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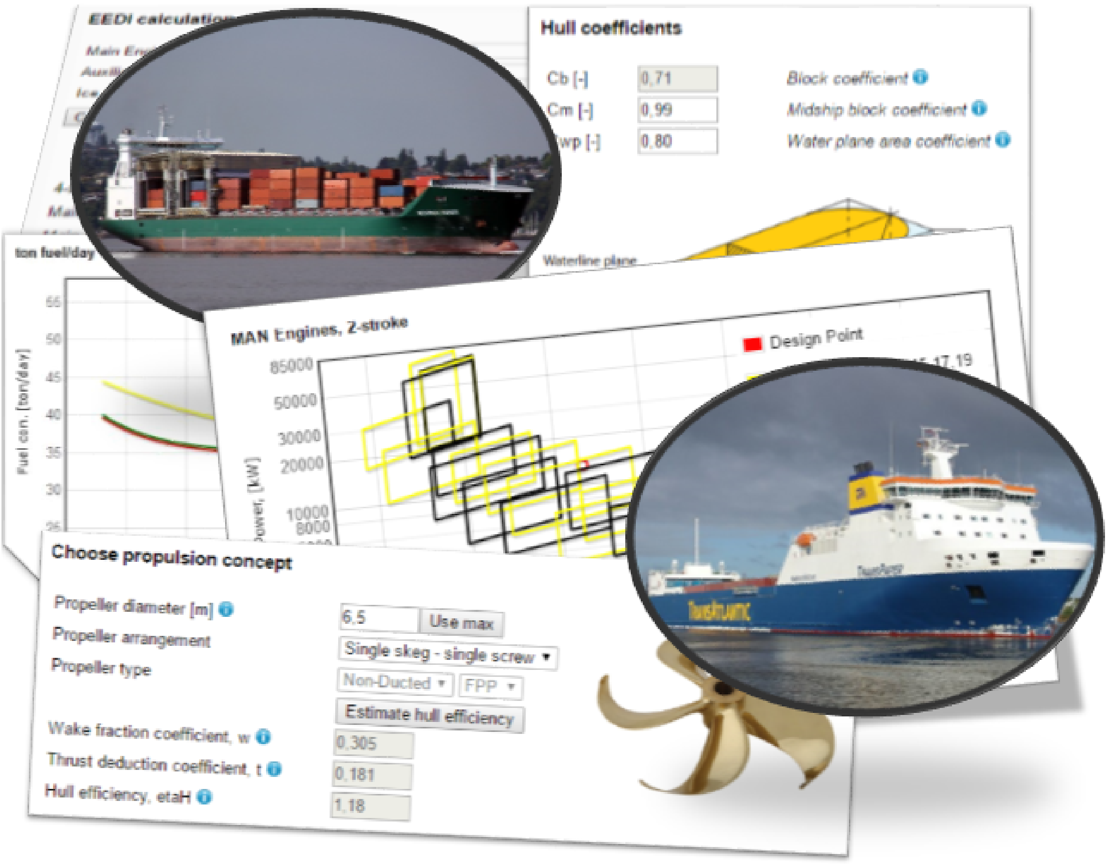

Design Evaluation Tool of Ship Concept

Master's Thesis in Naval Architecture and Ocean Engineering

Olle Valentin & Andreas Höglund

Department of Shipping and Marine Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

Master's Thesis X-16/346

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A report describing the web-based design tool

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Cover: Pictures of DEToSC and Reference ships

Abstract

Conventional merchant ship design is a complex process where each part of the process is strongly connected to the other. In order to achieve a good design everything needs to be put together in an understandable way. A web design tool is created and used for development of ship concept designs. With information about the transport mission it is possible to generate a complete ship through all the design steps with proposed hull forms, propeller concepts, main engines and get performance indicators such as fuel consumption and EEDI for the current ship.

Since a merchant ship has different loading conditions depending on the amount of cargo, and is operating in different weather conditions it is of big importance that the design is adapted to the right conditions. The user is able to specify the service conditions and design the propeller accordingly.

The web design tool is validated with three existing merchant vessels with good results. It will help naval architects to provide a quick concept at the early design phase and can be used in education to extend students knowledge in a more substantial way about merchant ship design.

Keywords: Ship design, hull resistance, propeller design, open water efficiency, main engine selection, block coefficient, deadweight estimation, advance coefficient, fuel consumption, design tool

Acknowledgements

This report is a part of the masters program Naval Architecture and Ocean Engineering as a master thesis. It stand for 30 credits and the project is performed together with the company ScandiNAOS AB. Deep appreciation to Bengt Ramne, Youming Huang, Joakim Bomanson, Per Fagerlund at ScandiNAOS AB for the opportunity to work with them with this project and the help provided to achieve this result. A special thanks to Mr Ramne who has provided us with great knowledge and extra guidance to perform this project.

Olle Valentin and Andreas Höglund, Gothenburg 25.05.16

Contents

List of Abbrevaitions

A_{OD}	The lateral projected area above the waterline
A_{XV}	Area of maximum transverse section exposed to the wind
A_{YV}	Projected lateral area above the waterline
C_{MC}	Horizontal distance from midship section to centre of lateral projected area AYV
C_B	Block coefficient
C_M	Midship section coefficient
C_{WP}	Waterplane area coefficient
η_M	Product of η_G and η_S
η_G	Gearing efficiency
η_S	Shaft efficiency
η_H	Hull efficiency
η_0	Open water efficiency
η_R	Relative rotative efficiency
η_S	Shaft efficiency
η_T	Total efficiency
H_{BR}	Height of top of superstructure
H_C	Height to center of lateral area
L_{OA}	Length Over All
L_{PP}	Length between perpendiculars
L_{WL}	Length at waterline
P_E	Effective power
ρ	Density of salt water 1025 kg/m3
V_A	Advance velocity
B	Beam

CPP	Controllable Pitch Propeller
DWT	Deadweight
D	Propeller diameter
DEToSC	Design Evaluation Tool of Ship Concept
EEDI	Energy efficiency design index
EAR	Blade area ratio
Fn	Froude number
FPP	Fixed Pitched Propeller
GUI	Graphical User Interface
ITTC	International Towing Tank Conference
J	Advance coefficient
KPI	Key Performance Indicators
KT	Dimensionless Thrust coefficient
KQ	Dimensionless Torque coefficient
LS	Lightship
MCR	Maximum continuous rating
n	Revolutions per minute
Ps	Propulsive power
P/D	pitch/diameter ratio
Ro-RO	Roll on and Roll of
Ro-pax	Roll on and Roll of and passenger
RAR	Added resistance, sum of RAA and RAW
RAA	Added resistance due to wind
RAW	Added resistance due to waves
RT	Total resistance
SFOC	Specific Fuel Oil Consumption

TD	Design draft
t	Thrust deduction
T	Thrust
V	Design speed
WC	Weight of cargo
w	Wake fraction

1

Introduction

The section introduces the project, by describing the projects background, purpose and objective. Also the methodology and limitations are brought up here.

1.1 Background

Merchant ship design is often a complex process where a lot of different competence areas has to be merged to fully utilize the potential of designing an effective and sustainable ship. Along the way of designing a ship there is a risk of missing important aspects due to the amount of participants in the design process. In the early design phase of the project it is difficult to know what the result will look like and what the outcome would be in terms of different key performance indicators (KPI). This information could be very helpful when setting up a ship design project, where expectations and hopes are not necessarily the same, and where calculations and budgets need to be accurate. An evaluation tool which in the early design phase can evaluate a conventional merchant ship from a ship's transport requirements, is not known to exist. Ship designers today often use their own documents, experiences, tools, expertise etc. when taking on a ship design mission. A web based tool where all these areas can meet, and be used by everyone to make an early evaluation of the ship is something that could be very helpful.

For students within the field of Naval Architecture there is a need of good resources to understand the complex processes within ship design. Since there are a lot of different competence areas that overlap each other it is important to give a clear and transparent view of the process when designing a new ship. If the student are given good tools and resources there is a greater chance that the

students even before graduation have good qualifications and understanding regarding ship design processes.
The ship design company ScandiNAOS AB have a desire to further develop their model that contain certain parts and suggests that further development of this model should be carried out into an evaluation tool. Therefore has this been suggested as a project for a master thesis.

1.2 Purpose

There are two important purposes when executing this project. The first is to assist ship designers around the globe to evaluate their merchant ships in an early design phase. Hull form, propeller arrangement, engine type and outcoming key performance indicators are aspects that will be generated and could help them estimating the ship outcome very early. The second purpose is, in an educational way, build competence and understanding regarding ship design amongst students within the Naval Architecture field where big focus is the educational part.

1.3 Objective

The objective of this project is to create a web based engineering tool for initial design of a merchant ship and provide important values for key performance indicators (KPIs) such as fuel consumption and emissions for transport work carried out. The objective is also that the web tool should be used in an educational way where the report works as a manual from which the users can get the details regarding the web tool's functions.

1.4 Methodology

Basic knowledge regarding ship design is a prerequisite for executing a project like this which is gained within the courses of the masters program Naval Architecture and Ocean Engineering. An overview of the ship design process is important to continue with the web tool development. By studying a lot of ship design literature, a theoretical framework could briefly be set up to continue the work. Specific design areas are identified and principles steps of ship design is set up according to Figure 1.1.

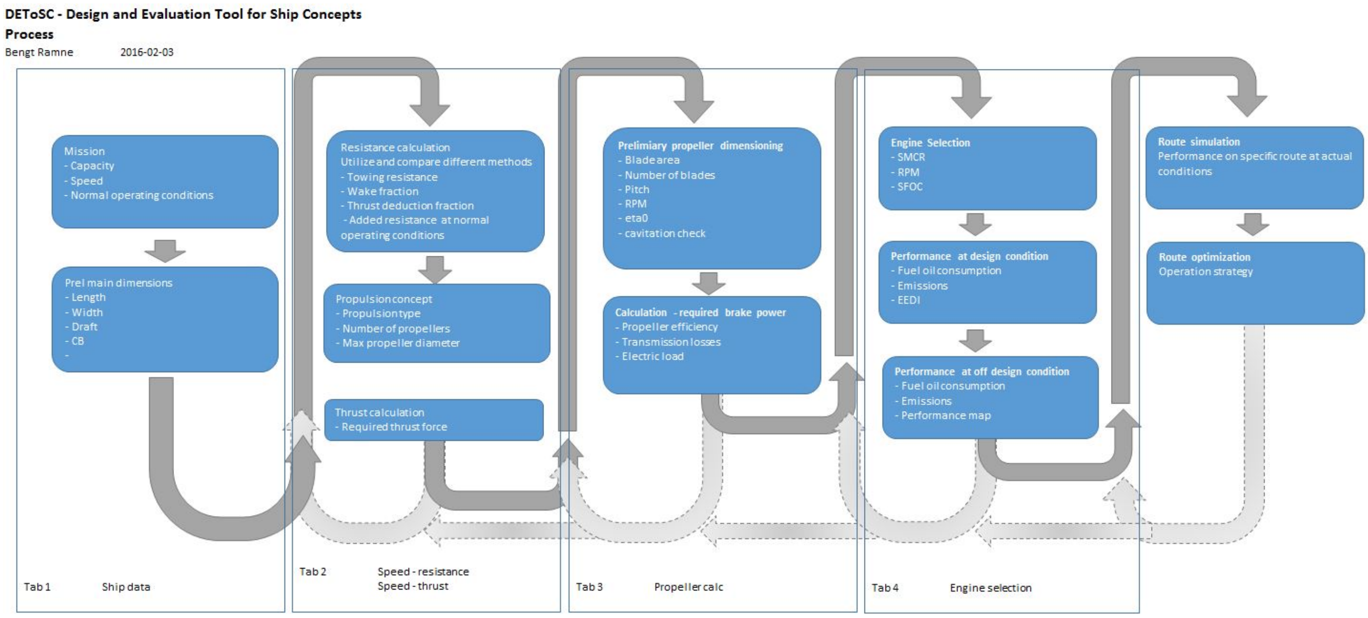

Figure 1.1: Process with design steps

An understanding of the process is vital to early make good decisions and estimations regarding project length and structure. The project process continue step by step identifying the different design areas and searching for empirical relations regarding the current ship parameters. Without performing any model tests the empirical relations are an important part for continuing the project. Studying statistics from existing ships often give a brief view of the value of the design parameters.

The development of the web tool is an on going activity through the whole process, gathering and expressing the literature into valuable code which executes and presents the results on the screen. Efforts making the web tool educational with an good interface is concentrated to the end of the project. The used tools for this project is the open source Net Beans Platform which provides a software for developing web applications Java, JavaScript, HTML5, PHP, C/C++ and more. In this project JavaScript, PHP and HTML languages are used.

1.5 Limitations

The development of the ship design evaluation tool has some limitations. The limitations occur within all different design areas from calculating the hull resistance to choosing main engine.

Resistance methods

When calculating the calm water hull resistance there are different methods how to do this. The Holtrop-Mennen method is the only one used in this web tool.

Head wind assumption

The added resistance is calculated with respect to different attributes including the incoming wind direction which affects the ship. In this tool, head wind is always assumed when calculating the added resistance. Head wind often gives the most conservative results.

Propeller arrangements

Limited propeller arrangements are offered for evaluation. The maximum number of propellers supported is two and the design tool supports only non-ducted propellers with fixed pitch (FPP). More on the number of blades on each propeller in limited to between two and six.

Cavitation

When evaluating the propellers to pass the cavitation check the Keller criteria is the only criteria used.

Engine selection

The main engine selection section is concentrated to two-stroke engines but one four stroke main engine is offered with no gear box efficiency losses. Furthermore no shaft generator equipment are included in the calculations.

Stability and manuevering

The design tool does not take stability and manuevering into account.

2

Theoretical framework

To create a red line through the report and webpage, a theoretical framework is set up to describe the interacting design areas. The framework is to be seen as a guide through all the design steps in the order they are executed by the design tool.
The setup of this chapter is in the same order as they appear on the webpage. Small information-icons are also put out on the graphical user interface (GUI) where the user can find out more about the current topic. Hoovering over the icon will present the information text.

2.1 Hull shape design

The first step in creating a ship is to determine shape of the hull. To define the shape the following parameters are used.

2.1.1 Main particulars

The first step involves the choice of main particulars for the vessel. The user is asked to select following main particulars:
- Shiptype
- Length overall (LOA)
- Beam (B)
- Design draft (T)
- Design speed (V)
- Cargo capacity
- Range

The selection of main particulars will be used in further calculations and estimations.

Ship type

Type of merchant ship. Eligible ship types are:
- Container ship
- Tanker ship
- Bulk carrier ship
- General cargo ship
- Ro-Ro ship
- Ro-pax ship
- Large pax ship (cruiser)
- Small pax ship

The selected ship type will greatly affect the generation of ship particulars. Many estimations of parameters through the design process is affected by the chosen ship type.

Length overall (LOA)

The ship's length overall [m]. Will be used when estimating length of waterline (LWL) and length between perpendiculars (LPP). The selection of length is the first step in a general merchant ship design process (Papanikolaou [2014]).The length can be estimated from the cargo capacity in a couple of different ways, although it is not brought up here.

Beam (B)

The breadth at mid ship [m]. The selection of beam is used in further calculations when deciding the block coefficient C_B. The user is always able to move back in the tool to adjust this value in order to achieve a block coefficient as desired.

Design draft (T)

The design draft of the ship [m]. Selected with relation to a desirable block coefficient (resistance) and route limits. A lower draft gives lower friction resistance but affect the stability and the maneuverability.

The draft is often affected by the depths on the navigating route. Well known-channels as Panama canal and Suez canal have restricted draft limits which ship designers have adapt to.

Design speed (V)

The design speed of the ship [kn]. The design speed is used when calculating the total resistance of the ship. It is also used when proposing a suitable block coefficient with Van Lammerens method, see chapter 2.1.3.

The design speed, also called contract speed, defines the speed at a certain draft (design draft) for which the ship must be able to steam. The design speed could be interpreted as a guaranteed speed from the ship designer.

Cargo capacity

The merchant ship's carrying capacity [ton]. Used when estimating the DWT of the ship, which affect the displacement.

Range

The range for which the ship should be able to operate in [nm]. A longer range will generate in a higher estimated DWT since larger fuel tanks is required and vice versa. Distances between certain ports are presented when hoovering the information-icon on the GUI.

2.1.2 Ship particulars

This section describes the ship particulars, what they stand for and how they are generated in detail.

