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CRITERIA OF SIMILARITY IN ANALYSIS OF MAIN DIMENSIONS AND PROPULSION POWER OF SHIPS AT PRELIMINARY STAGE OF DESIGN

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Abstract

The article presents the methodology of calculation of principal parameters of ship's hull dimensions, called „significant ships list", at preliminary stage of design process. Knowledge collected in the database is related to new buildings classified according to type, displacement, or DWT, shipping class, maximum speed etc. Are analysed dimensional constraints due of Froude Number, ships dimensional coefficients block and weigh coefficient, relations of main dimensions such as L/B, B/T, L/H, B/H etc. [7]. Those parameters coming out from ship-owners requirements like type of ship, load capacity, type of cargo, shipping zone, speed and some more. Very helpful tool for such analysis is list of significant ships created for specified types of ships. Mentioned lists are very effective under conditions that cover broad-spectrum new buildings and data included are credible. Uncritical taking values included in significant ships list can lead to critical errors in selection of main dimensions of a ship or its propulsion powering. For that reasons, basing on analysis, as main criteria of similarity of ship's hull were assumed mass coefficient, block coefficient and Froude Number [2]. That procedure has significant impact at proper estimation of propulsion power. Another reliable parameter of evaluation of power seems to be relation between power and load capacity Ne/D.

Keywords: *shipbuilding, calculation of hulls dimensions of ship and propulsive marine power*

Parameters

L, B, T, H – length, breadth, draught height, [m],
C_D, C_B, C_A – coefficients of mass, block coefficient and Admiralty Coefficient,
∇ – volumetric displacement [m^3],
D – mass displacement [t],
Ne – effective power of main engine [kW],
Fn – Froude number.

1. Comparison of ships

Preliminary chose of propulsion and Power plant's design affects subsequent designing phases. Very important is influence of proper selection of hull's dimensions and propulsion configuration at costs of design and construction of the ship. Proper conduction of preliminary design is crucial for next stages quality. Design process is carried on spiral way, what means that every next step is developing and improvement of solutions undertaken before [1].

That is a cause of necessity of exact realization of design assumptions and proper selection of preliminary configuration of the propulsion and the power plant. Correction of errors in preliminary phase is not expensive, while detection and correction of errors in construction phase results with significant increase of final product price [3].

Good effect can be achieved when designing is based on existing *„significant ships list"*. It encompasses general data about ship's load, capacity, displacement, basic dimensions, block and weight coefficient, Froude number, dimensional coefficients, speed, power, configuration of propulsion plant etc.

Credibility of that list depends on fundamental assumptions used for its construction. It is going on to include ships constructed in similar time period, according to undertaken capacity, for example TEU for container ships, the same class, for example bulk carriers, tankers, Ro-Ro ships, and similar shipping area (for example ice class requirement). Above requirements are coming from necessity of fulfilling stipulations given by classification societies such as free board, ice class, hull strength, displacement and shipping area limitations. Mentioned properties have mainly influence at mass and dimensional indexes. Because of that, analysing of dimensional data included in significant ships list, only these ships which fulfils criteria of similarity related to block and mass coefficients shall be considered. Very important is also retain value of Froude number, which describe wave resistance and is significant for ships with Froude number higher than 0.2. In this case, (FN > 0.2) local minima and maxima of resistance coefficient can be observed, what has influence at determination of ship's length.

Tab. 1. Comparison list of dimensional relations, Froude number and block coefficients

