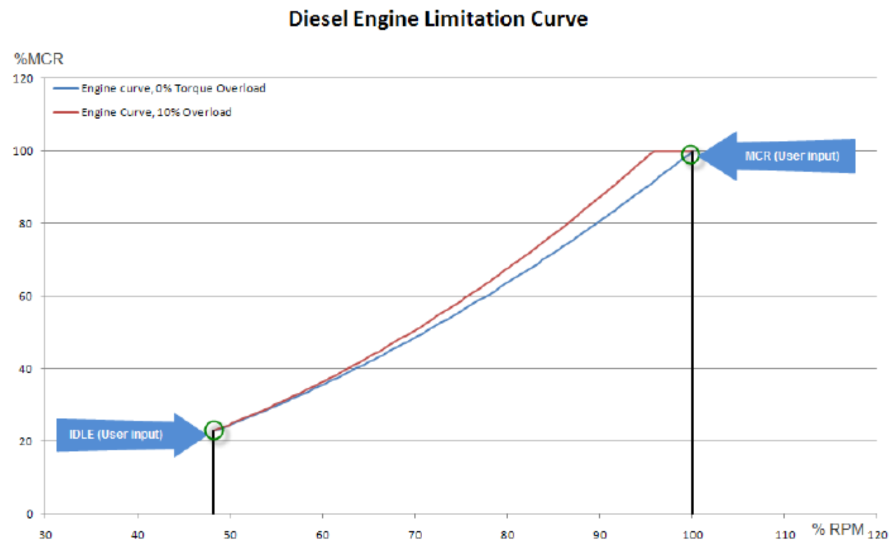
- We received several requests and questions related to the SRtP requirement, from the SFI design partners
- The questions involve hydrodynamic problems that we have focused on in the SFI
- The EEDI-related "Minimum propulsion power" for bulkers and tankers has many similarities to SRtP, and is important for SFI shipowner partners
- A good testcase was available through one of the SFI partners, making it possible to compare tools with different levels of fidelity


SMART MARITIME
Senter for forskningsdrevet innovasjon
Novel propulsion
Added resistance studies
Steering loss studies
Friction, roughness, fouling
Current WP2 Activities
Towing Tank
Ocean Basin
Cavitation tunnel
CFD Methods
Seakeeping Methods
Calm-Water performance Methods
Manoeuvering Methods
In-Service Monitoring
WP2-related methods and tools
Hydrodynamic Models
DYNAMIC VESSEL SIMULATIONS
STATIC AND QUASI-STATIC CALCULATIONS
LONG-TERM SIMULATIONS
Design Evaluation
Documentation of compliance
Facilitate and Evaluate innovations
Fleet optimization
Competitiveness
Environmental and climate impact
SFI GOALS AND AMBITIONS
Under arbeid

SRtP Propulsion and Minimum reuired Propulsion Power

- The framework is in principle simple; Prove that the vessel has sufficient available power and torque to maintain a specific speed in a specific weather condition (in head seas)





From calm water to BF8

estimates / Early Stage calculations

Comparison Ship/Hollenbach/Holtrop etc

Propeller Serie and estimated w, t.

Estimation of Cair, Brix etc

Empirical methods, Kwon, STAWAVE, etc

Propulsion point, estimate

Other Losses (steering etc)

Power and torque in defined Sea State

Calm Water Resistance

Propulsion efficiency in calm water

Wind Resistance

Added Resistance in Waves

Propulsion Loss in Waves

Other Losses (steering etc)

Power and torque in defined Sea State

High fidelity / Verification Stage

Standard Model Tests or CFD

Typically Model Tests

Wind Tunnel Tests / CFD / Brix

Model Tests / CFD / "Recognized Method"

Model Tests or simulations

Model Tests or estimates

Power and torque in defined Sea State

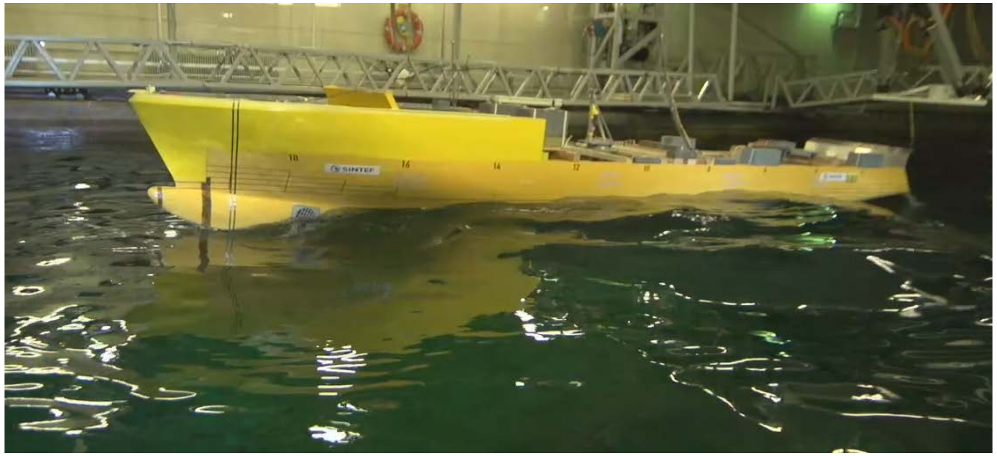
Case study - intentions

- Test and compare various approaches, especially related to added resistance due to waves
- Compare magnitudes of the resistance components
- Evaluate the effect of simplifications and assumptions
- Evaluate the effect of different sea state definitions