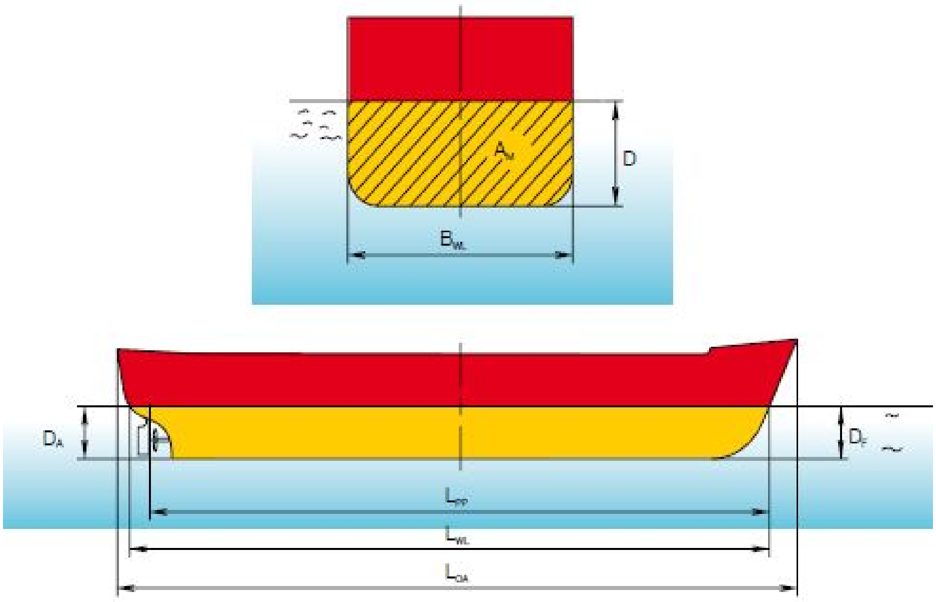

Figure 2.1: Ship particulars

Deadweight

The carrying capacity of the ship. This includes the cargo capacity, bunker, water and food supplies, crew etc. The deadweight is calculated as:

$$DWT = WC + WF + WPR + WCR \tag{2.1}$$

where:
WC: Weight of cargo
WF: WF1+WF2
WF1: Weight of bunker
WF2: Weight of lubricants
WPR: Weight of provisions and water
WP: Weight of passengers and luggage
WCR: Weight of crew members and luggage
The bunker weight, WF1 is estimated according to Papanikolaou [2014]:

$$WF1 = (PB1 * b1 * t1) * C * 10^-6 \tag{2.2}$$

where:
PB1: Required main engine power
b1: Specific fuel oil consumption, SFOC (g/kWh)
t1: Time for a roundtrip (hours). Calculated as the range divided by service speed (in this case the design speed).
C=1.2-1.4: A constant margin reserve which refers to any unexpected events that may occur during operation, such as change of course etc.
Since the required main engine power and SFOC is not known at this stage, these parameters are estimated based on shiptype, cargo capacity, range and chosen design speed. The required main engine power can be estimated according to Figure 2.2, where the ratio between installed propulsion power and displacement weight are shown. A mean value of the coefficient intervals are used respectively for each shiptype. The installed propulsion power are divided with η_M which is the product of the gearing efficiency (η_G) andthe shaft efficiency (η_S). By including the η_G, considering an eventual gearbox, the results become conservative. $\eta_S = 0.99$ according to MAN [2013] and $\eta_G = 0.965$ for medium speed diesel engines according to King [2013].
Auxiliary engines bunker weight are neglected since the effect is insignificant. This is validated in Chapter 3.2.1.

Ship type	P/Δ [PS/t]
Fast cargo ships (and containerships)	0.7–1.6
Slow cargo ships	0.4–0.6
Coaster cargo ships	0.4–0.6
Bulkcarriers	0.1–0.5
Tankers	0.10–0.35
Reefer ships	0.7–1.6
Fast passenger ships (non-high speed craft)	
Large	1.4–3.3
Small	1.6–3.3
Medium to slow passenger ships	
Large	1.1–1.2
Small	1.0–2.8
Tugboats (seagoing)	up to 6.0
Advanced Marine Vehicles (very high speed crafts)	
MONOHULL-AQUASTRADA	≅36.5
CATAMARAN	≅25.0
SWATH	≅20.0
SES	≅35.0
WAVE PIERCER	≅26.0
HYDROFOIL	≅63.0

Figure 2.2: Ratios between installed propulsion and power and displacement of different types of ships (Papanikolaou [2014], p.182)

To extract the propulsion power Ps from the ratio Ps/displacement, the displacement must be known. The displacement is the sum of the deadweight and the lightship weight, and the lightship weight are estimated according to Table 2.1. To extract the lightship weight from the table, DWT ≈ cargo capacity. This approximation is validated in Chapter 3.2.1.

The fuel consumption is estimated according to Papanikolaou [2014] where a low speed diesel engine has a specific fuel consumption of 170 g/kWh.
The weight of the lubricants, WF2 are estimated as 2-4% of the bunker weight (Papanikolaou [2014]).
The amount of crew members is set to 20 for every shiptype, except for the passenger ships where weight of passengers and crew, together with corresponding provisions, fresh water etc, should be included in "Cargo capacity".
The amount of food for each crew member is set to 20kg, and the amount of fresh water is according to Papanikolaou [2014] around 80-100 ton for a standard cargo ship. This will give the weight of the provisions and water, WPR.
Weight of passengers and luggage, WP=0 for all cargo ships. For the passengers ships, this weight should be included in the "Cargo capacity". The crew weight is estimated by an average weight of 75kg/person, together with an average weight of luggage of 50kg/person (Papanikolaou [2014]). Note that the weights of the crew and supplies will have a small effect on the ship's total deadweight, therefore no more effort will be given on this.

Lightship

The lightship weight is estimated from:
- Shiptype
- DWT
- LOA

In Table 2.1 in column 3, DWT/displacement ($ratio_{DWT/disp}$) relations are presented for different ship types of various sizes. Since DWT is already estimated before entering this step in the design tool (see Chapter Deadweight) the relation can instead be used to estimate the LS/displacement ($ratio_{LS/disp}$) according to equation:

$$ratio_{LS/disp} = 1 - ratio_{DWT/disp} \tag{2.3}$$

Using this equation together with the relationship between LS, DWT and displacement:

$$LS + DWT = displacement \tag{2.4}$$

which gives the final equation:

$$LS = \frac{DWT}{ratio_{DWT/disp}} \tag{2.5}$$

Since the ratios for each shiptype are described in intervals, a mean value of each of the intervals are used for the corresponding shiptype and size. In case of using ship data that not fit into the size intervals, an alert is given to inform the user that a correct lightship estimation is not fully supported. If the chosen shiptype have more than one size interval, a mean value of all $ratio_{DWT/disp}$ will be used in the calculation of the lightship weight.

	1	2	3	4	5	6
Ship type	Limits		DWT/Δ (%)	W_{ST}/W_L (%)	W_{OT}/W_L (%)	W_M/W_L (%)
	Lower	Upper				
General cargo ships (t DWT)	5,000	15,000	65–80	55–64	19–33	11–22
Coasters, cargo ships (GRT)	499	999	70–75	57–62	30–33	9–12
Bulk carriers[a] (t DWT)	20,000	50,000	74–85	68–79	10–17	12–16
	50,000	200,000	80–87	78–85	6–13	8–14
Tankers[b] (t DWT)	25,000	120,000	78–86	73–83	5–12	11–16
	200,000	500,000	83–88	75–88	9–13	9–16
Containerships (t DWT)	10,000	15,000	65–74	58–71	15–20	9–22
	15,000	165,000[c]	65–76	62–72	14–20	15–18
Ro-Ro (cargo) (t DWT)	$L \equiv 80$ m	16,000 t DWT	50–60	68–78	12–19	10–20
Reefers[d] (ft^3) of net ref. vol.	300,000	500,000	45–55	51–62	21–28	15–26
Passenger Ro-Ro/ferries/ RoPax	$L \equiv 85$ m	$L \equiv 120$ m	16–33	56–66	23–28	11–18
Large passenger ships (cruise ships)	$L \equiv 200$ m	$L \equiv 360$[e] m	23–34	52–56	30–34	15–20
Small passenger ships	$L \equiv 50$ m	$L \equiv 120$ m	15–25	50–52	28–31	20–29
Stern Trawlers	$L = 44$ m	$L \equiv 82$ m	30–58	42–46	36–40	15–20
Tugboats	$P_B \equiv 500$ KW	3,000 KW	20–40	42–56	17–21	38–43
River ships (towed)	$L \equiv 32$ m	$L \equiv 35$ m	22–27	58–63	19–23	16–21
River ships (self-propelled)	$L \equiv 80$ m	$L \equiv 110$ m	78–79	69–75	11–13	13–19

W_L light ship weight, W_{ST} weight of steel structure, W_{OT} weight of outfitting, W_M weight of machinery installation

[a] Bulk carriers without own cargo handling equipment

[b] Crude oil tankers

[c] Triple E class of containerships of Maersk, DWT = 165,000 t, first launched 2013

[d] Banana reefers

[e] Oasis class cruise ship of Royal Caribbean Int., $L = 360$ m, 225,282 GT, launched 2009

Table 2.1: Size and weight group relations for different ship types. Column 3 presents DWT/disp relation from where LS/disp relation is extracted.

Displacement

The total weight of the ship, [ton]. It can also be interpret as the weight of the volume of displaced water. Salt water is assumed where $\rho = 1025kg/m^3$.

$$Displacment = DWT + LS \tag{2.6}$$

The displacement value is automatically updated when either LS or DWT is changed.

L$_{PP}$

Length between perpendiculars, [m]. From forward perpendicular, a vertical line where the stem meets the waterline, to aft perpendicular, normally at the rudder, see Figure 2.1. L_{PP} is estimated by comparing a number of 20 existing vessels with respect to L_{OA} and L_{PP}. A ratio between the two parameters are found and expressed as:

$$L_{PP} = L_{OA} * 0.95 \tag{2.7}$$

L$_{WL}$

Length at waterline, [m]. For containers, tankers and bulkers, Kristensen and Lützen [2012]) equations are used:

$$L_{WL} = L_{PP} * 1.01\ (containers) \tag{2.8}$$

$$L_{WL} = L_{PP} * 1.02\ (tankers\ and\ bulk) \tag{2.9}$$

For the remaining shiptypes there is a general estimation by MAN [2013] which is expressed as:

$$L_{WL} = L_{PP} * 1.031\ (general) \tag{2.10}$$

2.1.3 Hull coefficients

At this stage the parameters that describe the hull shape is defined.

C$_B$

The most important hull coefficient is the block coefficient, C_B. It is expressed as a relation between the ship's displaced volume and a circumscribed box with dimensions $L_{WL} * B * T$, see Figure 2.3. A small block coefficient means lower hull resistance. Typical values of C_B for different shiptypes is presented in Table 2.2 and could be used as help for the user when selecting dimensions.

Ship type	Block coefficient $C_{B,PP}$	Approximate ship speed V in knots
Lighter	0.90	5 – 10
Bulk carrier	0.80 – 0.85	12 – 16
Tanker	0.80 – 0.85	12 – 17
General cargo	0.55 – 0.75	13 – 22
Container ship	0.50 – 0.70	14 – 26
Ferry boat	0.50 – 0.70	15 – 26

Table 2.2: Typical values of C_B for different shiptypes at design draft MAN [2013]

Block coefficient, [-]:

$$C_B = Displacment/(L_{WL} * B * T) \tag{2.11}$$

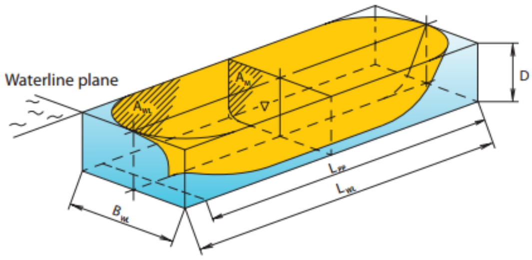

Figure 2.3: Hull coefficients

The block coefficient can also be estimated from the length, L_{WL}, and the ship speed, V. Van Lammeren (Papanikolaou [2014] p.150) uses a semi-empirical method considering hydrodynamic and economic critera and expresses the block coefficient as:

$$C_B = 1.08Fn - 1.68Fn - 0.224Fn^2 \tag{2.12}$$

where Fn is the Froude number:

$$Fn = \frac{V}{\sqrt{g * LWL}} \quad g = 9.81m/s \tag{2.13}$$

At the GUI of the web tool the user is provided the estimated value of C_B when proceeding to the next step after the calculated C_B value is shown. Providing this value helps the user to define a proper value of C_B.

$\mathbf{C}_M$

The midship section coefficient is described as the transverse area of the immersed midship section A_M dividied by the area of a rectangular with dimensions B_{WL}*T, see Figure 2.3. The midship section generally do not have a significant effect of the ship's resistance and typical values are 0.98-0.99 for bulkers and tankers, and 0.97-0.98 for containers (MAN [2013]).
There are different methods to estimate C_M from C_B but the different formulas provide similar results. In Figure 2.7 an analysis of four different methods is provided. The Figure shows that for typical values of $C_B = 0.5 - 0.9$, the methods provides similar results. The chosen method for the DEToSC tool is "Laboratory HSVA (Hamburg)" (Papanikolaou [2014] p.158) since it is most recent estimation formula and provides a reasonable value of C_M. It also gives a representative result of C_M.
Midship block coefficient, [-]:

$$C_M = \frac{1}{1 + (1 - C_B)^{3.5}} \tag{2.14}$$

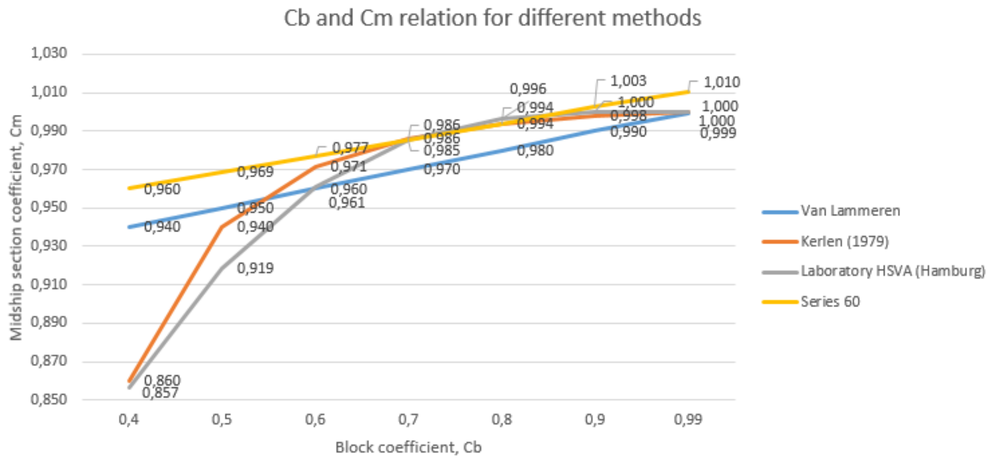

Figure 2.4: A comparison of different methods to estimate midship section coefficient C_M.

The value of C_M is set to be maximum 0.99 to provide reasonable results in further calculations.

$\mathbf{C}_{WP}$

The waterplane area coefficient measures the ratio between the waterplane area and the circumfering box with dimensions $L_{WL} * B_{WL}$ and is significantly affected by the transverse sections and C_B and C_M. The coefficient greatly affects the stability of the ship due to change of the moment of inertia. Generally the water plane are coefficient are slightly higher (+0.1) than the C_B but on fast vessels where the stern is also immersed in the water, the C_{WP} difference will be larger (MAN [2013]).

There are several methods of how to estimate C_{WP}. The methods consider different stern types but in general the results from each method are very similar. An analysis of the different methods are shown in Figure 2.5, where the methods have been evaluated for $C_B = 0.4 - 0.99$ with a constant $C_M = 0.98$. A variation of C_M from 0.97-0.99 give similar results. The chosen method for the DEToSC tool is "Normal section" (Papanikolaou [2014] p.163).