No	TEU	C_D	C_B	Fn	Lpp/B	B/T	B/H	Lpp/H	T/H	$L/\nabla^{1/3}$	Ne/D [kW/t]	C_A
1	1147	0.69	0.60	0.25	6.03	2.65	2.01	12.11	0.76	5.76	0.65	56.03
2	1254	0.72	0.58	0.24	5.69	2.82	2.06	11.73	0.73	5.63	0.35	83.06
3	1267	0.74	0.63	0.26	5.77	2.61	1.77	10.21	0.68	5.56	0.43	79.85
4	1388	0.74	0.64	0.24	6.27	2.54	1.87	11.69	0.73	5.61	0.41	69.67
5	1496	0.75	0.64	0.24	6.61	2.55	1.87	12.39	0.74	5.83	0.45	72.00
6	1684	0.77	0.61	0.26	5.59	2.58	1.92	10.75	0.75	5.31	0.43	72.30
7	1713	0.74	0.63	0.26	5.91	2.94	2.02	11.95	0.69	5.68	0.53	91.00
8	1756	0.74	0.66	0.25	5.37	3.14	2.06	11.03	0.66	5.36	0.44	73.90
9	1334	0.75	0.62	0.25	6.10	2.50	1.87	11.43	0,75	5.52	0.60	69.03
10	1572	0.76	0.68	0.26	5.84	2.75	1.85	11.67	0.67	5.44	0.44	66.89
11	1398	0.74	0.64	0.24	6.31	2.54	1.86	11.78	0.73	5.98	0.41	64.52
12	1262	0.88	0.57	0.23	6.47	2.61	1.75	11.30	0.67	5.59	0.58	47.90
13	1338	0.48	0.64	0.22	6.31	2.54	1.87	11.78	0.73	3.84	0.55	70.40
14	1841	0.74	0.64	0.26	6.34	2.44	1.61	10.23	0.66	5.59	0.52	82.01
15	1512	0.74	0.68	0.25	5.69	3.13	2.07	11.82	0.66	5.53	0.45	74.00
16	1444	0.75	0.71	0.25	5.8	3.10	1.97	12.17	0.63	5.50	0.43	75.10
17	1496	0.75	0.66	0.24	6.61	2.56	1.87	13.28	0.73	5.78	0.45	72.02
18	1572	0.76	0.68	0.26	5.84	2.75	1.85	11.67	0.67	5.44	0.44	66.82
Mean	1471	0.74	0.64	0.25	6.03	2.71	1.90	11.61	0.70	5.50	0.48	71.47
Stand. dev.	193	0.07	0.04	0.01	0.36	0.23	0.12	0.74	0.04	0.45	0.08	9.76
Stand. error	45	0.02	0.01	0.00	0.09	0.05	0.03	0.17	0.01	0.11	0.02	2.30

In Tab. 1 are presented values of ship's parameters and selected coefficients obtained in way of analysis of significant ships list [10]. Due to that, general tendency of changes depending of load capacity can be observed. The objects of analysis were container ships with capacity between 1447 and 3500 TEU. For that capacity, block coefficients values are placed between 0.58 to 0.66, Froude number is between 0.24 and 0.26, coefficient C_D is 0.69-0.77, $L/\nabla^{1/3}$ – 0.69-0.77, dimensional relations: Lpp/B is 5.59-7.13, B/T – 2.44-3.14, B/H – 1.5-2.06, Lpp/H – 9.85-12.11, T/H – 0.61-076, L/B – 5.97-7.5, L/H –10.41-13.28, L/Lpp – 1.05-1.12. More than 50 ships were analysed but for problem's characterization, only results from 18 units are presented. Presented results leads to conclusion that some parameters describing main dimensions and propulsion power declines significantly from mean values thus such ship cannot be included to similar ships set. Values differ than standards are marked in shadow and are related to power coefficient of ship number 1, mass coefficient of ship number 12 and 13 and block coefficient of ship 16. These units cannot be treated as similar ships because of disturbances of general picture of analysis data. Unreliability of such data can be caused by differences in dislocation of hull's mass because of reinforcements of the hull (ice class reinforcements) coefficient C_D, differences of hull's shape – coefficient C_B and lack of similarity of propulsion configuration – coefficient C_a and N/D. Very often, differences in evaluation of coefficients describing ship's shape and propulsion power are caused by undertaking improper hull's data and propulsion parameters presented in reference sources.

In Tab. 2 are presented mean values, standard deviations, and standard errors for 14 ships being objects of analysis after rejection of group of ships differ from similar ship definition.