Case Vessel

- ~140m Cruise Vessel
- Twin screw propeller/rudder configuration
- Extensive Safe Return to Port model test program in addition to performance and seakeeping tests, allowing evaluation of SRtP through several approaches:
    - Propulsion test in SRtP condition
    - Towing tests in calm water and SRtP condition
    - Towing tests with locked propellers

Case Vessel Flow1 – Propulsion in BF8

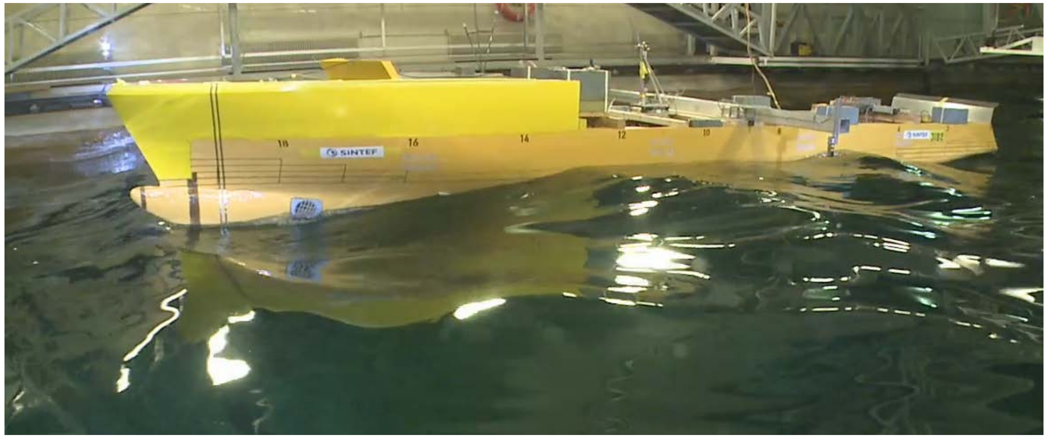


- Free running propulsion test with autopilot
- The model tests are set up to represent the complete SRtP condition
- One propeller is locked or watermilling (latter requires estimate of braking torque)
- Constant RPM (or power) is applied to the working propeller
- A fan applies the wind force, as well as friction correction (towrope force)
- Propulsive losses, required power, torque etc follows directly from the measurements
- Motions and accelerations are typically also measured and evaluated

Calm Water Resistance
↓
Propulsion efficiency in calm water
↓
Wind Resistance
↓
Added Resistance in Waves
↓
Propulsion Loss in Waves
↓
Other Losses (steering etc)
↓
Power and torque in Required Sea State

All included in free running tests in waves

Case Vessel Flow2 – Resistance in BF8



- Towing test in waves are carried out, either in the SRtP irregular wave condition or in regular waves to derive the ARO
- The tests are carried out without propellers, but towing test with locked propeller can be carried out to measure the corresponding drag
- Propulsion losses or steering losses are not accounted for
- The advantage of this method is that other wave (when ARO is derived) and wind conditions can easily be calculated for.

Calm Water Resistance

Propulsion efficiency in calm water

From standard performance tests

Wind Resistance

Calculated and added in prediction

Added Resistance in Waves

From towing test(s) in waves

Propulsion Loss in Waves

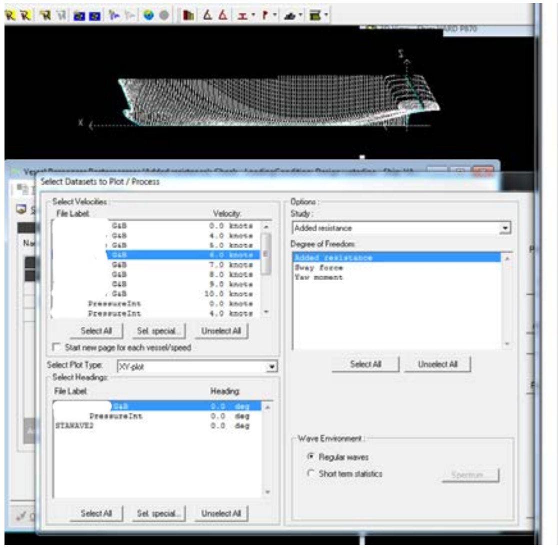
only difference in eta0. w and t from calm water tests

Other Losses (steering etc)