Waterplane area coefficient, [-]:

$$C_{WP} = \frac{1 + 2C_B}{3} \tag{2.15}$$

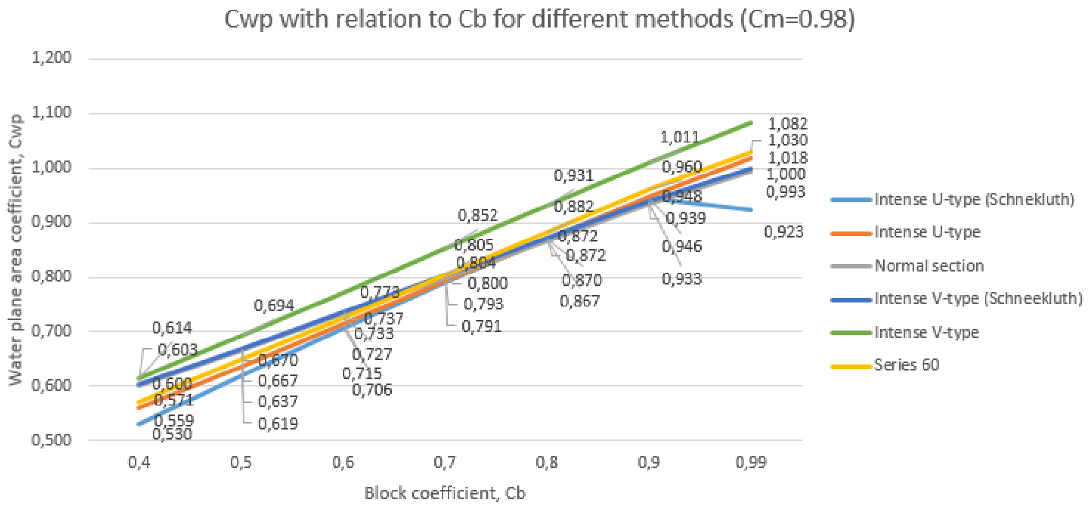

Figure 2.5: Different mehods to estimate C_{WP} according to different values of C_B when $C_M = 0.98$.

2.1.4 Superstructure parameters

To calculate the added resistance due to wind, the design and size of the superstructure is needed. The superstructure design are divided in six parameters explaining the size of different areas of the superstructure, including the lateral and transverse location of those areas, see Figure 2.7. The parameters are estimated according to the chosen size of the ship where L_{PP} and the beam, B, of the ship are used.

Since no earlier studies provide information on how to estimate the superstructure areas, new relations between size of the ship and the needed parameters needs to be extracted. From looking and comparing 20 existing ships of various types the relationships are invented. To further look on how big influence the wind has on the total added resistance, a short comparison is performed between a typical containership with generated superstructure parameters according to the formulas, and a containership completely without superstructure. The comparison is made looking at Beaufort states from 3 to 9 and the results are shown in Figure 2.6. Note that the results provide the *relative* difference between the two cases. Thus for example an added resistance in Beaufort 3 *with* a superstructure of 5%, will result in, if the superstructure is removed, an added resistance of 4%.

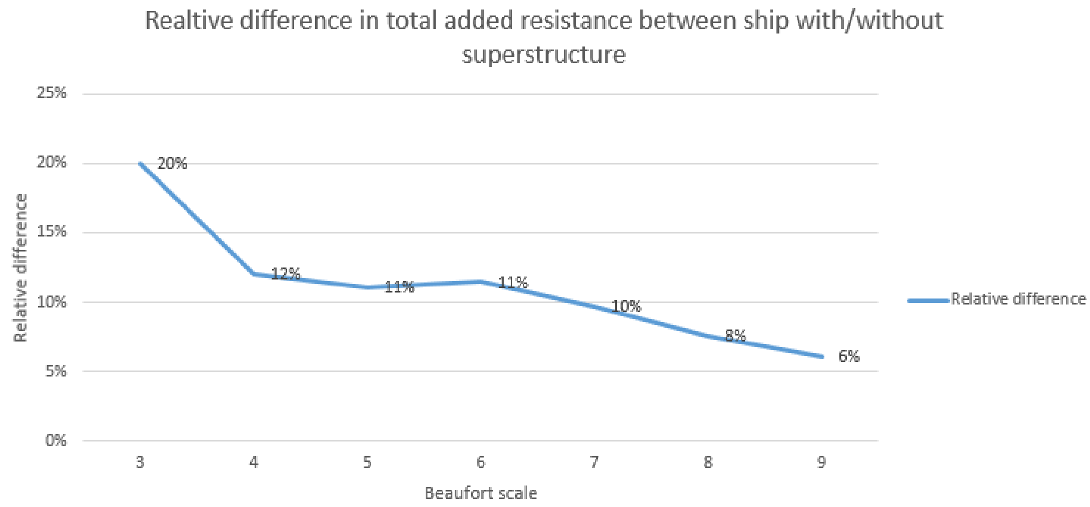

Figure 2.6: Shows the difference in added resistance between a ship with generated superstructure parameters, and a ship without. Main dimensions and other data for the current ship can be found in Appendix A.

From the figure it is clear that the superstructure affects the total added resistance, but it is obvious that the wind is not the major factor in the total amount of added resistance, especially not in heavier weather conditions.

By showing this the influence of wrongly estimated superstructure parameters is not a major factor and will not affect the total calculated added resistance significantly.

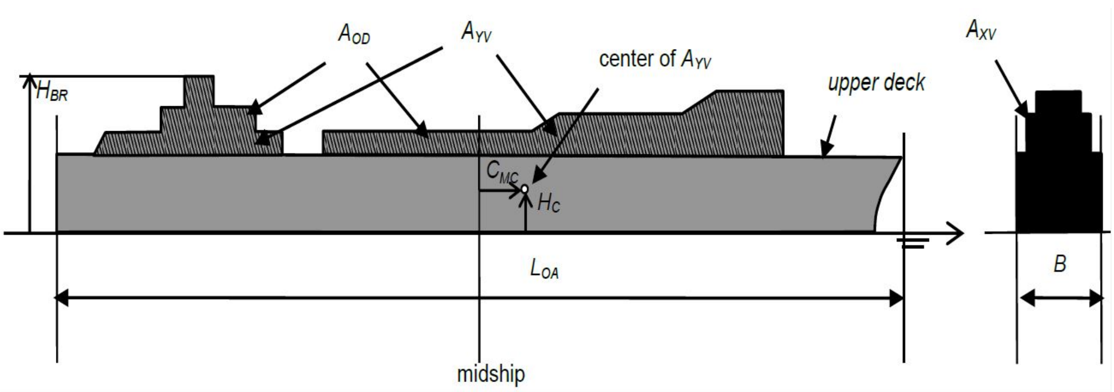

Figure 2.7: Superstructure parameters

A_{OD}

The lateral projected area above the waterline, $[m^2]$. Estimated to $3L_{PP}$.

$\mathbf{A}_{XV}$

Area of maximum transverse section exposed to the wind, $[m^2]$. Estimated to 20B.

$\mathbf{A}_{YV}$

Projected lateral area above the waterline, $[m^2]$. Estimated to $10L_{PP}$.

$\mathbf{C}_{MC}$

Horizontal distance from midship section to centre of lateral projected area AYV, [m]. Estimated to $0.05L_{PP}$.

$\mathbf{H}_{BR}$

Height of top of superstructure, [m]. Estimated to 20m.

$\mathbf{H}_{C}$

Height to center of lateral area, [m]. Estimated to 6m.

2.1.5 Added resistance due to wind and waves

The formulas and methods suggested by ITTC [2014] has been used as a base for calculation of the added resistance, RAR. Both the wind, RAA, and wave, RAW, needs input such as speeds and heights. It was decided that the Beaufort's scale is to be used, so that the user will have an easier way to input needed parameters. In the calculation of wind resistance, head wind is always assumed.

$$RAR = RAA + RAW \tag{2.16}$$

Beaufort scales

The scale consists of 13(0-12) different sea states that state wind speeds, wave amplitude and wave length from calm water, 0, to a hurricane, 12 (BEA). These are used together with parameters mentioned earlier to determine the added resistance. See Appendix E.

Shallow water

To determine the added resistance of shallow water effect another input is needed in the form of the height from sea bottom to water surface. Depending on the chosen design speed, the user is given a water depth which gives no loss in terms of resistance from the shallow water effect as a start value. The formulas used in DEToSC for this shallow water effect is based HydroComp Inc. (HydroComp [2003]).

2.1.6 Calm water hull resistance

One important step is the estimation of the resistance the ship will create when moving through the water at certain speeds. For this project the Holtrop-Mennen method is used.

Holtrop-Mennen method

The Holtrop-Mennen method is based on regression for wave resistance. It approximates the ship as two points that generates the waves. The coefficients used in the formula has been determined statistical through experiments and existing data. It also uses the viscous resistance from ITTC-57.

2.1.7 Total resistance

The total resistance, RT, is then the sum of calm resistance and added resistance. It is calculated as:

$$RT = RT_{H.M.} + RAR \tag{2.17}$$

Its components is then illustrated with a plot, see figure 2.8.

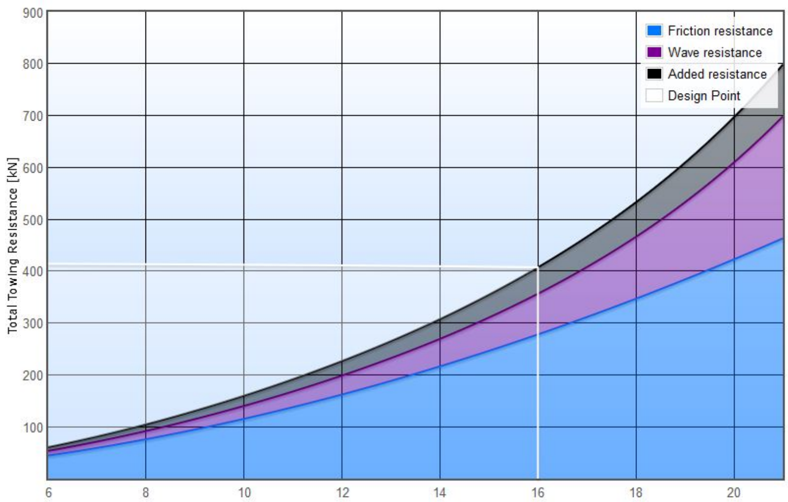

Figure 2.8: Example plot of total resistance from DEToSC

2.2 Propeller design

When the hull shape has been defined the next step is to select a propeller. A propeller concept is about to be selected as well as the diameter of the propeller. The propeller dimensions will together with the resistance and other parameters calculate the optimal open water efficiency (highest) according to some performance critera.

Starting from this step two profiles are used for the ship. One design profile and one service profile. The design profile corresponds to what the engine and propeller have to perform according to the contract which is not necessarily the service condition. The service profile is the condition which the ship perform it's mission in. Figure 2.9 shows a ship's speed distribution from which an average service speed could be extracted. The design speed according to the figure is around 16 knots.

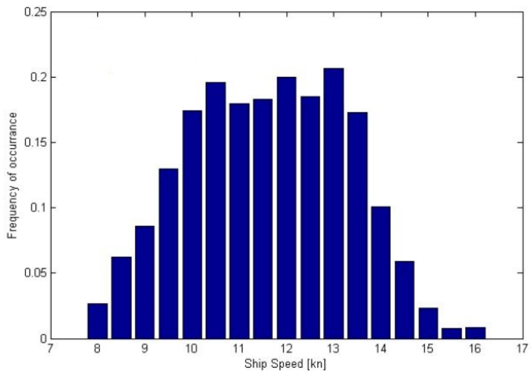

Figure 2.9: Example plot of speed distribution of a ship

On the DEToSC webpage a function exists that finds the optimal open water efficiency. Read more about this in Chapter 2.2.3.

2.2.1 Hull efficiency

The first part of this step is to calculate the hull efficiency. This is calculated according to:

$$\eta_H = \frac{(1 - t_{SSPA})}{(1 - w_{Taylor})} \tag{2.18}$$

In turn t_{SSPA}, thrust deduction according to SSPA (Bertram [2012]) and w_{Taylor}, wake fraction according to Taylor(Younis [2002]) needs information about the size, type and arrangement of the propeller.

Propeller diameter

For the diameter of the propeller the max size allowed on the ship is normally the one that give the highest open water efficiency, therefore a function has been implemented that calculates the max size allow. It is calculated according to:

$$D_{propeller} = x * TD\ [m] \tag{2.19}$$

where:
x: Tanker or bulk = 0.65, Container and other = 0.74, (MAN [2013])
TD: Design draft

Propeller arrangement

Depending on the arrangement of the propeller different number of propellers are used. Single screw use one propeller, twin screw use two propellers. This has impact in the coming calculations, generally if one propeller is used no correction is made but if two is used certain parameters are divided by two. The type of arrangement also have an impact on what formula is used for calculating the wake fraction, w and the trust deduction coefficient, t.
The arrangement with twin skeg - twin screw propellers have almost unchanged values of w and t compared to single skeg - single screw arrangement. Therefore the hull efficiency for this arrangement is calculated according to single skeg - single screw (MAN [2013]).

Propeller type

The DEToSC tool only evaluates propeller types of FPP, fixed pitch propellers. The fixed pitch will be optimized to the service speed of the vessel.

Wake fraction coefficient

The wake fraction coefficient describes the relation between the arriving velocity (speed of advance) at the propeller and the ship speed. The wake fraction is expressed as:

$$w = \frac{V - V_A}{V} \tag{2.20}$$

V is the ship speed and V_A is the speed of advance. Since the speed of advance in not known at this stage the wake fraction coefficient needs to be estimated. There are many different techniques of how to estimate w and a lot of authors use different formulas. A comparison study is carried out and the results is presented in Figure 2.10 for single screw ships, and Figure 2.11 for twin screw ships.

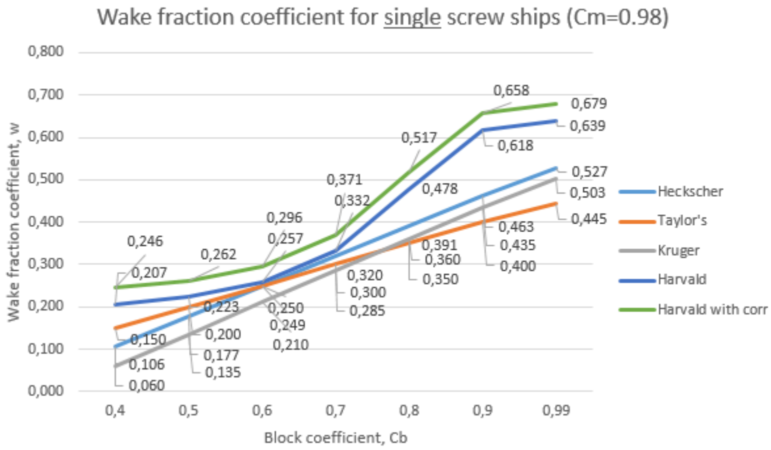

Figure 2.10: Comparison of different methods to estimate wake fraction for single screw vessels. $C_M = 0.98$ and $D_{prop} = 7.2m$

Heckscher, Taylor and Kruger uses more simplified formulas only including hull coefficients C_B and C_M, whereas Harvald uses more complicated formulas involving also the stern type and the propeller diameter. The chosen method in the DEToSC tool is Taylor's (Bertram [2012]) and is expressed as:

$$w = 0.5C_B - 0.05 \ (single \ screw) \tag{2.21}$$

$$w = 0.55C_B - 0.2 \ (twin \ screw) \tag{2.22}$$

Thrust deduction coefficient

When the propeller rotates the water is "sucked back" at the propeller and this causes some extra resistance to the hull. The thrust deduction is expressed as:

$$t = \frac{F}{T} \tag{2.23}$$

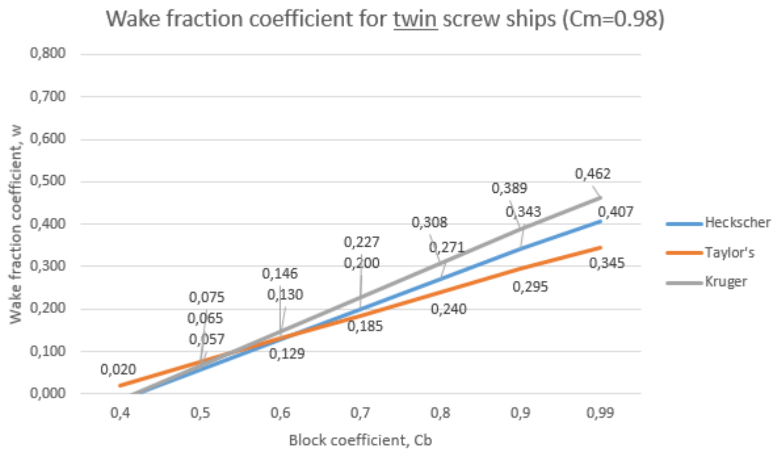

Figure 2.11: Comparison of different methods to estimate wake fraction for twin screw vessels. $C_M = 0.98$.

where F is "the loss of thrust" and T is the total required thrust. The thrust deduction factor t is dimensionless and increases in general when w increases. For estimation of the thrust deduction coefficient at an early design stage there are several existing techniques. A comparison of different methods is shown in Figure 2.12 for single screw vessels, and in Figure 2.13 for twin screw vessels.