Tab. 2. Presented mean values, standard deviations and standard errors

No	TEU	C_D	C_B	Fn	Lpp/B	B/T	B/H	Lpp/H	T/H	$L/\nabla^{1/3}$	Ne/D [kW/t]	C_A
Mean	1520	0.75	0.64	0.25	6.00	2.70	1.90	11.55	0.70	5.56	0.45	74.08
Stand. dev.	182	0.01	0.03	0.01	0.38	0.23	0.13	0.81	0.04	0.15	0.06	7.42
Stand. error	49	0.00	0.01	0.00	0.10	0.06	0.03	0.22	0.01	0.04	0.02	1.98

Analysis of values of standard deviation and mean value presented in tables 1 and 2, shows that rejection of unreliable ships from similar unit list does not affect significantly statistical values of comparison parameters. Nevertheless, for further analysis only these values characterised by lowest error, shall be considered.

2. Selection of reliable parameters defining main dimensions of a hull

Taking the list of similar ships as a basis, were elaborated relations between Froude number, mass coefficient, block coefficient, and number of carried containers TEU.

2.1. Froude number

In accordance to the theory of hydrodynamic similarity and assumption for model research according to Froude criterion, wave making resistance coefficient is strictly dependent on Froude number. One has to assume that its value specified in tank tests is the same like real object steaming with undertaken constant Fn number.

For all range of load capacities of contemporary container ships. Froude number takes values from range 0.24-0.26, thus passing by zone of local maximum at functional characteristic of wave resistance coefficient (see Fig. 1).

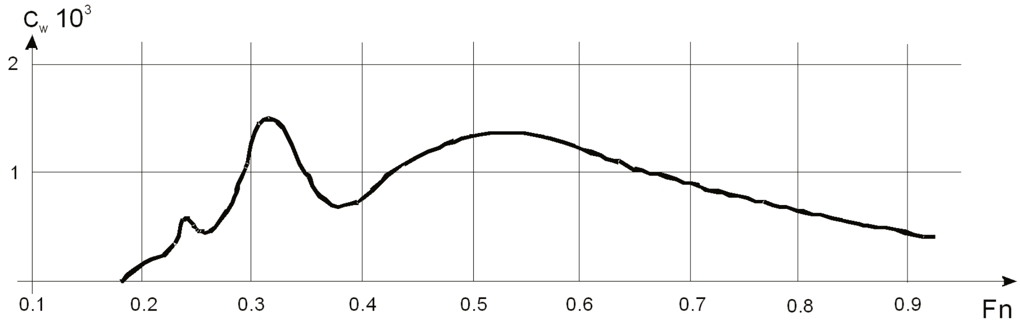

Fig. 1. Wave resistance coefficient and Froude number relation [4]

Taking proper Froude number allows selection such ship's length for undertaken value of its speed, which ensures minimal magnitude of bow and stern waves generated by ship’s movement, and their attenuation due to wave superposition. It causes minimization of wave resistance, what is especially important for fast ships, sailing in Fn range of first maximum and above. In Fig. 2 is presented function DWT = f(TEU) for container vessel about 1500 TEU.