Added resistance of locked propeller can be included from test

Power and torque in Required Sea State

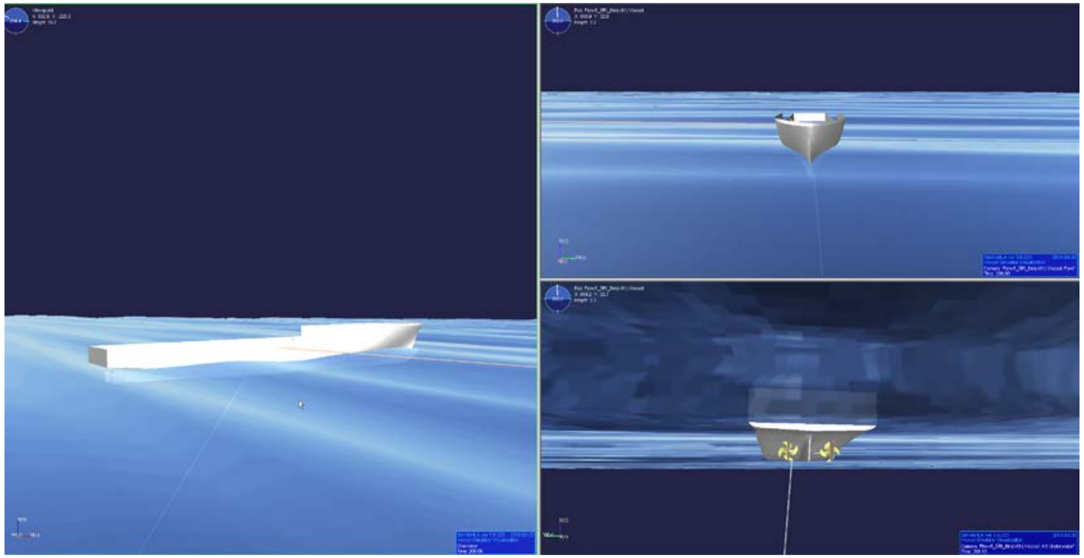
Case Vessel Flow4 G&B Frequency Domain



- Added resistance transfer function is calculated (VERES G&B in this case, other methods may be CFD, 3d panel codes, STA2 – But needs to be accepted by class)
- Towing test with locked propeller can be carried out to measure the corresponding drag
- Propulsion losses (except for change in propulsion point) or steering losses are not accounted for (ventilation model can be applied)
- The setup allows calculations for arbitrary wave conditions and wind speeds (and headings)
- Calculation of mean forces, power and torque in frequency domain

Calm Water Resistance	From standard performance tests
Propulsion efficiency in calm water	From standard performance tests
Wind Resistance	Calculated and added in prediction
Added Resistance in Waves	Calculated by VERES (G&B)
Propulsion Loss in Waves	only difference in eta0. w and t from calm water tests. Ventilation model can be included
Other Losses (steering etc)	Added resistance of locked propeller can be included from test or estimate
Power and torque in Required Sea State	

Case Vessel Flow5 G&B Time Domain



- Added resistance transfer function is calculated (VERES G&B in this case, other methods may be 3d panel codes, CFD, STA2 – But needs to be accepted by class in the documentation stage)
- Drag on dead propeller/rudder by numerical model
- Propulsion losses are accounted for where modelled
- The setup allows calculations for arbitrary wave conditions and wind speeds (and headings)
- Calculation of mean forces, power and torque from the time series output. As the propulsion test, it allows for investigating for instance speed variations, maximum values as well

Calm Water Resistance

Propulsion efficiency in calm water

From standard performance tests

Wind Resistance

Calculated and added in prediction

Added Resistance in Waves

Calculated by VERES (G&B)

Propulsion Loss in Waves

Accounted for where modelled

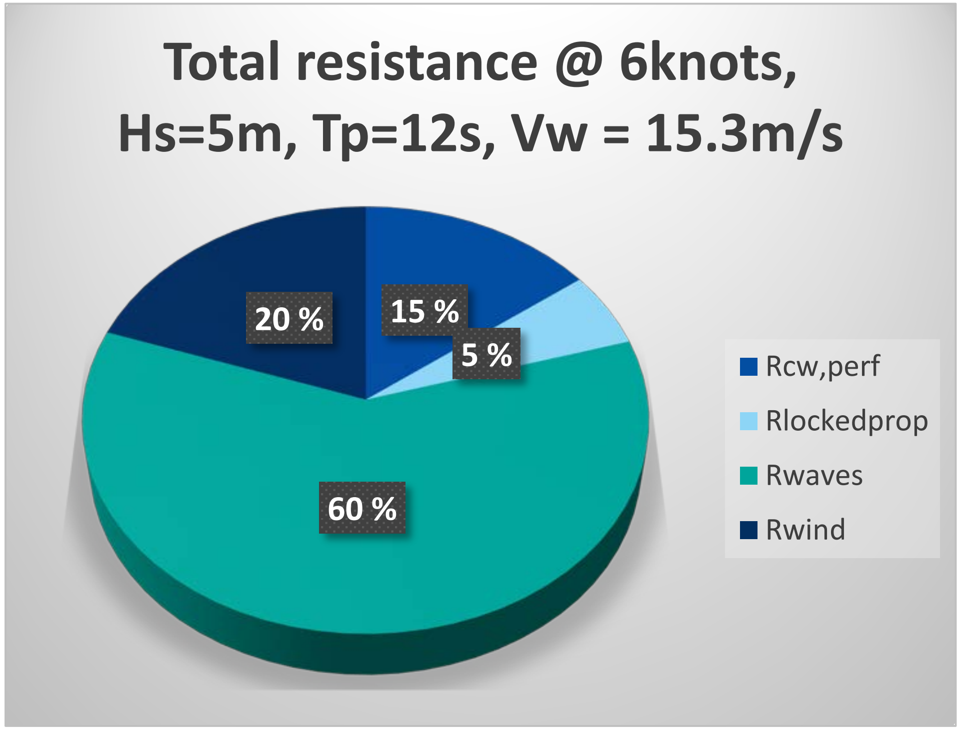
Other Losses (steering etc)