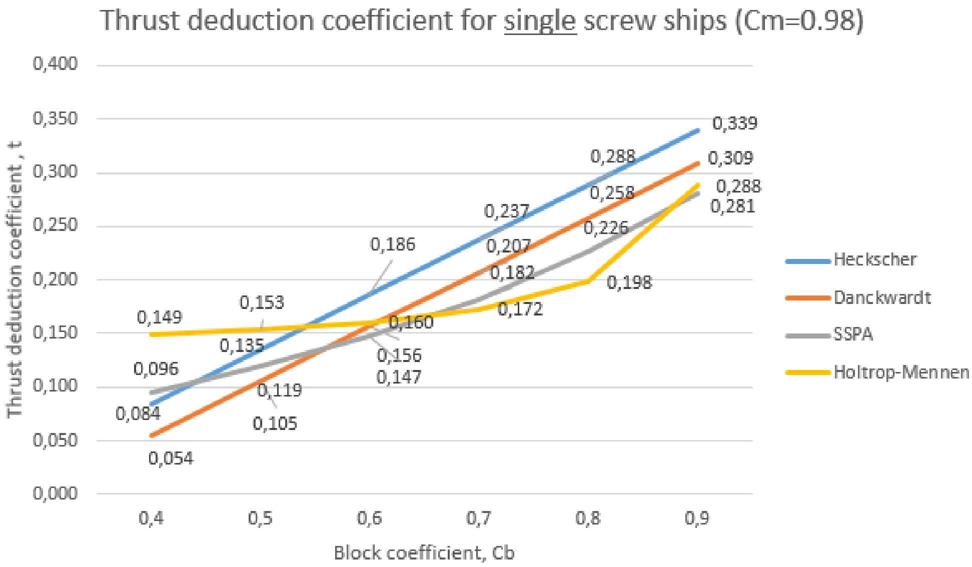

Figure 2.12: Comparison of different methods to estimate thrust deduction for single screw vessels. $C_M = 0.98, D_{prop} = 7.2m$, T=9m

Figure 2.13: Comparison of different methods to estimate thrust deduction for twin screw vessels. $C_M = 0.98$,$D_{prop} = 7.2m$, T=9m

Hecksher and Danckwardt uses simplier formulas only considering C_B and C_M whereas SSPA and Holtrop-Mennen uses more complicated formulas. The SSPA model use w in the model together with C_{WP} (water plane area coefficient) and C_B, and Holtrop-Mennen use a combination of constants toghether with length/breadth relations with draft and propeller diameter. For twin screw vessels the thrust deduction coefficient will be much lower since the ”sucking” will occur much further away from the hull than for a conventional single screw arrangement. This phenomena is verified by the SSPA model when comparing the single versus twin screw values of t.
When estimating the thrust deduction coefficient the model created by Bertram [2012] is used. The formula is expressed as:

$$t = w(1.57 - 2.3\frac{C_B}{C_{WP}} + 1.5C_B)\ (single\ screw) \tag{2.24}$$

$$t = w(1.67 - 2.3\frac{C_B}{C_{WP}} + 1.5C_B)\ (twin\ screw) \tag{2.25}$$

where w is wake fraction coefficient by Taylor’s for the corresponding block coefficient and single/twin screw arrangement. C_{WP} is estimated according to ”Normal section”, see chapter 2.1.2 ”Hull coefficients”.

2.2.2 Set service profile

When designing the propeller it is important that the propeller is designed for the condition which it operates most often in. Since the vessel will operate with different speeds in different conditions it is difficult to set an optimal design for the propeller. When setting up the service profile the user is given the opportunity to specify a service speed for the transport mission. This speed is then used for finding the most optimal propeller.

Ship speed

The user specify the service speed [kn] when operating the transport mission. The speed affects the required thrust and therefore the design of the propeller.

Loading rate

The user is able to specify the loading rate for which the propeller should be designed for. The loading rate can be seen as an average percent of DWT the ship will operate with and the propeller will be generated henceforth.

When adjusting the loading rate there will be a new displacement used in the required thrust (resistance) calculation. Furthermore there will be a new draft of the ship which will affect the required thrust. The difference in draft is calculated from the decreased DWT and the waterplane area coefficient Cwp. The difference in draft is expressed as:

$$T_{diff} = \frac{DWT_{diff}/1.025}{Area_{WP}} \tag{2.26}$$

where $Area_{WP}$ is the water plane area:

$$Area_{WP} = C_{wp} L_{WL} B \tag{2.27}$$

Hence, the new draft:

$$T_{new} = T - T_{diff} \tag{2.28}$$

Speed of advance, $\mathbf{V}_A$

The arriving water velocity [m/s] at the propeller disk. Calculated with the service speed as:

$$V_{AService} = \frac{V_{service}}{1 - w} \tag{2.29}$$

Total resistance

The total hull resistance [kN] is calculated for the given service condition (service speed) according to the Holtrop-Mennen method as mentioned in Chapter 2.1.

Effective power

The effective power [kW] is calculated for the given service condition with the service condition resistance and the new service speed:

$$P_E = R_T * V_{service} \tag{2.30}$$

Required thrust

The required thrust for the specified service speed. Calculated as:

$$T = \frac{RT_{service}}{1 - t} \tag{2.31}$$

2.2.3 Search propeller

The DEToSc tool is capable of finding a suitable propeller according to the given service profile. It searches through the Wagening B-series propellers with a couple of criteria:

- Searching for highest possible open water efficiency
- Cavitation check for service speed
- Cavitation check for design speed

The result is a 4-bladed non-ducted FPP with iterated values of:

- Optimum blade area ratio, EAR
- Optimum pitch, P/D
- Required RPM for the given thrust

There is also an option for the user to specify the number of blades from 2-6. In total, 800 different combinations of EAR, pitch and number of blades are available for search request.

Input data

The input data used by the search propeller function is:

- Thrust, T
- Speed of advance, Va
- Propeller diameter, D
- Minimum RPM for propeller, n
- Number of blades

The thrust is calculated from the hull resistance at the given design draft.

Wagening B-series

The Wagening B-series are a widely used fixed pitch, non-ducted propeller series. (Carlton [2012]) It contains of derived polynomials from 120 propeller models tested at Netherlands Ship Model Basin in Wagening (Bernitsas et al. [1981]). The propellers are evaluated for the ranges of:

- Blade area ratio 0.30-1.05 (step 0.05)
- Pitch-diameter ratio 0.5-1.4 (step 0.1)
- Number of blades 2-6

A plot of the open water characteristics of a 4-bladed propeller with EAR 0.5 is shown in Figure 2.14.

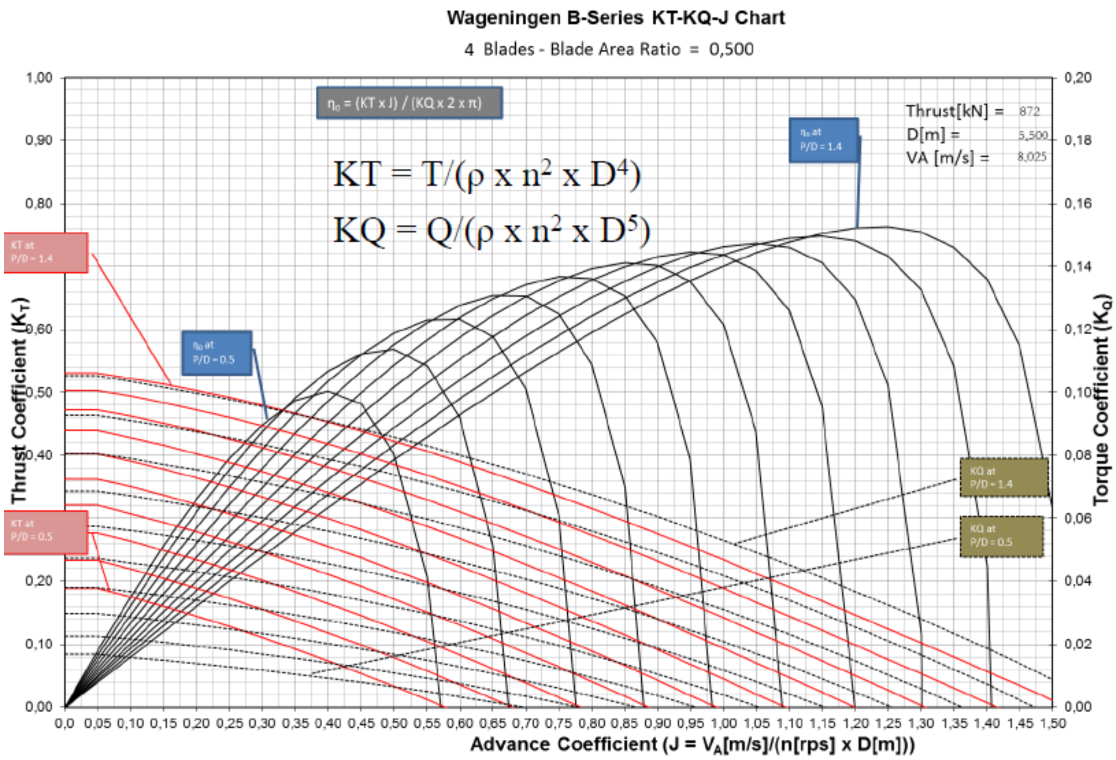

Figure 2.14: Open water characteristics for a propeller in Wagening B-series. The green line corresponds to KT with constant thrust.

$$KT = \frac{T}{\rho * n^2 * D^4} \; (Red\ line) \tag{2.32}$$

$$KQ = \frac{Q}{\rho * n^2 * D^5} \; (Dotted\ line) \tag{2.33}$$

KT is the dimensionless thrust coefficient and KQ is the dimensionless torque coefficient.
The x-axis on Figure 2.14 is the advance coefficient J which is a dimensionless expression of the speed of advance. It is expressed as:

$$J = \frac{V_a}{n * D} \tag{2.34}$$

The Wagening B-series polynomials can be found in Appendix B.

Deriving the highest open water efficiency

A KT-line with the required thrust (service profile) is plotted into the propeller diagram, see Figure 2.15. KT is rewritten from equations 2.32 and 2.34 into:

$$KT = J^2 * \frac{T}{{V_A}^2 * D^2} \ (green\ line) \tag{2.35}$$

At the intersection of the green (KT) and red (KT at P/D=0.5-1.4) lines, a vertical line is drawn up to the corresponding η_0 (η_0 at P/D=0.5-1.4). This action is performed for all the available P/D-ratios, see the blue lines in Figure 2.16. A number of open water efficiencies are found with related P/D-ratios and the highest efficiency and the corresponding P_D-ratio are read and saved.
The open water efficiency is expressed as:

$$\eta_0 = \frac{KT}{KQ} * \frac{J}{2\pi} \tag{2.36}$$

Where:
$J = \frac{V_A}{n*D}$ Advance coefficient
$V_A = V * (1 - w)$ Advance velocity
n = propeller speed, [rpm]
D = propeller diameter, [m]
K_T = Thrust coefficient
K_Q = Torque coefficient

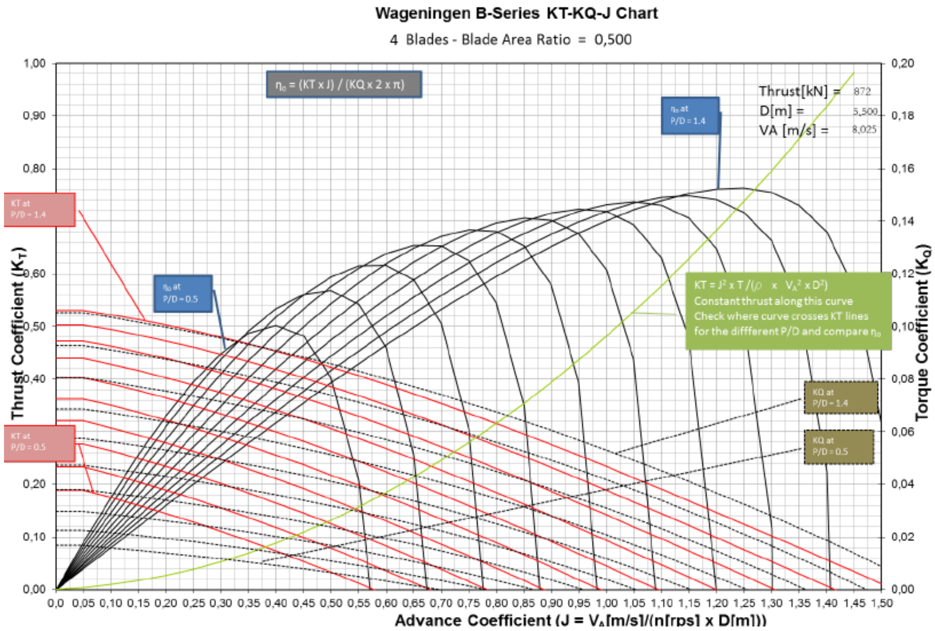

Figure 2.15: Open water characteristics for a propeller in Wagening B-series. The green line corresponds to KT with constant thrust.

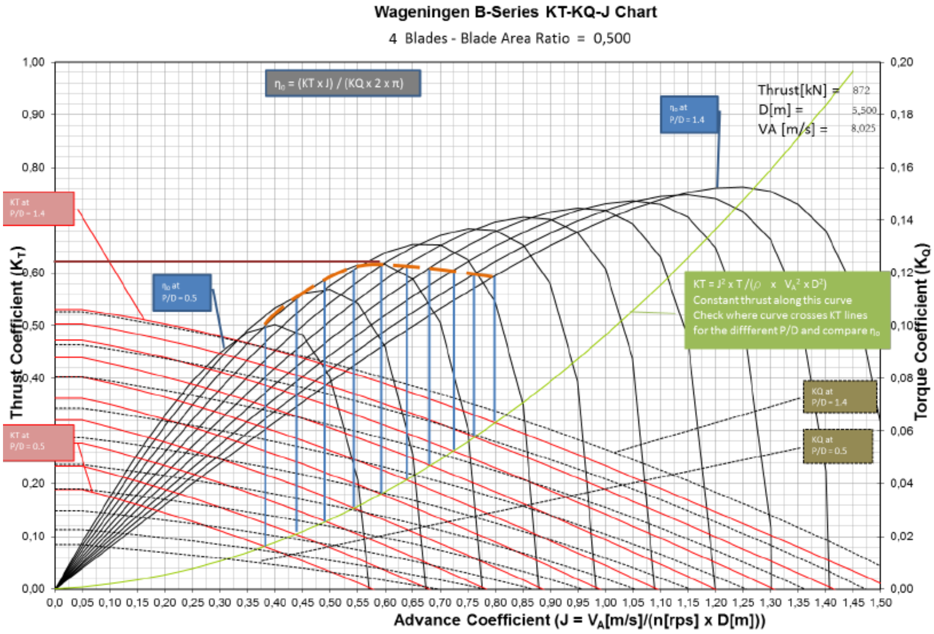

Figure 2.16: Open water characteristics for a propeller in Wagening B-series. The red line and the blue vertical lines indicates the maximum open water efficiency for the different P/D.

Minimum RPM

The user input of minimum value of RPM (n) results in a maximum value of J according to equation 2.34. A small value of n results in a large value of J. Therefore setting a higher minimum value of n there is a possibility that not all P/D-ratios are evaluated and the highest efficiencies are left out.

Cavitation criteria

The propellers are tested against cavitation according to the Keller criteria (read more about cavitation and Keller in chapter 2.3.2). In order to ensure that the propeller not only works properly at service speed, the cavitation check is also performed for the design speed. According to the Keller criteria this often results in that lower blade area ratios are not selected since those would have had problems with cavitation at the higher design speed. According to this, an optimum value of the blade area ratio is said to be found.

