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DESIGNING CONSTRAINTS IN EVALUATION OF SHIP PROPULSION POWER

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Abstract

Preliminary ship owners' assumptions for new ship consist of deadweight (for container vessel load capacity TEU), speed shipping line and others. Taking it as a base, in early stage of design one has to select propulsion type. This goal needs definition of principal dimensions of a vessel, which are the base for further calculations of hull's resistance and evaluation of necessary power of main engine (engines) to fulfil shipping requirements. Selection of main dimensions of vessel is limited by rules regarding buoyancy, stability, hull strength, manoeuvring capability, and limitations related to seaways or harbours characteristic. In this paper is presented the methodology of calculation of principal parameters of a vessel, necessary for calculation of displacement in relation to vessel's type, volumetric coefficients, Froude number, and others values affecting ship's dimensions. It is about midship section coefficient, waterline coefficient, prismatic coefficients and hull feature and area coefficients. Those values are necessary for calculation of hull resistance. In the table are presented comparison of results of calculations above mentioned values and movement resistance and propulsion power of three container vessels representing different load capacity and one bulk carrier. There are also presented different calculation methods of transverse midship section coefficient and wet area coefficient, for 5000TEU container vessel.

Keywords*: seagoing ships, hull coefficient, hull dimensions parameters, propulsion power*

1. Introduction

In ship owner assumptions, load capacity (TEU) for container vessels and dead weight (DWT) for other classes, and speed are given. Those values have strong impact at necessary power of the first estimate that the Naval Architect makes is to estimate the lightweight of the new ship. Starting with some definitions:

1. *Lightweight*: This is the weight of the ship itself when completely *empty*, with boilers topped up to working level. It is made up of steel weight, wood and outfit weight and machinery weight.
2. *Deadweight*: This is the weight that a ship *carries*. It can be made up of oil fuel, fresh water, stores, lubricating oil, water ballast, crew and effects, cargo and passengers.
3. *Displacement*: This is the volume of water displaced by submerged part of the hull ∇ [m^3]. Also expression mass displacement is used $\Delta = \nabla\rho_{fw}$. For Baltic Sea, sea water density value is ρ_{fw} =1025.6 kg/ m^3 at water temperature 15°C [2].

2. Definition of displacement of ship Δ

Deadweight coefficient CD links the deadweight with the displacement. CD will depend on the ship type being considered.

Step by step, all parameters and any other important subject related to the planning of our power plant will be calculated, so that at the end of this project the complete and correctly design of it will be provided.

Considering ship mass one has:

mass displacement Δ= dead weight (DWT) + mass of hull.

That why important is knowing of relation TEU/DWT and DWT/Δ. Relations enable to define ships dead weight in domain of container vessel load capacity, and capacity expressed in mass units as a function of ship's dead weight. Mass of cargo and provisions is a part of whole ship mass.

During the last years, as our comparison ships are showing, the deadweight of these vessels has slowly and slightly decreased. Putting aside the difference of weight, because of the number of containers loaded on board, which is not so decisive, we could explain this as following. Defining deadweight as:

$$DWT = w_{\mathrm{load}} + w_{provisions} + w_{crew} + w_{stores}\,, \tag{1}$$

where: $w_{provisions} = w_{fuel} + w_{oil} + w_{\text{fresh water}} + w_{food}$.

We can suppose, that being a reduction of the weight of the crew, stores, fresh water, food, oil or load totally illogical and out of order, the main reason for this decrease of the deadweight during the time is the possibility of a fuel amount reduction.

Another scope of project is to show the importance of using a proper propulsion system in a ship as described. This will result in a better employment of the general resources of the ship, what means a reduction of consumption in fuel oil, lubrication oil, etc. and a more efficient maintenance.

To have a general view of the designed ship, we will show the most important data, as main dimensions of the hull, block coefficient, deadweight or Froude number, in following points of this project.

3. Hull Dimensions parameters´ calculations

The first and essential step before beginning with the calculations to design our power plant is to estimate the main dimensions of the hull of our vessel.