Accounted for where modelled

Power and torque in Required Sea State

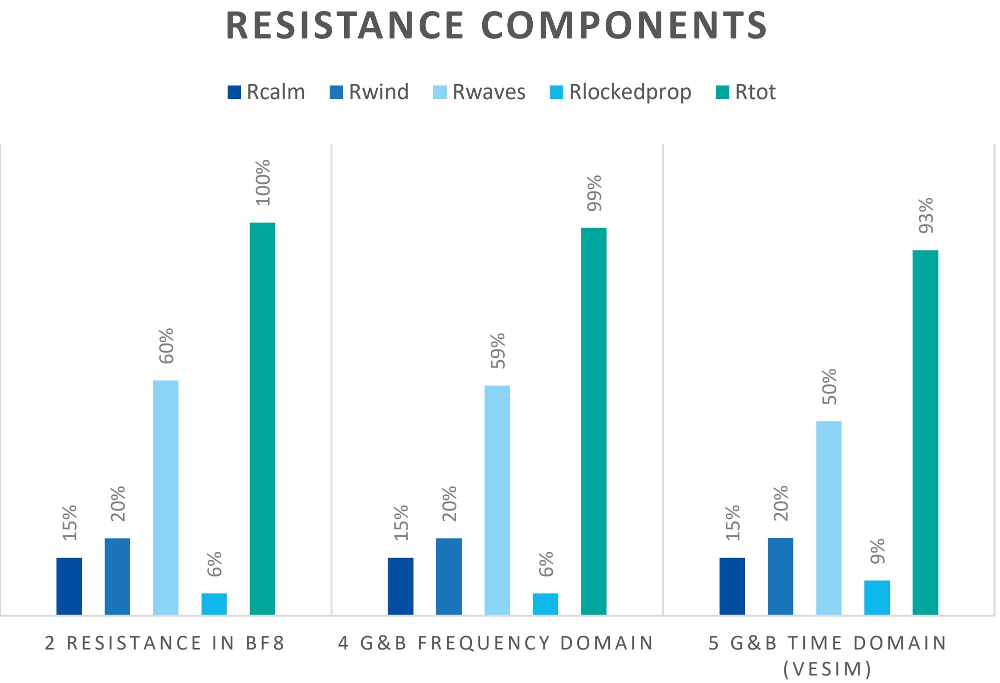
Example Case, main findings
- Resistance components

- The total resistance is in this case dominated by the added resistance in waves (~60%)
- Wind resistance is the second largest (~20%)
- The drag of the dead propeller (including interactions) accounts for about 5%, Correspond to a drag coefficient of about 0.55.
- In such low speeds, the calm water resistance is relatively small



Case vessel – Added resistance in waves

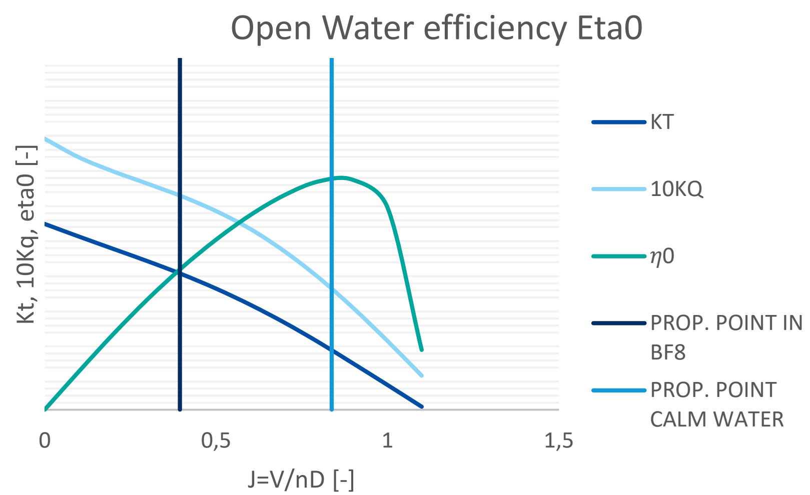
- Added resistance due to waves is the largest component in this situation
- It is also challenging to predict, however G&B method give very similar results to the model test in this case.
- The average resistance in the time domain simulations is noticably lower than in the frequency domain