2.2.4 Propeller dimensioning results

The result from the "Search propeller"-function is a 4-bladed propeller which fulfills the criteria stated in section 2.2.3 "Search Propeller". The following dimensions and efficiencies are presented (see Figure 2.17):

- RPM [revolutions per minute]
- J [-]
- EAR [-]
- P/D [-]
- No. of blades [-]
- η_0[-]
- η_R[-]
- η_S[-]
- η_T[-]
- PB [kW]

Operational profile	4 blades	
	Operational	Design
RPM [/min]	71	82
J [-]	0,66	0,66
EAR [-]	0,40	0,40
P/D [-]	1,00	1,00
No. blades	4	4
eta0 [-]	0,63	0,63
etaR [-]	0,95	0,95
etaS [-]	0,99	0,99
etaT [-]	0,69	0,68
PB [kW]	5533	8641

Figure 2.17: Example propeller dimension result

Service condition

The purpose of the specified service condition is to generate the optimized propeller dimensions in terms of EAR and P/D. These dimensions are optimized for the specified service speed and the loading rate, and will give the highest open water efficiency, η_0, for this condition.

Design condition

The design condition uses the optimized EAR and P/D from the service condition and calculates an open water efficiency with respect to the design speed. The J-value is identified and the propeller speed (RPM) is calculated according to equation 2.34. Together with the relative rotative efficiency and the shaft efficiency, the effective brake power PB can be extracted. The effective brake power needed from the design condition is together with the corresponding RPM, used to find an appropriate main engine.

Revolutions per minute (RPM)

The propeller's required rate of revolution to generate the required thrust. The rate of revolution is calculated when the optimized design parameters (EAR and P/D) are decided. Could be rewritten from equation 2.34 to:

$$n = \frac{V_a}{J * D} \tag{2.37}$$

Advance coefficient (J)

The advance coefficient J is a dimensionless expression of the propeller's speed of advance, see equation 2.34.

Expanded Area Ratio (EAR)

Also referred to as blade area ratio and is the surface area of the blades divided with the area of the propeller disk see Figure 2.18

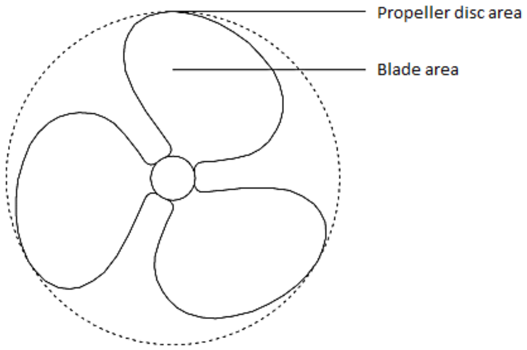

Figure 2.18: Explanation of blade area ratio. It is the blade area divided by the propeller disc area.

A factor of 0.55 is a normal value for conventional ships with moderately loaded propeller. Ships with heavier propeller load may have higher values. The ratio is iterated in the search propeller function in the interval 0.3-1.05 with steps of 0.05.

Pitch/Diameter ratio (P/D)

The pitch is the distance one blade travels in one revolution. The pitch/diamater ratio is the difference between that distance and the diameter of the propeller. See figure 2.19. The ratio is iterated in the search propeller function in the interval 0.5-1.4 with steps of 0.1.

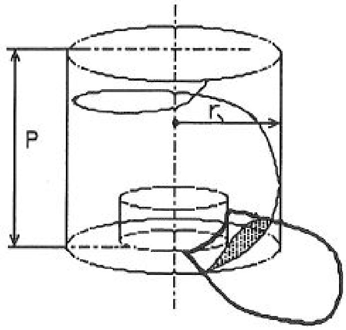

Figure 2.19: Pitch ratio (Dyne,Bark)

Number of blades

The possible selection of number of blades is 2-6.

Open water efficiency (η_0)

Calculated from J, EAR, P/D and no. of blades, see equation 2.36. For more information of how it is calculated see Chapter 2.2.3.
The open water efficiency is normally determined by performing an open water test in a towing tank or in a cavitation tunnel. During this test the thrust and torque is measured and then used to calculate the open water efficiency (Dyne and Bark [2005]). When this is not possible, the Wagening B-series propeller diagrams are used.

Relative rotative efficiency (η_R)

The relative rotative efficiency, η_R stands for that the water flow into the propeller has a kind of rotational flow. For a single skeg ship with one propeller η_R is normally around 1.0-1.07 (MAN [2013]) which means that the rotational flow in this case is beneficial. For a conventional ship with two propellers, η_R is quite lower, around 0.98. For a twin skeg vessel with twin-screw the value is approximately the same as for single skeg single screw concept.
The formulas used in the evaluation tool is Holtrop-Mennen from Carlton [2012] and are expressed as (for single skeg - single screw, and twin skeg - twin screw):

$$\eta_R = 0.992 - 0.05908EAR + 0.07424(Cp - 0.0225LCB) \tag{2.38}$$

and for single skeg twin screw as:

$$\eta_R = 0.9737 + 0.111(Cp - 0.0225LCB) - 0.06325 * P/D \tag{2.39}$$

Shaft efficiency (η_S)

The shaft efficiency is often around 0.99 which is the value used in the DEToSC tool. It depends on the alignment and lubrication of the shaft bearings, and also if there is any gearbox installed.

Total efficiency (η_T)

The total efficiency η_T is a product of the previous efficiencies and expressed as:

$$\eta_T = \eta_H \times \eta_0 \times \eta_R \times \eta_S \tag{2.40}$$

Brake power (PB)

The brake power is the required engine power to the propel the ship at given conditions, see Figure 2.20. The brake power is used to chose an appropriate engine for the ship.
The shaft generator power take out (PTO) is included in the brake power but is here assumed to zero.

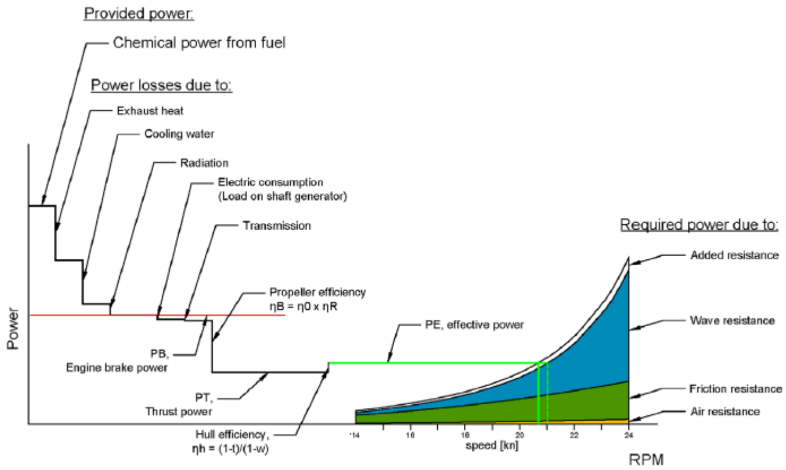

Figure 2.20: Required power and brake power

The propeller diagram

The propeller diagram shows the current 4-bladed propeller as a function of the advance coefficient J, see Figure 2.21. The blue and green line shows the thrust and torque coefficient for the given propeller design (given EAR and number of propellers) together with the red line which corresponds to the open water efficiency curve for the given P/D-ratio. The yellow line indicates the advance coefficient J, and corresponding open water efficiency, η_0.

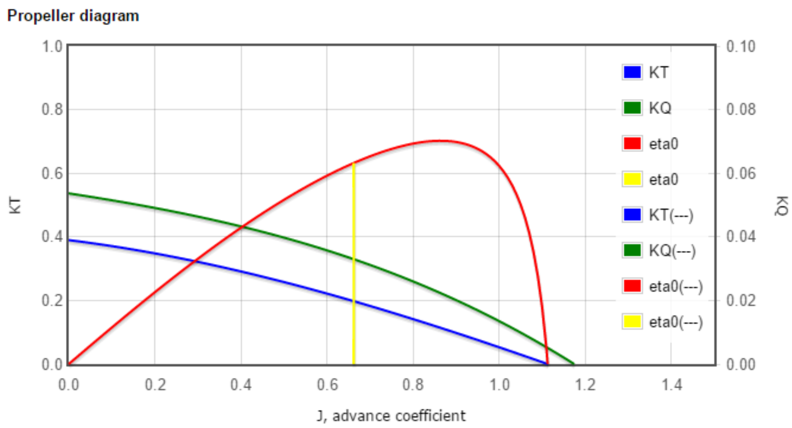

Figure 2.21: Propeller diagram with one propeller

The propeller diagram is also capable of showing an alternative propeller design with a another number of blades (2-6). This design and its corresponding KT, KQ and η_0 is shown as dotted lines, see Figure 2.22.

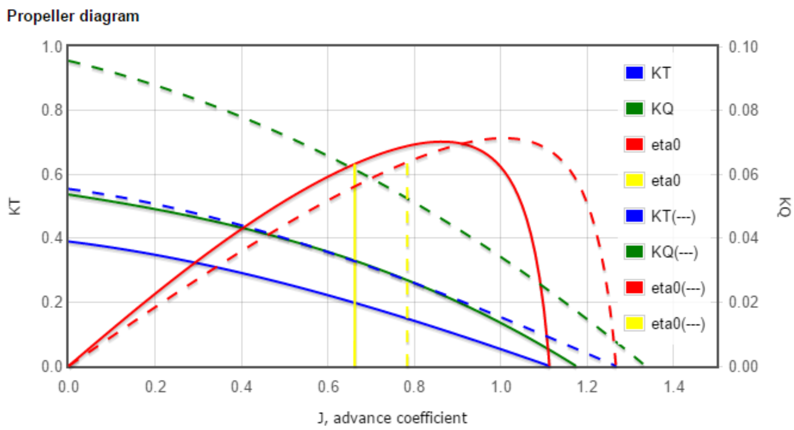

Figure 2.22: Propeller diagram with two propellers

2.3 Main engine selection

On the tab "Main engine(3)" the first step for the user is to initiate the "Search for engine" function by clicking on the associated button. This will activate a function that matches engines(with stored engines on the database) with the given setup from "Hull shape(1)" and "Propeller(2)".

2.3.1 Search for engine

This function contains a number of steps which will end in a number of suggested two-stroke engines and one four-stroke depending on the input. Information such as fuel consumption at max load and at operating speed is then displayed. This output is displayed both in figures as well as in a table to get a good overview. First, all of the stored engines is defined with its limits, defined by the minimum and maximum rpm and effective power that the engine produce, see Figure 2.23. For this design tool MAN tier II engines has been chosen, both two- and four-stroke.

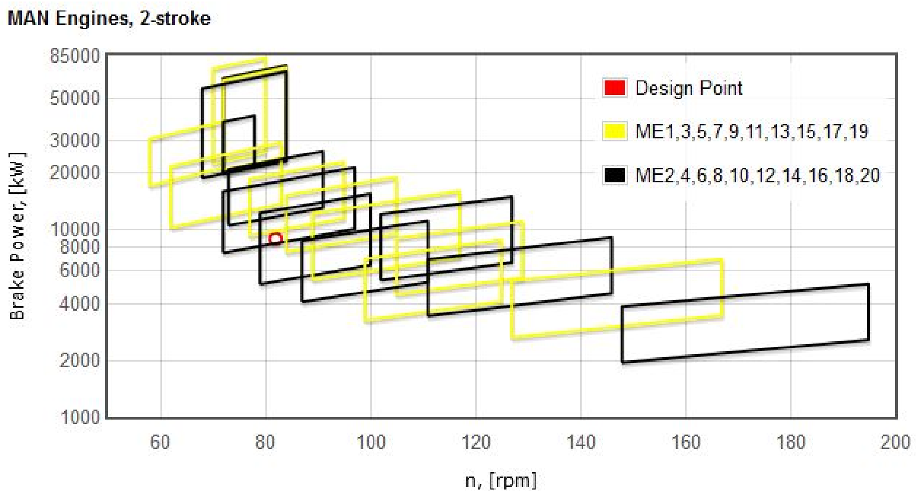

Figure 2.23: two-stroke MAN engines stored in database, one box defines one MAN engine

In this figure the "Design point" is displayed. It is this point, with rpm and brake power from the design condition, that the function compares the limits of the engines and assesses if it is within an engines limits. If it passes the check it moves to the group of suggested engines.

For the four-stroke engine the case is different. Since the four-stroke operates in an higher rpm, 500-1000, a gearbox is needed to connect with the propeller(rpm within 50-190). With the gearbox the four-stroke engine matches most of the

propellers and therefore only one four-stroke engines has been used in the design tool. Any efficiency on the gearbox has not be taken into consideration.
The next figure, Figure 2.24, gives a better view of the matched or suggested engines with the propeller curve for that case.

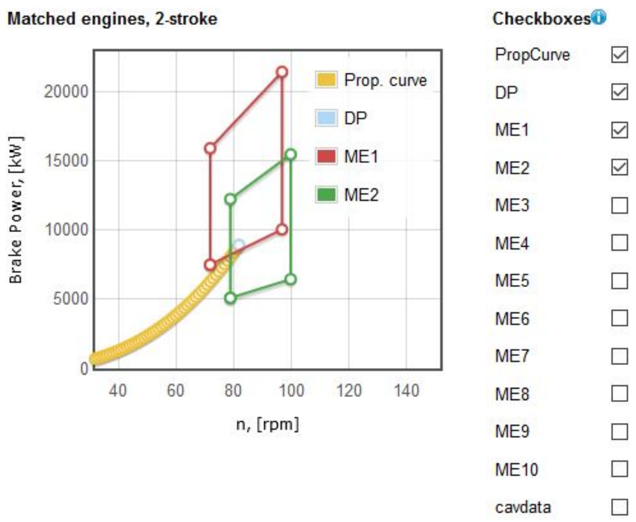

Figure 2.24: Propeller curve with suggested two-stroke engines

Within the figure it is also possible to see the cases where cavitation can occur. This is viewed by checking the "cavdata" checkbox. See Figure 2.25 for an example.

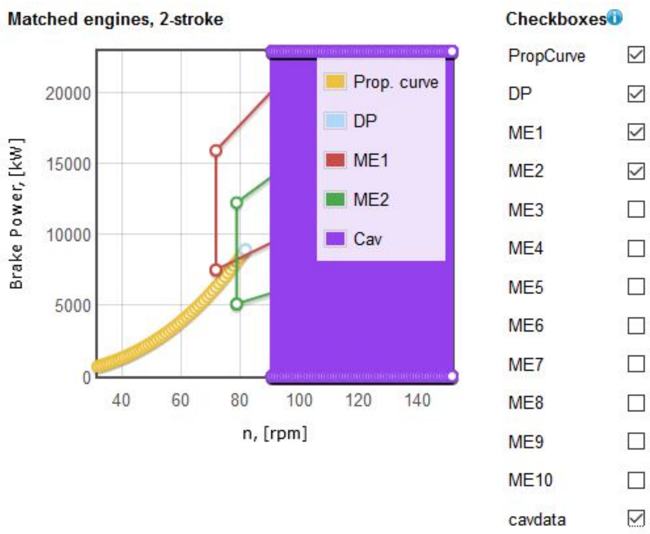

Figure 2.25: Propeller curve with suggested two-stroke engines and cavitation area

2.3.2 Cavitation data

In the propeller curve graph, the cavitation data are plotted. The cavitation data describes where in the graph there is a risk for cavitation. The data are extracted from the Keller Criteria which uses a blade area estimation technique where the mean thrust are put in relation to the required blade surface area. The Keller criteria is derived as:

$$\frac{A_E}{A_0} = \frac{(1.3 + 0.3Z)T}{(P_0 - P_V)D^2} + K \tag{2.41}$$

where
A_E/A_0: Blade area coefficient
P_0: Static pressure at centerline of the immersed propeller [kN/m^2]
P_V: Vapour pressure [1.7 kN/m^2]
Z: Number of blades
D: Propeller diameter [m]
T: Propeller thrust[kN]
K is constant which varies with number of propellers and shiptype as:
K = 0.0 for fast naval ships (twin screw)
K = 0.1 for slow merchant ships (twin screw)
K = 0.2 for single screw ships
The formula can be rewritten as:

$$T_{max} = (\frac{A_E}{A_0} - K)\frac{(P_0 - P_V)D^2}{(1.3 + 0.3Z)T} \tag{2.42}$$

where T_{max} is a maximum thrust is calculated for a given blade area ratio of the design. This maximum thrust should not be exceeded to minimize the risk of cavitation. The thrust is evaluated for all rpm as follows:

$$T = \frac{R_T}{1-t}/no.Props \tag{2.43}$$

where t is the given thrust deduction coefficient (derived from the hull form), and R_T is the total resistance evaluated by the Holtrop-Mennen method for each rpm with corresponding ship speed. To minimize risk of cavitation, $T/T_{max} < 1$. For the chosen design of the propeller, there is a certain value of rpm from which a cavitation risk is active. When using the Keller criteria, typically it is face and back cavitation that are evaluated. The face and back cavitation will result in thrust breakdown and is something very important trying to eliminate or minimize in the design.