In order to achieve this we will estimate the main dimensions of the hull of vessels in design employing the values of the comparison ships´ tables above.

For practical implementation, the obtained values should be optimized by additional calculation loops, if necessary.

A proper development of a detailed table which contains the most important data of very similar ships to ours is the first and one of the most important steps to estimate the main dimensions of the hull of our vessel.

From all the values of our comparison ships´ tables we will take the Froude number (Fn) and the block coefficient (C_B) as constants, for beginning our calculations.

Doing selection of principal dimensions of a vessel, especially length (L) ranges of Froude numbers when local maxima of wave resistance occurs, must be omitted. The maxima can be observed in range 0.22-0.23; and 0.32 and global value of that coefficient for F_n=0.5.

This is very important for fast ships like passenger ships or container vessels, for which typical Froude number is placed in range of first local maximum. For typical cargo vessels like tankers or bulk carriers, the Froude number is below 0.2, when problem of wave resistance does not occur.

3.1. Calculation of the Block Coefficient (C_B)

That coefficient, basing on data base elaborated with support the knowledge about contemporary ships, is defined by different formulas, corresponding to different classes of vessels. Formula given bu C.D Barras [1] relates CB to Froude number, and it is assumed that those are limit values for different classes of vessels.

$$C_B = 1.20\text{-}2.378\ Fn. \tag{2}$$

In Fig. 1. there are presented typical relations of Block Coefficient and Froude number. One has to notice that for contemporary vessels, Froude number values are in recommended intervals, what means that are over values of local maxima of wave resistance coefficient. Also taking container vessels as an example, is clear that Block Coefficient is below recommended limit value 0.65 [5].

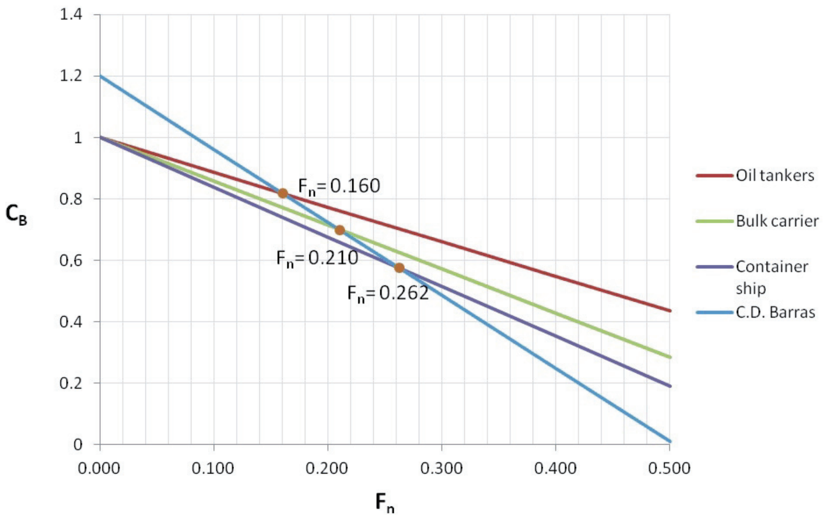

Fig. 1 Relation of Block Coefficient to Froude number

3.2. Calculation of the Volumetric Coefficient (C_∇) or slender coefficient $L/\nabla^{1/3}$

The volumetric coefficient describes the relation between the submerged ship´s volume and its length]. One of the suggested formulas to estimate this coefficient is this one $C_\nabla = \nabla/L^3$[1]. Volumetric coefficient is often swapped with coefficient $L/\nabla^{1/3}$. For typical cargo vessels it takes value between 4 and 6, and for fast vessels, i.e. container and passenger ships from 6 to 7.5 [2].

3.3. Calculation of the Midship Section Coefficient (C_M)

$$C_M = A_M/BT, \tag{3}$$

where:
A_M– midship section area,
L,B,T – length, breadth and draft.