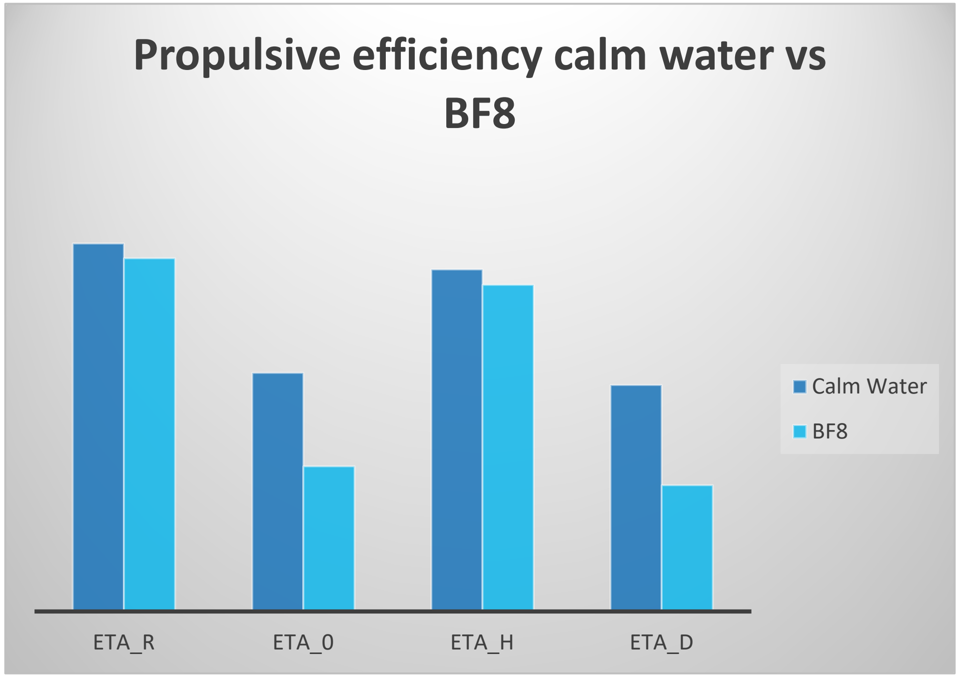


Example Case, main findings
- Propulsive efficiency

- Small reductions in relative rotative efficiency and hull efficiency are seen

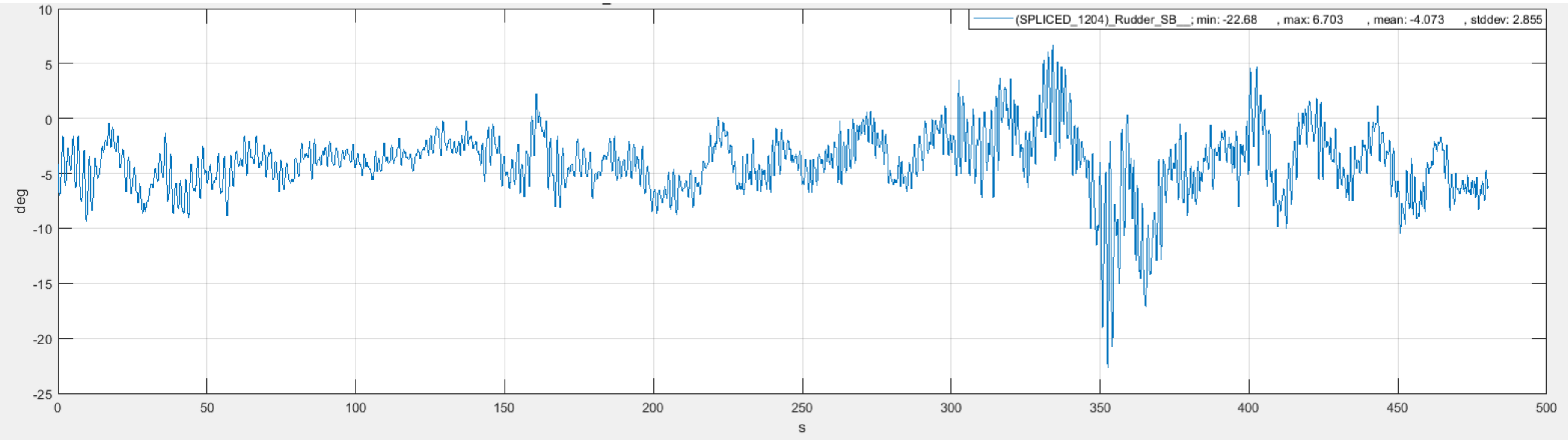
- The open water efficiency is significantly reduced as the propulsion point becomes less favorable, due to increased resistance and only one working propeller





*The total propulsive efficiency $\eta D = \eta R \times \eta 0 \times \eta H$,
$\eta H = (1-t)/(1-w)$