2.3.3 Engine performance

With a number of engines matched, the interest now lay on the performance of these engines. With information about these engines, from MAN (MAN [2016]) and their CEAS tool(CEA), polynomials on the fuel consumption has been created for each engine. These polynomials for the engines that has been matched are plotted in the next step. The Fuel consumption are displayed both in grams of fuel per kiloWattHour and ton fuel per day. See Figure 2.26 and 2.27.

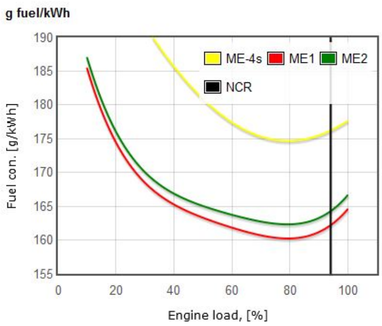

Figure 2.26: Fuel consumption [g/kWh] versus engineload [%]

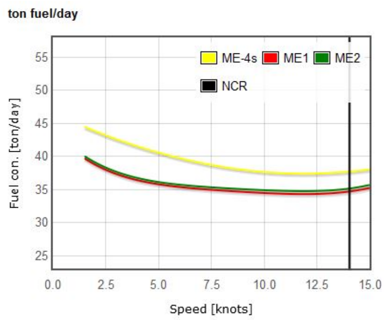

Figure 2.27: Fuel consumption [ton/day] versus speed [kn]

2.3.4 Suggested engine

This section ends with a table of suggested engines and relevant information such as names and number of engines, SFOC at different conditions and cylinder utilization. In the SFOC columns the fuel consumption is displayed as gram fuel per kWh and as kg per day to better see the difference between the engines. For the last SFOC column, SFOC min, the minimum fuel consumption is displayed together with the speed for that fuel consumption.

With these graphs and the table a choice can be made on which engine the user wants to use. For further comparison an EEDI, Energy Efficiency Design Index value can be calculated for each engine by going to the ”EEDI(4)” tab. More on this in the EEDI chapter.

2.4 EEDI

To evaluate the environmental impact of the engines an Energy Efficiency Design Index, EEDI, is calculated. The EEDI is an index the define the amount of carbon dioxide that the ship produce during operation. The unit is gram CO_2 per ton-mile.
In these calculations a required EEDI and a attained EEDI is determined. The attained EEDI have to be equal to or lower then the required EEDI. The EEDI has been developed by IMO(IMO [2014]) and are today a commonly used index. By filling in some more information such as type of fuel on the main engine, the auxiliary engine and ice class, the user can then activate the function and receive a required EEDI and a attained EEDI for all of the suggested engines. The attained EEDI is calculated for the design condition, the operating condition and for the case where the fuel consumption is at its lowest.

2.4.1 Required EEDI

The required EEDI is calculated with:

$$EEDI_{req} = a * b^c \tag{2.44}$$

where:
a,c are variables determined by the type of ship.

Table 2.3: EEDI required variables

Ship type	a	c
Container	174.22	0.201
Tanker	1218.80	0.488
Bulk	961.79	0.477
General cargo	107.48	0.216
Ro-Ro ship	1405.15	0.498
Ro-Pax ship	752.16	0.381
Large pax	not used*	not used*
Small pax	not used*	not used*

* EEDI not valid for this case
b = capacity(different depending on ship type).
Capacity depends on ship type. See table 2.4.
V = volume
k1 = 0.2+0.02*$log10(V)$ (ORGANIZATION [1983])

Table 2.4: Capacities for different shiptypes

Ship type	**Capacity**
Container	0.7*Deadweight
Tanker	Deadweight
Bulk	Deadweight
General cargo	Deadweight
Ro-Ro ship	Deadweight
Ro-Pax ship	Deadweight
Large pax	GT, not used (GT=k1*V)
Small pax	GT, not used (GT=k1*V)

2.4.2 Attained EEDI

From the inputs by the user the attained EEDI can be calculated by:

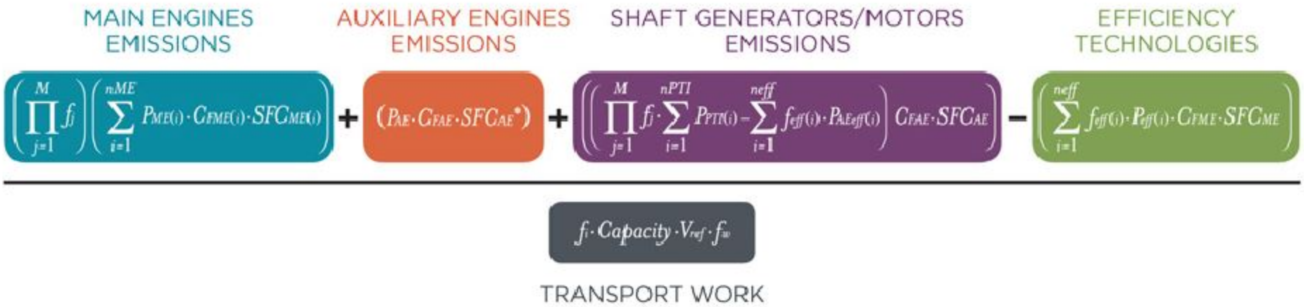

Figure 2.28: Formula for EEDI

The first term, marked blue, is a summation of the main engines times the f_j term. f_j is a correction factor that takes design elements in to consideration. It depends on the type of ship and the ice class and if no ice class is given $f_j = 1$.

Each engine term is a multiplication of the engine power(P_{ME}), fuel type coefficient(CF_{ME}) and the fuel consumption($SFOC_{ME}$).
In similar fashion the auxiliary engine, marked orange, is a multiplication of the power(P_{AE}), fuel type coefficient(CF_{AE}) and the fuel consumption($SFOC_{AE}$). In this design tool a simplified formula to estimate the size of the auxiliary engine is used (Rowen et al. [1990]).

$$kWe = 100 + 0.55 * MCR^{0.7} \tag{2.45}$$

where:
MCR= main engine maximum continus rating in kW.
The third term, purple, defines the shaft generator or motors. For the design tool a choice has been made to not include this part. Both since more input is needed by user that could be hard to estimate and the design tool searches for a brake power and estimates a main engine. No information about the auxiliary system. In this case the simplified formula is used for an easy way to estimate one auxiliary engine, no shaft generator. This term is removed.
The three terms for the Main engine, auxiliary engine and the shaft generator is added and then subtracted with the saving from the efficiency technologies. The efficiency technologies used in the design tool is a "Air lubrication system" and a "Waste heat recovery system".
This sum is then divided by the transport work:

$$f_i * Capacity * V_{ref} * f_w \tag{2.46}$$

f_i is a capacity factor for any technical/regulatory limitations on capacity. It depends on ship type and ice class and if no ice class is given $f_i = 1$.
V_{ref} is the speed in knots.
f_w is a coefficient that indicate the decrease of speed in different sea conditions, for example Beaufort 3. For most new ships $f_w = 1$.

3

Results

3.1 DEToSC (Design Evaluation Tool of Ship Concept)

The work of this thesis has resulted in a design tool accessible on the webpage paae.se under the SSEM Display section. An overview of the page and its tabs can be seen in Appendix C.

3.2 Validation of DEToSC

The validation of this design tool has been performed by comparing its output to existing ships and their data. The validation has been divided into different section to better validate the design tool. This way each sections output does not disturb the next sections output(a fault in an early stage will be carried on and cause an impact). The input for each section is the data from the reference ships. The ships chosen to be reference ships is called RoRo1, RoRo2 and general1, Two Ro-Ro ships and one general cargo. See Appendix D for information on the reference ships. Due to the fact that the data available on existing ships does not contain all the information that is needed, only the first few sections could be validated separately. Therefore an overall validation has been performed. This validation is easier to perform since the input is only the ship particulars.

3.2.1 Hull shape (1)

The first validation is on the ship particulars and the hull coefficients followed by the resistance calculations.

Generate ship particulars

As Table 3.1 displays in the difference column it determines the ship particulars quite well. Most of the variables differ by only ± 3%.

Table 3.1: Validation of ship particular

Input	RoRo1			RoRo2			General1		
LOA	183,1			190,2			199,9		
Beam	25,2			26			31		
Draft	7,5			7,5			11,5		
Cargo capacity	-			12000			37000		
Range	-			6000			10000		
Shiptype	Ro-Ro			Ro-Ro			General cargo		
Output	***Reference***	***DEToSC***	***Difference***	***Reference***	***DEToSC***	***Difference***	***Reference***	***DEToSC***	***Difference***
Deadweight	12500	-	-	14000	12834	-8%	40000	38991	-3%
Lightship	9167	-	-	10174	10501	+3%	14000	14790	+6%
Displacment	21667	-	-	24174	23335	-3%	54000	53781	-0,4%
LPP	172,82	174	+1%	178,6	181	+1%	191	190	-1%
LWL	174	179	+3%	183,716	187	+2%	191	196	+3%

Deadweight estimation

An approximation of the deadweight ≈ cargo capacity, when extracting the lightship weight from the ratio lightship/displacement in Table 2.1, shows no significant effect on the result.
Neglecting the auxiliary engines bunker weight gives a lower deadweight. A validation shows that auxiliary engines bunker weight up to 300 tons can be neglected since it will result in no change of the block coefficient $C_B b$. The validation is performed with a containership with LOA=200m, B=30m, T=9m, Design speed=16kn, Cargo capacity=20,000 ton, Range=2000nm, C_B=0.56.

Generate hull coefficients

The next validation is on the hull coefficients and the results can be seen in table 3.2. It can be seen that the block coefficient, C_B, differ from -0,3% to +6%. The other outputs, the midship coefficient and waterplane area coefficient, does not have enough reference data to compare with. Only RoRo2 have information on these.

Table 3.2: Validation of hull coefficients

Input	*RoRo1*			*RoRo2*			*General1*		
Deadweight	12500			14000			40000		
Lightship	9167			10174			14000		
Displacment	21667			24174			54000		
LPP	172,82			178,6			191		
LWL	174			183,716			191		
Beam	25,2			26			31		
Draft	7,5			7,5			11,5		
Output	***Reference***	***DEToSC***	***Difference***	***Reference***	***DEToSC***	***Difference***	***Reference***	***DEToSC***	***Difference***
Cb	0,6219	0,66	+6%	0,672	0,67	-0,3%	0,7717	0,79	+2%
Cm	-	0,98	-	0,991	0,98	-1%	-	0,99	-
Cwp	-	0,77	-	0,852	0,78	-8%	-	0,86	-

Resistance calculation

In this validation certain inputs are now lacking from the reference ships as well as some of the outputs to compare with. The reference ship RoRo2 contain enough data to make a full comparison on.

Table 3.3: Validation of the resistance calculations

Input	*RoRo1*			*RoRo2*			*General1*		
Deadweight	12500			14000			40000		
LOA	183,1			24174			54000		
LWL	174			183,716			191		
Beam	25,2			26			31		
Draft	7,5			7,5			11,5		
Stern type	normal			normal			normal		
Design speed	18			19,5			17		
Cb	0,6219			0,672			0,7717		
Cm	-			0,991			-		
Added res.	-			0			0		
Output	***Reference***	***DEToSC***	***Difference***	***Reference***	***DEToSC***	***Difference***	***Reference***	***DEToSC***	***Difference***
RT	647	0,608,9	-6%	679,55	786,7	+16%	-	1140,8	-

3.2.2 Propeller (2)

The second validation is on the propeller section of the design tool. This section contains four parts, hull efficiency, propeller dimensioning, relative rotative efficiency and the brake power. The reference data to use as inputs and compare outputs to, on these parts, are all lacking some data therefore the validation on this section is not so accurate.

Hull efficiency

For the hull efficiency a full comparison could only be performed on the reference ship RoRo2. See table 3.4.

Table 3.4: Validation of hull efficiency

Input	***RoRo1***			***RoRo2***			***General1***		
Prop.con.	Single			Single			Single		
Diameter Prop.	5,2			5,5			6,8		
Cb	0,6219			0,672			0,7717		
Beam	25,2			26			31		
LPP	172,82			178,6			191		
Stern type	normal			normal			normal		
Output	***Reference***	***DEToSC***	***Difference***	***Reference***	***DEToSC***	***Difference***	***Reference***	***DEToSC***	***Difference***
w	-	-	-	0,21	0,285	+36%	-	-	-
t	-	-	-	0,2	0,171	-15%	-	-	-
etaH	1,14	1,16	+2%	1,013	1,16	-15%	1,21	1,19	+2%

Propeller dimensioning, eta0

The way that the design tool is designed, the input for this part, the thrust, can only be modified by changing the operating speed. By changing it, a thrust that match the thrust from the reference ships can be achieved and a comparison can be performed. See table 3.5.

Table 3.5: Validation of propeller dimensioning

Input	***RoRo1***			***RoRo2***			***General1***		
Thrust	785			865			-		
Output	***Reference***	***DEToSC***	***Difference***	***Reference***	***DEToSC***	***Difference***	***Reference***	***DEToSC***	***Difference***
RPM	122,5	137	+12%	128	130	+2%	85,5	-	-
J	-	0,55	-	-	0,55	-15%	-	-	-
EAR	-	0,65	-	-	0,8	-	-	-	-
P/D	-	0,9	-	1	0,9	-10%	0,765	-	-
blades	-	4		4	4		5	-	
eta0	0,61	0,58	-5%	-	0,57	-	0,559	-	-

Relative rotative efficiency

This part is lacking to much input data on the reference ships to be able to perform a good validation. Information on the longitudinal center of buoyancy, prismatic coefficient, blade area ratio and pitch ratio are needed also some data from previous parts. The output is the Relative rotative efficiency.

Brake power, PB

Since this part need inputs from previous parts a validation can not be performed. The information needed are hull efficient, open water efficient, relative rotative effficienct, shaft efficiency, sea margin and engine margin. The output is the brake power, PB.

3.2.3 Main Engine (3)

The output from the ”Main Engine (3)” tab is a number of suggested engines. Since the tool only use MAN engines the best validation would be to compare the suggested engines to that of ships with MAN engines installed. It can also be compared to reference ships that do not have MAN engines by comparing its engine to a MAN engine. This way the validation can be performed by checking that the design tool either suggest one of equal size or a larger engine. In the case where the design point lies outside all of the MAN two-stroke engines the design tool will give no suggestion for two-stroke but will always give a suggestion for a four-stroke engine. If a MAN two-stroke engine still is desired changes need to be made. For the three reference ships the following engines where suggested, see table 3.6.

Table 3.6: Validation of Main engine

	RoRo1		***RoRo2***		***General1***	
Engine	Name	Power [kW]	Name	Power [kW]	Name	Power [kW]
Installed	*1xSulzer 7 RTA52U*	10920	*2xMAN 9L48/60B*	18000	*1xMAN 6S60ME*	17661
Suggested						
4-stroke	*1xMAN 12V48/60CR*	14400	*1xMAN 14V48/60CR*	16800	*1xMAN 16V48/60CR*	19200
2-stroke	-	-	-	-	-	-

3.2.4 EEDI (4)

The fourth and the last individual validation is on the EEDI section. The EEDI is calculated according to IMO (IMO [2014]) and the values calculated for the reference ships are close to that of existing ships values. See table 3.7.

Table 3.7: Validation of EEDI

	EEDI req	**EEDI at Design speed**
RoRo1	*12,81*	*9,54*
RoRo2	*12,1*	*9,88*
General1	*10,9*	*8,54*

3.2.5 Overall

To be able to perform a validation of this design tool an overall validation has been chosen. In this case it has been decide to compare the Brake power output to that of the data from the reference ship. The input for this validation has been the ship particulars. See table 3.8.