During the last years, some formulas to calculate the midship section coefficient were developed. All these equations are based on the experience of existing hull forms.

This coefficient describes the relation between the midship section (until a determined waterline) and the area of a rectangle, which sides are the draft and the breath of the ship.

Next we will expose three of the most used formulas to calculate our C_M according to.[6] and calculations their values for container Vessel of 5000TEU, for which block coefficient is C_B and calculate their value for container ship with loading capacity 5000TEU,wich the coefficient of the hull C_B is 0.626.

Equation of Benford: $C_M = 0.977 + 0.085 * (C_B - 0.60)$ C_M=0.979, (4)

Equation of Schneekluth and Bertram: $C_M = 1.006 - 0.0056 * C_B^{-3.56}$, (5)

Equation of Jensen: $C_M = (1 + (1 - C_B)^{3.5})^{-1}$, (6)

Equation of Nogid: $C_M = 0.928 + 0.080 C_B$, C_M =0.978. (6a)

In this way we are avoiding to have a bad value according to the hull´s resistance and we are not losing the “box” form recommended in this kind of ships for a better stow of the load.

3.4. Calculation of the Waterplane Coefficient (C_{WP})

$$C_{WP} = A_{wp}/LB. \tag{7}$$

The waterplane coefficient plays a very important role in the stability and resistance of the ship.

It is described as the relation between the area by a determined waterline and that from a rectangle which sides are the length over all and the breath of the vessel (for the same determined waterline).

There are many formulas to estimate this coefficient depending on the form of the ship´s stern. In our case we will use the Schneekluth´s equation valid for average stern forms [6]:

$$C_{WP} = \frac{(1+2*C_B)}{3} \quad C_{WP} = 0.75. \tag{8}$$

3.5. Calculation of the Vertical Prismatic Coefficient (C_{VP})

$$C_{VP} = \nabla / A_m T. \tag{9}$$

The vertical prismatic coefficient describes the vertical distribution of the hull below the design waterline .

Having it, is possible to calculate the position of the initial vertical center of buoyancy (KB), which is necessary to find the initial stability of the vessel.

3.6. Calculation of the longitudinal Prismatic Coefficient (C_P)

$$\mathbf{C_P} = \nabla / A_m L. \tag{10}$$

The longitudinal prismatic coefficient describes the distribution of volume along the hull form

Knowing the midship and block coefficients of ship, we can obtain the C_P using the following equation: $C_B=C_M C_P$

Values of coefficients mentioned above are necessary during calculations of shape coefficient or wet area coefficient, which are subsequently used for resistance and power calculations.

4. Coefficient of form ($1+k_1$) and wetted area of hull S

At early stage of propulsion designing, ships resistance has to be calculated. Resistance is calculated in approximation way and later, experimentally by model towing in model tanks.
For computing of resistance, necessary is knowledge of form coefficient value and wetted area of hull. Shop resistance is expressed by equation:

$$R_T = C_T S\, \rho_{fw}\, v^2/2 = [C_f(1+k_1)+C_W]\, S\, \rho_{fw}\, v^2/2, \tag{11}$$

where:
R_T – overall resistance,
C_T, C_f, C_W – coefficients of overall resistance, friction and wave resistance.

4.1. Form factor of the hull ($1+k_1$):

Calculating resistance according to Froude similarity, resistance is divided on frictional resistance and residuary resistance. Coefficient of friction resistance is to be calculated according to recommendations [1, 2, 5-7] using relation ITTC57. That relation gives coefficient of friction resistance depending on Reynolds number $C_f = f(Rn)$.

It is true for flat plate. In order to consideration shaped body and pressure fluctuation influence at flow character, form coefficient was implemented ($1+k_1$). Thus corrected frictional resistance coefficient is $C_f(1+k_1)$.