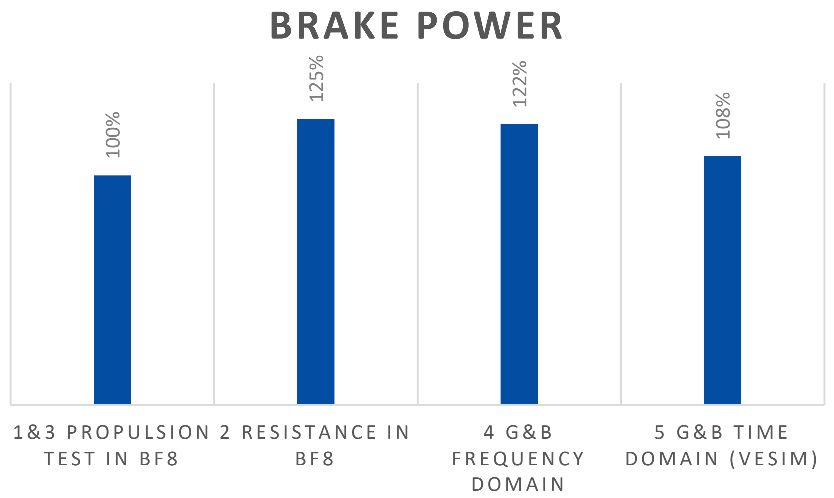
Steering losses

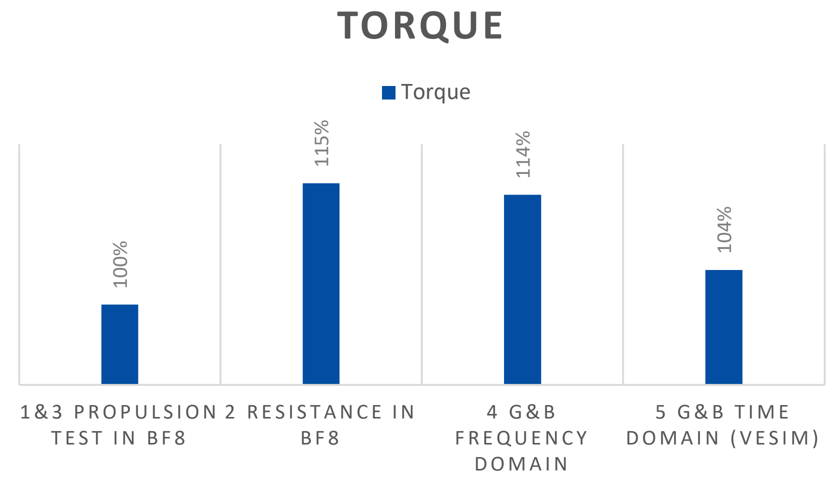


- The working rudder needs to counteract the induced moment from only one working propeller (and drag from the faulty propeller)
- The propulsion model test show an average of 4 degrees. Added drag resulting from the average rudder angle is thus relatively small
- Note that this is only part of what can be called "steering losses" which also include drag due to yawing, dynamic losses or loss in propeller efficiency.

Predicted Power @ 6knots in BF8 by various Methods

- The brake power needed to maintain 6 knots in BF8 is overpredicted in this case by applying added resistance from towing in BF8 directly, and by frequency domain calculations (these two approaches are in many ways similar)
- The predicted power by Time Domain simulations are closer to the propulsion test in BF8
- Part of the remaining difference between Propulsion test and time domain simulations is explained by the drag of dead propulsor which is higher in the simulation

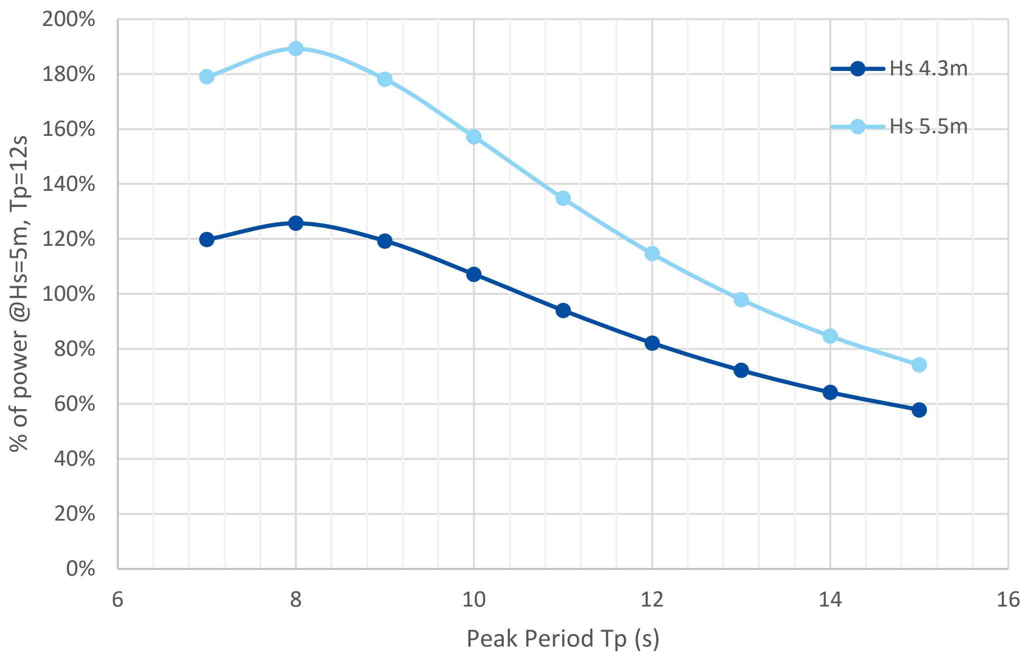




Sensitivity, choice of sea state

- The original definition of BF8 describes a range of wind, wave heights and wave periods:
  - Hs between 4.3m – 5.5m
  - Peak periods 7 – 15 seconds (depending on Hs)
  - Wind speeds 16 – 21 m/s