Table 3.8: Overall validation

Input	*RoRo1*	*RoRo2*	*General1*
LOA	183,1	190,2	199,9
LPP	172,82	178,6	191
LWL	174	183,715	191
Beam	25,2	26	31
Draft	7,5	7,5	11,5
Deadweight	12500	14000	40000
Lightship	9167	10174	14000
Displacement	21667	24174	54000
Shiptype	RoRo	RoRo	General cargo
Design Speed	18	19,5	17
Propeller Diameter	5,2	5,5	6,8
Output			
PB_ref	10920	18000	17661
PB_DEToSC	12542	16507	21370
Difference	+15%	-8%	+21%

4

Future Work

One step or function in this design tool that there was a hope to implement in DEToSC was that of a route simulation. The function would for instance take a route as input from a map and then use statistics on the weather to calculate the added resistance, use the length to decide amount bunker and more. Data needed to get as accurate conditions for the mission as possible. This function was decided to not be of high priority until more important steps/function had been created. Since it was deemed large and complicated it was never implemented.
Another implementation that was discussed but not implemented was to have two different start points, either ”Design new ship” or ”evaluate existing ship”. At this moment everything lies within ”Design new ship” where there is possibility to both design a new ship and input information from a reference ship to evaluate an existing ship. By separating the start point, a better structure for the ”evaluate existing ship” is possible and make it so a user could both input their own values or select a reference ship from stored ships.
Today only certain information is stored on a database. A wish was to improve the connection and the usage of the database so that the user can create and store their ships and new ships in our design tool. This way the user can compare his or her designs with each other. Another good thing about the storing of data is that it will become a source of information about new ships and existing ship which can be used by ScandiNAOS AB or students to learn, validate designs or validate functions.
In the first part, hull design, two things would be good to look at. First the superstructure parameter. More reference data needs to be gathered to create a good formula for estimating these parameters if they are not known. The second thing links with the route simulation mention earlier, how to implement that into resistance calculation. Perhaps by first having one calm resistance calculation and then when the user comes to the route simulation calculate a resistance with

the added resistance.

Some changes to the search propeller function like displaying more of the approved propeller designs could be made. The function gives the design which gives the best open water efficiency, but it could be interesting to see the other approved propeller designs with their lower open water efficiency. The function could be written in such a way that it displays all the approved designs.

In the design tool it was decided to use MAN-engines, since they are widely used and have much information about their engines. The design tool needs to be expanded in the Main engine section with more brands and more engines. The validation on the engine part resulted in a four-stroke engine for all of the reference ships, due to the rpm and brake power. With lower rpm or brake power two-stroke engines would have been suggested. If there would have been more engines of different brands more suggested engines could be displayed and a good comparison between the brands could be made. The design tool does not look at auxiliary engines or shaft generators, it only estimate these in the EEDI calculations. A new part could be made that calculates these and gives some suggestion.

A study on the EEDI results of the design tool could be made. A number of ships needs to be designed and their EEDI values stored. By then comparing these results, the EEDI value, type of ship and deadweight, with that of the regular values for those shiptypes and deadweights a good validation on the EEDI calculations can be made.

More reference ships and information on these is needed to perform a good validation. A difficult step is to get a hold of all the information on the ship that is needed to validate each part separately.

Opportunity exists to develop the tool further with new functions but also improvements to the current functions. Also on the design tools visual aspect. By making it user-friendly and modern more people are enticed to use it.

5

Conclusion

The result seen as a web based design tool are over expectation. As a design tool to get a good overview over each element and how they interact it is very good. The state of the design tool should give one of the planned users, student, a good experience and learn something from using it. It ties the separate area together and displays how they interact. For the other planned users, ship designers, the design tool needs more fixing and correcting of the outputs of each part so that they are reliable.

Looking at the result from each sections separate validation, a conclusion can be drawn that the design tool is quite accurate to determine the lengths, weights and block coefficient. On the other sections, starting from the resistance calculations, the results are not as good. They differ more and are less accurate since there are less reference data available.

An innovative idea implemented in this design tool is the view on at what condition the propeller should be optimized for. The search propeller function optimises for the service condition and not the design condition which is the normal way of doing it. In the next step when selecting a main engine the design condition is used since it needs to be able to perform at this condition. A slight improvement on the open water efficiency has been seen in a few cases but a study of this need to be performed to determine this improvement. Overall the search propeller works well, where it also takes cavitation into consideration for both the service condition and the design condition.

Regarding cavitation it is assumed that it has its maximum at design speed. This will affect the blade area. By implementing it this way it is assured that the propeller designed for the service condition does not get cavitation at the design speed. This will results in fewer propeller cases that is approved by the ”search propeller” function, but it ensures that the propeller will not be subject to cavitation in any service condition.

The main engine selection function performs well, it always suggest engines that is equal to or larger than the brake power at design speed. But it should be expanded so that more engines from MAN and from other manufacturers can be suggested. The two resulting graphs on fuel consumption and the table that presents the engines show the result in a good way. The project as a whole has had a steep learning curve, where both knowledge in each section hull design, propeller design and engine selection where gathered and knowledge in the programming language used where learned. The layup or structure of the code can be improved. Since most of the knowledge have been self learned the structure is not always as clear as it should be. Some functions could be streamlined, minimized and made more logical to both lower the amount of code as well as making it easier to understand for the coder.
The usability of the page have been implemented to a good degree. Throughout the steps and tabs exists a clear line and a possibility to go back is presented at many parts. The results from every step and calculations is presented and explained in the information icon. Figures and graphs is presented to give the user as much understanding as possible. Some of which can be interacted with. As a webpage the goal was to create a page that contain much data yet looks simple to be informative yet quick to get a grasp of the scope of the design tool.

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A

Appendix A - Data used for determining the influence of the superstructure on added resistance

Ship data for used ship en evaluation of the influence from head wind in added resistance calculation:

Ship 1	
Parameter	Value
Type	Containership
LOA	200 m
B	30 m
T	9 m
Design speed	16 kn
Cargo capacity	20000 ton
Range	2000 NM
DWT	20577 ton
LS	8610 ton
Displacement	29187 ton
LPP	190 m
LWL	192 m
Cb	0.56
Cm	0.95
Cwp	0.71

Ship 1.1 and 1.2 data:

Added resistance			
Beaufort scale	Ship 1.1	Ship 1.2	Relative difference
3	8%	10%	20%
4	22%	25%	12%
5	48%	54%	11%
6	85%	96%	11%
7	159%	176%	10%
8	294%	318%	8%
9	522%	556%	6%

B

Appendix B - Wagening B-series

Coefficients for KT and KQ for the Wagening B-series polynomials are shown in Table B.1 and Table B.2. The coefficients are used to plot all the Wagening B-series propellers in the web design tool.
Below are the summation equations used to derive KT and KQ from the coefficients. The coefficients are valid for Reynolds number $R_n = 2 \times 10^6$.

$$KT = \sum_{s,t,u,v} C^{T}_{s,t,u,v} \times J^s \times (P/D)^t \times (Ae/Ao)^u \times z^v \tag{B.1}$$

$$KQ = \sum_{s,t,u,v} C^{Q}_{s,t,u,v} \times J^s \times (P/D)^t \times (Ae/Ao)^u \times z^v \tag{B.2}$$

Table B.1: Coefficients for the polynomials of KT in Wagening B-series

		KT		
$C^T_{s,t,u,v}$	s (J)	t (P/D)	u (Ae/Ao)	v (Z)
0,00880496	0	0	0	0
-0,204554	1	0	0	0
0,166351	0	1	0	0
0,158114	0	2	0	0
-0,147581	2	0	1	0
-0,481497	1	1	1	0
0,415437	0	2	1	0
0,0144043	0	0	0	1
-0,0530054	2	0	0	1
0,0143481	0	1	0	1
0,0606826	1	1	0	1
-0,0125894	0	0	1	1
0,0109689	1	0	1	1
-0,133698	0	3	0	0
0,00638407	0	6	0	0
-0,00132718	2	6	0	0
0,168496	3	0	1	0
-0,0507214	0	0	2	0
0,0854559	2	0	2	0
-0,0504475	3	0	2	0
0,010465	1	6	2	0
-0,00648272	2	6	2	0
-0,00841728	0	3	0	1
0,0168424	1	3	0	1
-0,00102296	3	3	0	1
-0,0317791	0	3	1	1
0,018604	1	0	2	1
-0,00410798	0	2	2	1
-0,000606848	0	0	0	2
-0,0049819	1	0	0	2
0,0025983	2	0	0	2
-0,000560528	3	0	0	2
-0,00163652	1	2	0	2
-0,000328787	1	6	0	2
0,000116502	2	6	0	2
0,000690904	0	0	1	2
0,00421749	0	3	1	2
5,65229E-05	3	6	1	2
-0,00146564	0	3	2	2

Table B.2: Coefficients for the polynomials of KQ in Wagening B-series

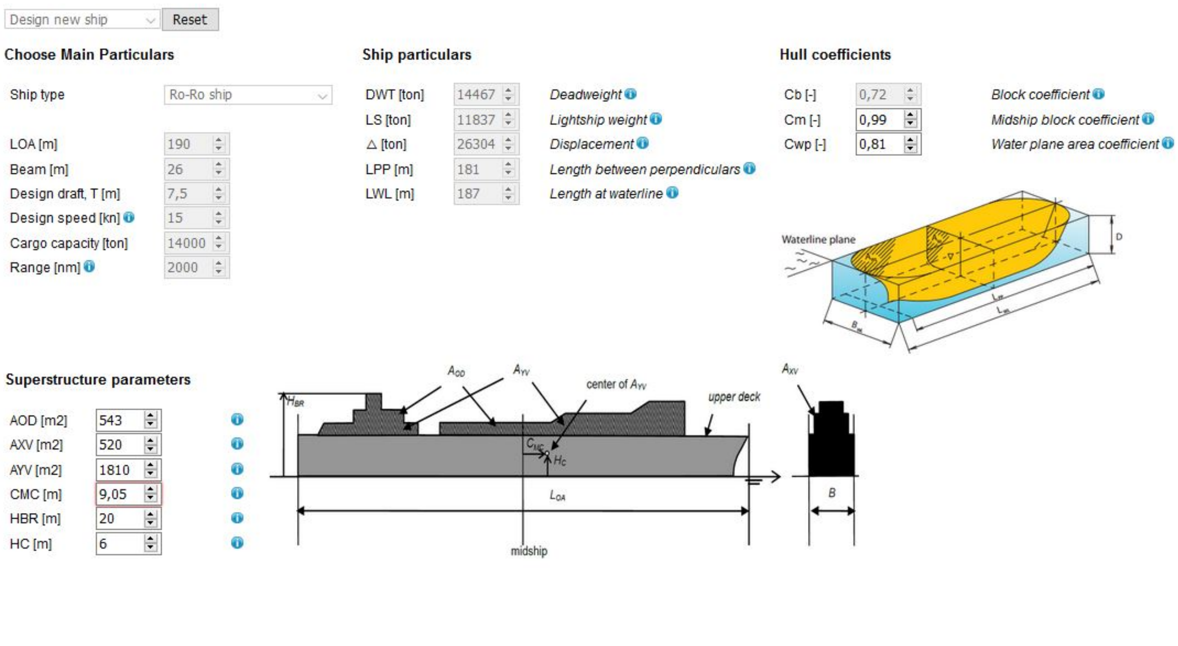
		KQ		
$C^{Q}_{s,t,u,v}$	s (J)	t (P/D)	u (Ae/Ao)	v (Z)
0,00379368	0	0	0	0
0,00886523	2	0	0	0
-0,032241	1	1	0	0
0,00344778	0	2	0	0
-0,0408811	0	1	1	0
-0,108009	1	1	1	0
-0,0885381	2	1	1	0
0,188561	0	2	1	0
-0,00370871	1	0	0	1
0,00513696	0	1	0	1
0,0209449	1	1	0	1
0,00474319	2	1	0	1
-0,00723408	2	0	1	1
0,00438388	1	1	1	1
-0,0269403	0	2	1	1
0,0558082	3	0	1	0
0,0161886	0	3	1	0
0,00318086	1	3	1	0
0,015896	0	0	2	0
0,0471729	1	0	2	0
0,0196283	3	0	2	0
-0,0502782	0	1	2	0
-0,030055	3	1	2	0
0,0417122	2	2	2	0
-0,0397722	0	3	2	0
-0,00350024	0	6	2	0
-0,0106854	3	0	0	1
0,00110903	3	3	0	1
-0,000313912	0	6	0	1
0,0035985	3	0	1	1
-0,00142121	0	6	1	1
-0,00383637	1	0	2	1
0,0126803	0	2	2	1
-0,00318278	2	3	2	1
0,00334268	0	6	2	1
-0,00183491	1	1	0	2
0,000112451	3	2	0	2
-2,97228E-05	3	6	0	2
0,000269551	1	0	1	2
0,00083265	2	0	1	2
0,00155334	0	2	1	2
0,000302683	0	6	1	2
-0,0001843	0	0	2	2
-0,000425399	0	3	2	2
8,69243E-05	3	3	2	2
-0,0004659	0	6	2	2
5,54194E-05	1	6	2	2

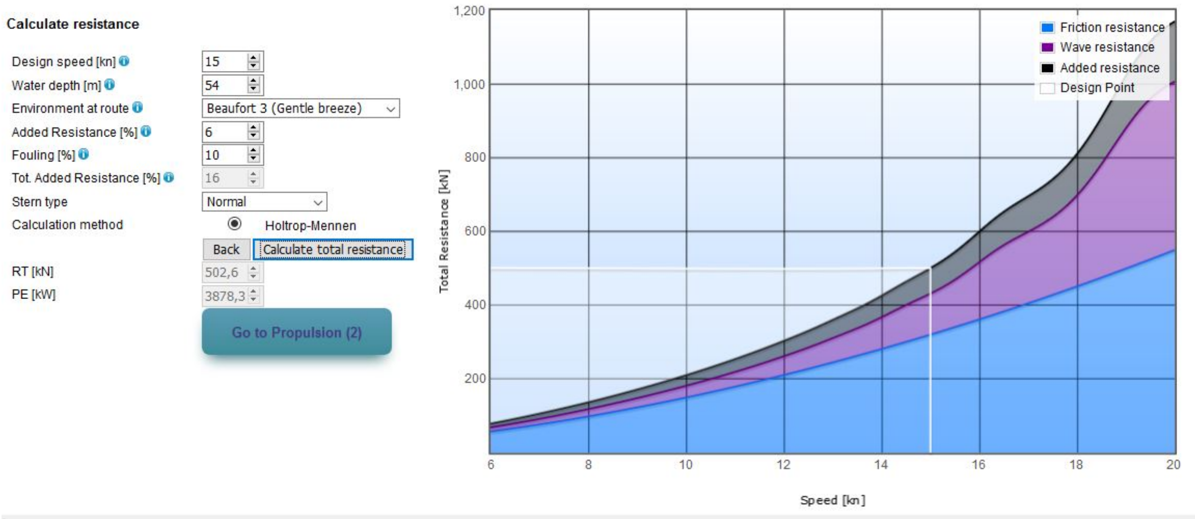
C

Appendix C - Overview of DEToSC

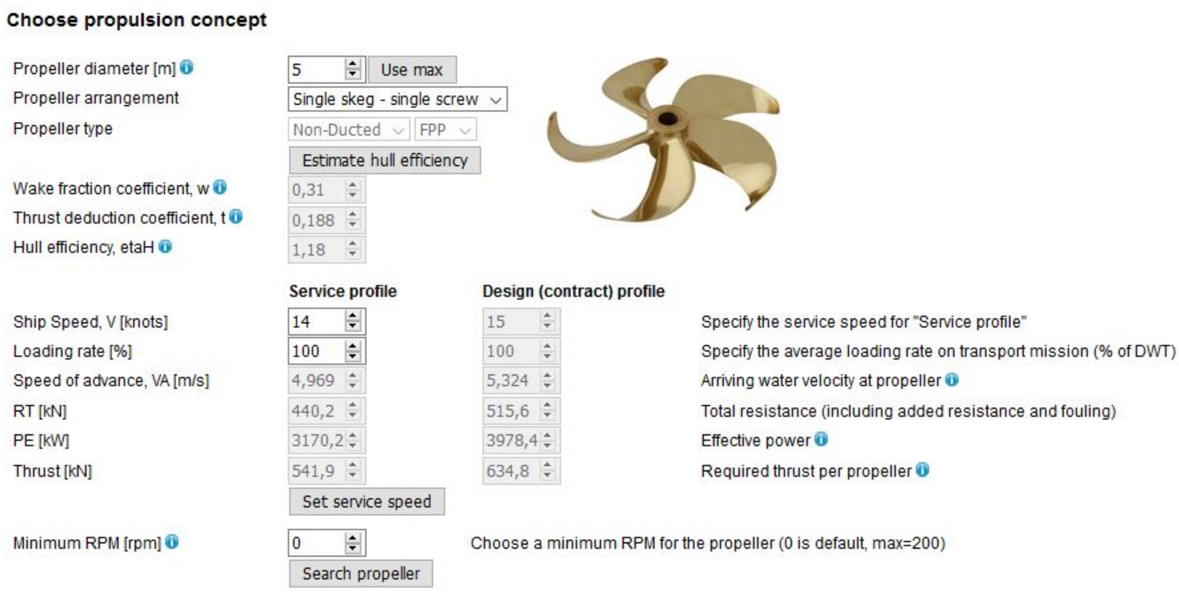
An example run of the DEToSC in the order they appear on the webpage.