That coefficient can be determined in different ways. One is form factor of the hull $(1+k_1)$ described as [4]. That method relay on model tests' results of representative number of vessels' types. It covers precisely many coefficients describing hull, which are very hard to determine at early stage of design process. Very often simplified formula is used, according to [3]:

$$(1+k_1) = 1.9\ C_B B/L. \qquad (12)$$

For exemplary container ship, coefficient calculated according to above formula is 0.149, and calculated according to [4] is 0.146

4.2. Wetted area of Hull

Information about wetted area is absolutely necessary for calculation of total resistance of hull. There are many methods of its calculation, based on statistical analysis, of contemporary (corresponding to date of method elaboration) vessels. Most actual are Holtrop and Mennen's formulas [4]. However method is complicated and requires knowledge about numerous coefficients describing hull's form, which not always are known at early design stage. That is why in the paper are presented different methods for calculation of wetted area and calculated values for typical container vessel of 5000TEU. According to Holtrop and Mennen's formula, wetted area is calculated using equation:

$$S=L(2T+B)C_M^{1/2}(0453+0.4425C_B- 0.2862C_M-0.003467B/T+03696C_{WP})+2.38\ A_{BT}/C_B. \qquad (13)$$

Priority is now to obtain the value of the transverse sectional area of bulb (A_{BT}). In cases like ours, in which the type of bulbous bow is not determined, some authors recommend to take $A_{BT} = 0,08 * A_M$. In other words, the transverse sectional area of the bulb corresponds approximately to the 8% of the midship section area.

A_M is the area of the midship section, that we can estimate using the following equation [4].

$$A_M = C_M BT. \qquad (14)$$

According to presented relation, for exemplary vessel, wetted area is:

$$S = 11951.9\ m^2. \qquad (15)$$

Also calculation of wetted area can be calculated in more simple way [2]

- Taylor formula: $S=2,75 = 12698\ m^2$, (16)
- Muragin formula: $S = L_W T(1.36 + 1.13 C_B \frac{B}{T}) = 11739\ m^2$, (17)
- Mumford formula: $S = L_W T(1.7 + C_B \frac{B}{T}) = 12057\ m^2$, (18)
- Kirk formula: $S = L_W T(2 + C_B \frac{B}{T}) = 13065\ m^2$. (19)

Conclusion coming out from presented calculations is that differences between results are slight and at early stage of wetted area estimation, useful can be Taylor formula, basing on principal data about vessel. Of course in advanced calculation like "numerical towing tanks", contemporary methods have to be used.

5. Comparison of values of characteristic features of hulls

Preliminary design stage is designated for evaluation of necessary power of ship's propulsion corresponding to required parameters i.e. deadweight or cargo capacity, speed, shipping line etc.

In Tab. 1 are presented exemplary calculations main parameters corresponding a hull and propulsion power of four vessels calculated according to presented methodology.

Presented results confirm undertaken calculation methods, because obtained power of ships propulsion is very close to propulsion power of existing vessels considered as a standard.

Tab. 1. Calculated values of significant coefficients and propulsion

Ship type		Container ship	Container ship	Container ship	Bulk carrier
Capacity	TEU	1300	5000	9000	-
Deadweight	DWT	20355	54240	103000	75000
Mass displacement	t	26780	76780	145200	82470
Displacement	m^3	26110	74900	141700	84530
Speed	kn	18	22	25	15
Empty ship mass	t	6430	22540	42200	7470
LxBxT	m	152x25.2x11	271x36.5x12	319x44.4x14.5	210x33x14.1
H	m	14.3	22.9	26.4	18.8
Fn		0.24	0.23	0.24	0.17
c_B		0.62	0.626	0.62	0.86
c_m		0.975	0.978	0.98	0.975
c_p		0.636	0.625	0.69	0.86
S	m^2	5166	11419	12632	10820
c_f		$3.09 \cdot 10^{-3}$	$2.575 \cdot 10^{-3}$	$1.32 \cdot 10^{-3}$	$1.147 \cdot 10^{-3}$
R_T	kN	1052	1760	2690	802.7
Ne	kW	15500	40000	69200	10000

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