- The choice of sea state has significant influence on the required power (and the relative magnitudes of wind/wave resistance)



Some conclusions from SRtP case study

- Resistance of the dead propeller in the case study accounts for about 5% of the total resistance (or put in another way, about a third of the calm water resistance of the ship in 6 knots)

- Added resistance due to waves is the largest component, in the case study it accounts for 60% of the total resistance. Selection of method for determining the added resistance is therefore important

- Frequency domain calculations and towing tests in irregular waves overpredict the added resistance versus what is experienced by the vessel when propelled, as also found in earlier studies. In the case study, this effect seems to be larger than the effect of neglecting losses such as steering, etc.

- Starting with simple, slightly conservative methods makes sense. Should the results indicate that the requirements are not met, or the margins are low, moving further to model tests/time domain simulations would be the natural next step.

- The definition of the sea state (wave height, wave period and wind) has significant influence on the required power, while still within BF8 ranges.

IMO Res. MEPC.232 “minimum required propulsion power”

- Regulation to verify that ships, complying with EEDI requirements set out in regulations on Energy Efficiency for Ships, have sufficient installed propulsion power to maintain the manoeuvrability in adverse conditions

- Applicable to <u>oil tankers, bulk carriers and combination carriers having more than 20,000 DWT</u>

Definition of "Adverse conditions"

1 Definition

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

Significant wave height h_s, m	Peak wave period T_P, s	Mean wind speed V_w, m/s
5.5	7.0 to 15.0	19.0

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.

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

Two optional assesment levels

- Assessment level 1 – minimum power lines assessment
  - Conservative value of minimum installed power based on a simple expression:

Minimum Power Line Value = $a \times (DWT) + b$

Where:

DWT is the deadweight of the ship in metric tons; and
a and *b* are the parameters given in table 1 for tankers, bulk carriers and combination carriers.

Table 1: Parameters a and b for determination of the minimum power line values for the different ship types

Ship type	a	b
Bulk carrier which DWT is less than 145,000	0.0763	3374.3
Bulk carrier which DWT is 145,000 and over	0.0490	7329.0
Tanker	0.0652	5960.2
Combination Carrier	see tanker above	

"

The total installed MCR of all main propulsion engines should not be less than the minimum power line value, where MCR is the value specified on the EIAPP Certificate.

Two optional assesment levels

- Assessment level 2 – simplified assessment
  - "The simplified assessment procedure is based on the principle that, if the ship has sufficient installed power to move with a certain advance speed in head waves and wind, the ship will also be able to keep course in waves and wind from any other direction"

  - The required advance speed is determined as the larger of:
    - 4 knots ("minimum navigational speed")
    - "minimum course-keeping speed", calculated as follows:

$$V_{ck} = V_{ck,\,ref} - 10.0 \times (A_{R\%} - 0.9) \qquad (1)$$

where V_{ck} in knots, is the minimum course-keeping speed, $V_{ck,\,ref}$ in knots, is the reference course-keeping speed, and $A_{R\%}$ is the actual rudder area, A_R, as percentage of the submerged lateral area of the ship corrected for breadth effect, $A_{LS,\,cor}$, calculated as $A_{R\%} = A_R/A_{LS,\,cor} \cdot 100\%$. The submerged lateral area corrected for breadth effect is calculated as $A_{LS,\,cor} = L_{pp}T_m(1.0+25.0(B_{wl}/L_{pp})^2)$, where L_{pp} is the length between perpendiculars in m, B_{wl} is the water line breadth in m and T_m is the draft a midship in m. In case of high-lift rudders or other alternative steering devices, the equivalent rudder area to the conventional rudder area is to be used.

3.7 The reference course-keeping speed $V_{ck,\,ref}$ for bulk carriers, tankers and combination carriers is defined, depending on the ratio A_{FW}/A_{LW} of the frontal windage area, A_{FW}, to the lateral windage area, A_{LW}, as follows:

.1 9.0 knots for A_{FW}/A_{LW} =0.1 and below and 4.0 knots for A_{FW}/A_{LW}=0.40 and above; and

.2 linearly interpolated between 0.1 and 0.4 for intermediate values of A_{FW}/A_{LW}.