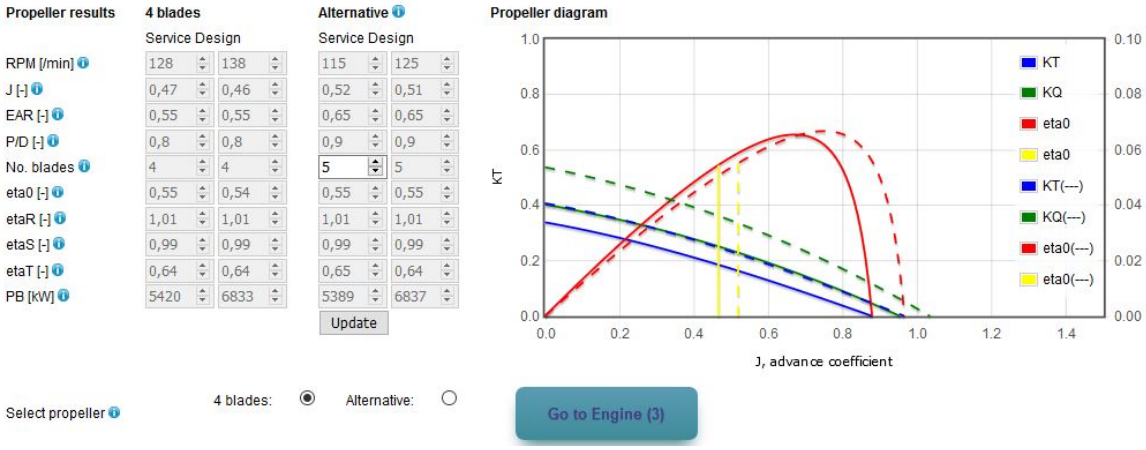
Hull shape (1)



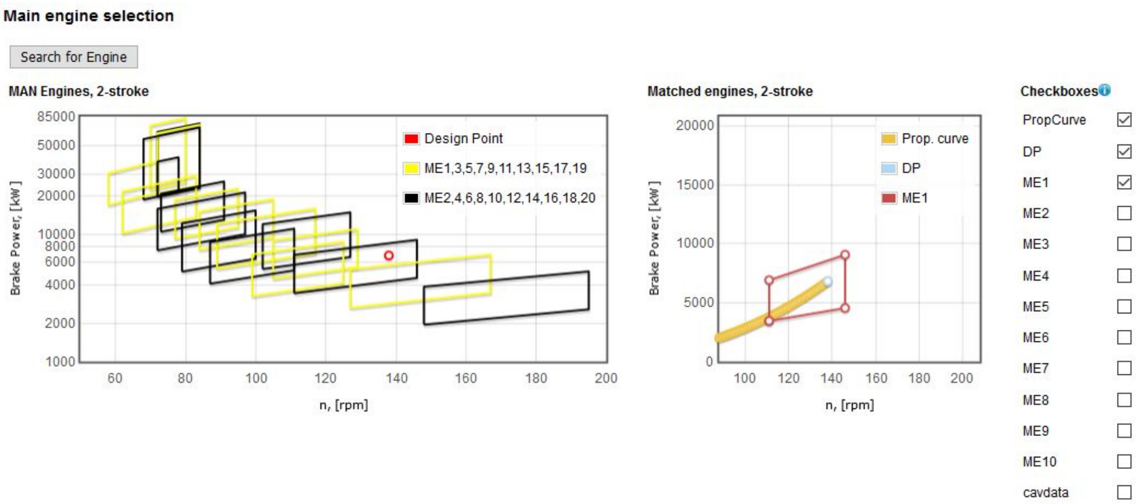

Calculate resistance
Design speed [kn]
15
Water depth [m]
54
Environment at route
Beaufort 3 (Gentle breeze)
Added Resistance [%]
6
Fouling [%]
10
Tot. Added Resistance [%]
16
Stern type
Normal
Calculation method
Holtrop-Mennen
Back
Calculate total resistance
RT [kN]
502,6
PE [kW]
3878,3
Go to Propulsion (2)
Friction resistance
Wave resistance
Added resistance
Design Point
Total Resistance [kN]
Speed [kn]

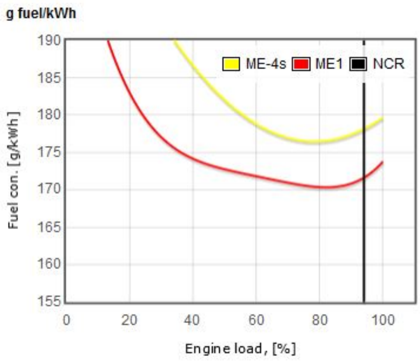
Propeller (2)

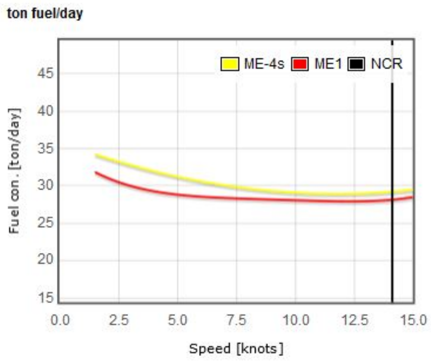

Choose propulsion concept
Propeller diameter [m]
5
Use max
Propeller arrangement
Single skeg - single screw
Propeller type
Non-Ducted
FPP
Estimate hull efficiency
Wake fraction coefficient, w
0,31
Thrust deduction coefficient, t
0,188
Hull efficiency, etaH
1,18
Service profile
Design (contract) profile
Ship Speed, V [knots]
14
15
Specify the service speed for "Service profile"
Loading rate [%]
100
100
Specify the average loading rate on transport mission (% of DWT)
Speed of advance, VA [m/s]
4,969
5,324
Arriving water velocity at propeller
RT [kN]
440,2
515,6
Total resistance (including added resistance and fouling)
PE [kW]
3170,2
3978,4
Effective power
Thrust [kN]
541,9
634,8
Required thrust per propeller
Set service speed
Minimum RPM [rpm]
0
Choose a minimum RPM for the propeller (0 is default, max=200)
Search propeller



Main engine (3)







Suggested engines:

	Manufacturer	Name	No.	No. cyl.	Cyl. util. [%]	SFOC (100% MCR) [g/kWh]	SFOC (100% MCR) [kg/day]	SFOC (NCR) [g/kWh]	SFOC (NCR) [kg/day]	SFOC (min) [g/kWh]	SFOC (min) [kg/day]	Required speed[kn]
ME-4 stroke:	MAN	L48/60CR	1	7	130.58	179.7	29466.1	178.1	29213.7	176.465	28938.9	11.700C
Main engine 1:	MAN	S40ME	1	7	18	173.8	28498.9	171.6	28145.0	170.342	27934.8	12.300C

Go to EEDI(4)

EEDI (4)

EEDI calculation

Main Engine, Type of fuel: Heavy Fuel Oil, HFO

Auxiliary engine, Type of fuel: Heavy Fuel Oil, HFO

Ice class: No ice class

Calculate EEDI

	EEDI required, [gCO2/tnm]:	EEDI, [gCO2/tnm]: At design speed:	EEDI, [gCO2/tnm]: At operating speed:	EEDI, [gCO2/tnm]: At minimum SFOC:
4-stroke engine:	11,91	1,1	1,2918	2,1603
Main engine 1:	11,91	1,06	1,2445	1,8101

D

Appendix D - Reference ships for validation

Reference data for the three ships, RoRo1, RoRo2 and General1, used to validate DEToSC. See next page.

NAME	RoRo1
Main Particulars	
LOA [m]	183,1
Beam, B [m]	25,2
Design draft, T [m]	7,5
Design (contract) speed [kn]	18
Ship type	RoRo
Cargo capacity [ton]	
Range [nm]	
Ship particulars	
DW [ton]	12500
LS [ton]	9167
Volume [m3]	
Displacement [ton]	21667
LWL [m]	174
Maximum section area Amx [m2]	
Waterplane area, Awl [m2]	
LPP [m]	172,82
Block coefficient, Cb = Volume/(Lwl x B x T)	0,6219
Maximum section coefficient, Cm = Amx/(B x T)	
Waterplane coefficient, Cwp = Awl/(Lwl x B)	
Prismatic coefficient, Cp Volume/(Lwl x Amx)	
Wetted surface area WSA	4977
Wetted surface area WSA incl appendix	
Generated superstructure parameters	
No superstructure parameters	
Environmental conditions	
No enviormental conditions	
Calculate resistance	
Stern type	
SM [%]	0,21
Added Resistance [%]	0,167
Resistance method	Holtrop-Mennen
Operational profile	
Ship Speed, V [knots]	18
Speed of advance, VA [m/s]	
RT [kN]	647
PE [kW]	5238
Thrust [kN]	785
Wake fraction coefficient w	
Thrust deduction coefficient t	
Hull efficiency	

Propeller diameter [m]	5,2
Propeller arrangement	Single
Propeller type	CPP
RPM [/min]	
Advance number, J	
EAR, EAR	
Pitch ratio, P/D	
Number of blades, z	
Open water efficency, eta0	61%
Relative rotative efficency, etaR	100%
Propeller efficiency, behind hull = etaB = eta0 x etaR	61%
Hull efficiency = etaH = (1-t)/(1-w)	114%
Propulsive efficency, etaD = etaB x etaH	70%
Shaft efficiency, etaS	99%
Total efficency, etaT = etaD x etaS	69%
PD_des_est [kW]	8593
PB_des_est [kW]	
Cotract SM	
Contract engine margin	
Contract shaft generator	
Design (contract) Brake power, PB [kW]	10920
RPM at contract brake power [RPM]	122,5
ME:	1xSulzer 7 RTA 52 U disel
link with info about ship :	http://www.faktaomfartyg.se/sp

NAME	RoRo2
Main Particulars	
LOA [m]	190,2
Beam, B [m]	26
Design draft, T [m]	7,5
Design (contract) speed [kn]	19,5
Ship type	RoRo
Cargo capacity [ton]	
Range [nm]	6000
Ship particulars	
DW [ton]	14000
LS [ton]	10174
Volume [m3]	
Displacement [ton]	24174
LWL [m]	183,716
Maximum section area Amx [m2]	
Waterplane area, Awl [m2]	
LPP [m]	178,6
Block coefficient, Cb = Volume/(Lwl x B x T)	0,672
Maximum section coefficient, Cm = Amx/(B x T)	0,991
Waterplane coefficient, Cwp = Awl/(Lwl x B)	0,852
Prismatic coefficient, Cp Volume/(Lwl x Amx)	0,678
Wetted surface area WSA	5860
Wetted surface area WSA incl appendix	5929
Generated superstructure parameters	
No superstructure parameters	
Environmental conditions	
No enviormental conditions	
Calculate resistance	
Stern type	
SM [%]	
Added Resistance [%]	0
Resistance method	Holtrop-Mennen
Operational profile	
Ship Speed, V [knots]	19,5
Speed of advance, VA [m/s]	
RT [kN]	679,55
PE [kW]	6830,5
Thrust [kN]	
Wake fraction coefficient w	0,21
Thrust deduction coefficient t	0,2
Hull efficiency	1,013

Propeller diameter [m]	5,5
Propeller arrangement	Single
Propeller type	CPP
RPM [/min]	128
Advance number, J	
EAR, EAR	
Pitch ratio, P/D	1
Number of blades, z	4
Open water efficency, eta0	
Relative rotative efficency, etaR	
Propeller efficiency, behind hull = etaB = eta0 x etaR	
Hull efficiency = etaH = (1-t)/(1-w)	
Propulsive efficency, etaD = etaB x etaH	
Shaft efficiency, etaS	
Total efficency, etaT = etaD x etaS	59%
PD_des_est [kW]	12789
PB_des_est [kW]	
Cotract SM	15%
Contract engine margin	90%
Contract shaft generator	800
Design (contract) Brake power, PB [kW]	18000
RPM at contract brake power [RPM]	130
ME:	2 x MAN 9L48/60B diesel
link with info about ship :	http://www.faktaomfartyg.se/

NAME	General1
Main Particulars	
LOA [m]	199,9
Beam, B [m]	31
Design draft, T [m]	11,5
Design (contract) speed [kn]	17
Ship type	General cargo
Cargo capacity [ton]	37000
Range [nm]	10000
Ship particulars	
DW [ton]	40000
LS [ton]	14000
Volume [m3]	
Displacement [ton]	54000
LWL [m]	191
Maximum section area Amx [m2]	
Waterplane area, Awl [m2]	
LPP [m]	191
Block coefficient, Cb = Volume/(Lwl x B x T)	0,7717
Maximum section coefficient, Cm = Amx/(B x T)	
Waterplane coefficient, Cwp = Awl/(Lwl x B)	
Prismatic coefficient, Cp Volume/(Lwl x Amx)	
Wetted surface area WSA	8470
Wetted surface area WSA incl appendix	
Generated superstructure parameters	
No superstructure parameters	
Environmental conditions	
No enviormental conditions	
Calculate resistance	
Stern type	
SM [%]	
Added Resistance [%]	
Resistance method	
Operational profile	
Ship Speed, V [knots]	17
Speed of advance, VA [m/s]	
RT [kN]	
PE [kW]	
Thrust [kN]	
Wake fraction coefficient w	
Thrust deduction coefficient t	
Hull efficiency	

Propeller diameter [m]	6,8
Propeller arrangement	Single
Propeller type	FPP
RPM [/min]	85,5
Advance number, J	
EAR, EAR	
Pitch ratio, P/D	0,769
Number of blades, z	5
Open water efficency, eta0	55,9%
Relative rotative efficency, etaR	100%
Propeller efficiency, behind hull = etaB = eta0 x etaR	55,9%
Hull efficiency = etaH = (1-t)/(1-w)	121%
Propulsive efficency, etaD = etaB x etaH	67,6%
Shaft efficiency, etaS	99%
Total efficency, etaT = etaD x etaS	67,0%
PD_des_est [kW]	6500
PB_des_est [kW]	14200
Cotract SM	12%
Contract engine margin	90%
Contract shaft generator	
Design (contract) Brake power, PB [kW]	17661
RPM at contract brake power [RPM]	
ME:	1 x MAN 6S60 MC-C
link with info about ship :	https://www.fleetmon.com/ve

E

Appendix D - Beaufort Scales

The data used to transfer Beaufort scales to wind speed, wave heights and wave lengths. Some modifications has been made to have a good range and to be conservative.

Table E.1: My caption

Beaufort	**Description**	**Wind [km/h]**	**Wave length [m]**	**Wave height [m]**
0	*Calm*	0-1	-	-
1	*Light air*	2-6	to 5	0,1-0,2
2	*Light breeze*	7-12	to 15	0,2-0,3
3	*Gentle breeze*	13-18	to 25	0,6-1,0
4	*Moderate breeze*	19-26	to 50	1,0-1,5
5	*Fresh breeze*	27-35	to 75	2,0-2,5
6	*Strong breeze*	36-44	to 100	3,0-4,0
7	*Near gale*	45-54	to 135	4,0-5,5
8	*Gale*	55-65	150-200	5,5-7,5
9	*Strong gale*	66-77	150-200	7,0-10,0
10	*Storm*	78-90	to 250	9,0-12,5
11	*Violent storm*	91-104	to 300	11,5-14,0
12	*Hurricane*	>104	300 and longer	15,0 and higher