Example case, ~200m x 32m Bulk Carrier

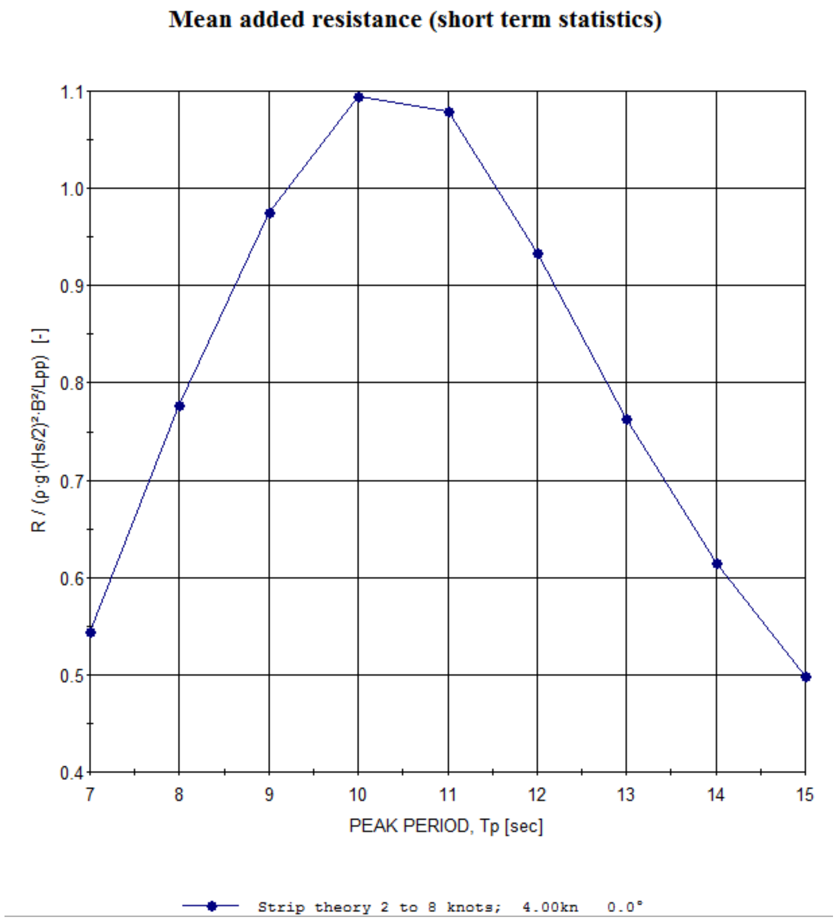
1.2 The following adverse condition should be applied to ships defined as the following threshold value of ship size.

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

- Relatively large rudder area => <u>Vnav = 4 knots</u> is the larger.

Example case, ~200m x 32m Bulk Carrier

- Peak period which gives highest added resistance (wave lengths close to ship length)



Example case, ~200m x 32m Bulk Carrier

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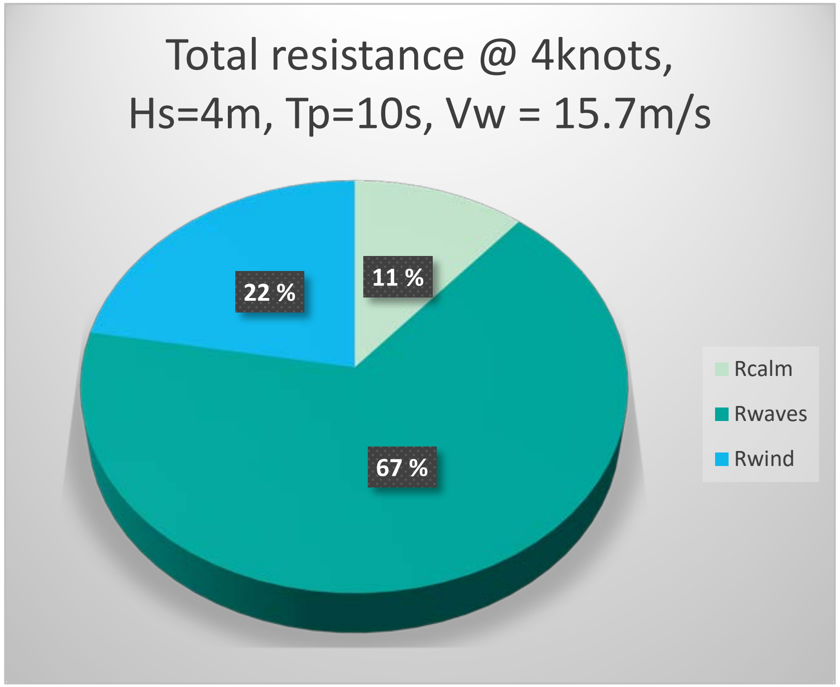

Example case, ~200m x 32m Bulk Carrier

Minimum Power Line Value = $a \times (DWT) + b$

Ship type	a	b
Bulk carrier which DWT is less than 145,000	0.0763	3374.3
Bulk carrier which DWT is 145,000 and over	0.0490	7329.0
Tanker	0.0652	5960.2
Combination Carrier	see tanker above	

- In the example case, Minimum power from this expression is about 7300 kW
- Calculated required power in this condition is only about 2000 kW, but the minimum power lines account for power and torque limitations at low RPM / High loading.

Example case 190m x 36m Car carrier

- Not under the IMO regulation for minimum power, but still an important issue
- As an example, using the IMO regulation would give the following condition:
  - Hs = 4.0m
  - Tp (most severe) = 11s
  - Wind Speed = 15.7 m/s
  - Minimum speed (Vck) = 5.1 knots

Example case 190m x 36m Car carrier

- Due to the large windage, wind resistance become increasingly important - even if this is only head seas and most severe wave period.