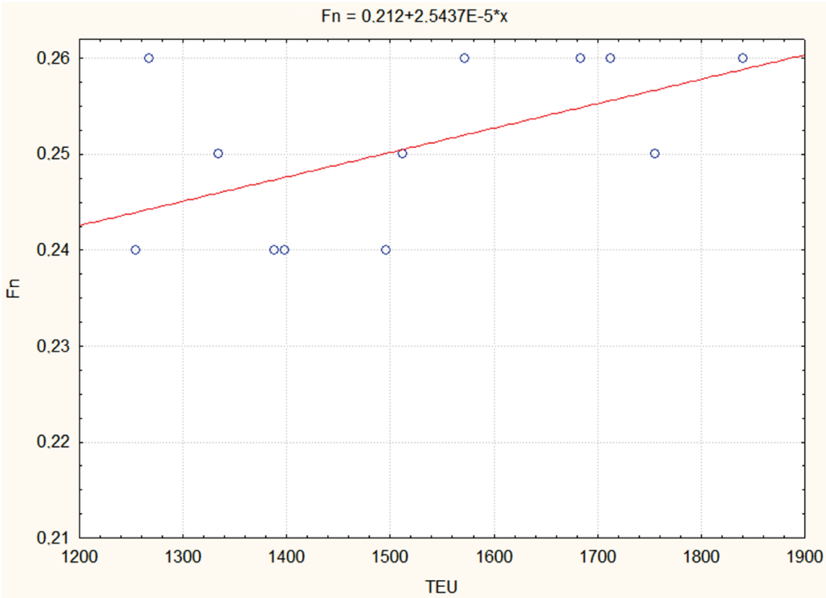

Fig. 2. Froude number function Fn = f(TEU)

2.2. Mass coefficient

In this case, we will use two methods to calculate the displacement of the ship in design.

The first of these two possible ways consists of using the arithmetic mean’s value of the Deadweight-Displacement ratio. Deadweight includes cargo, fuel, oil, fresh water, stores, crew, and effects. Cargo is the only component of deadweight, which will bring revenue; hence, other items of deadweight should be kept to a minimum.

Knowing the deadweight of our vessel, our displacement will be then:

$$DWT/\ \Delta = C_D. \tag{1}$$

Exemplary recommended values of that coefficient defining share of hull mass, propulsion mass, crew and stores mass according to [8] are

- Cargo vessels 0.65-0.75,
- Large tankers/bulk 0.79-0.85,
- Ore 0.82,
- Container 0.60.

Moreover, for container ship, one has to know the relation between container capacity TEU and deadweight DWT. Standard mass of one container is 14t/ TEU. Good results are given by statistic elaboration of data from significant ships list. In Fig. 3 is presented function DWT = f (TEU) for container vessel about 1500 TEU.

2.3. Block coefficient

Value of that coefficient depends on ship type and its cruising coefficient means less slim hull, then resistance has bigger value.

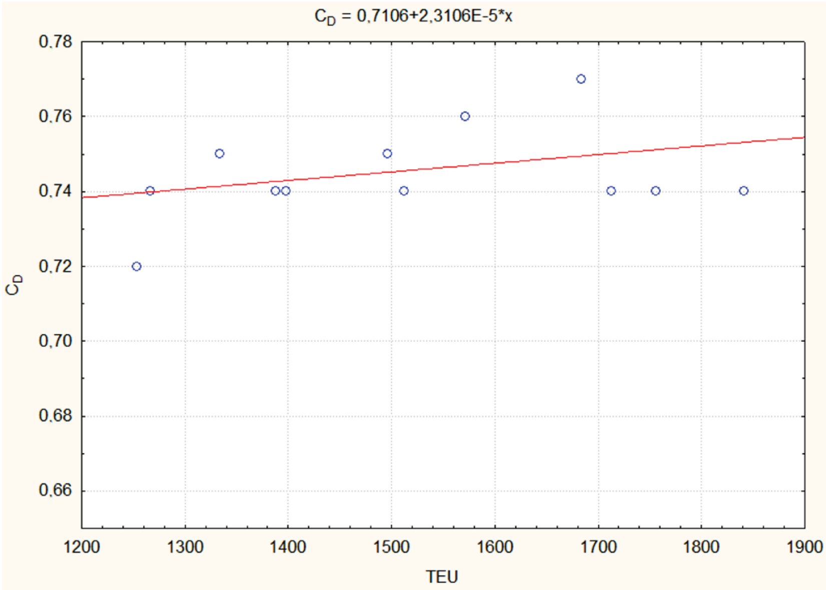

Fig. 3. Cargo capacity function DWT = f(TEU)

For economical propulsion, from a hydrodynamic point of view, length and fullness at a given speed are closely related. Recommended C_B values for container ship are given by equation [9]:

$$C_{B_{min.Schneekluth}} = \frac{0.145}{F_n}. \tag{2}$$

For container ships, contemporary fastest developing class of vessels, maximum C_B value should be up to 0.65[6].

In Fig. 4 is presented function C_B = f(TEU) for container vessel about 1500 TEU.

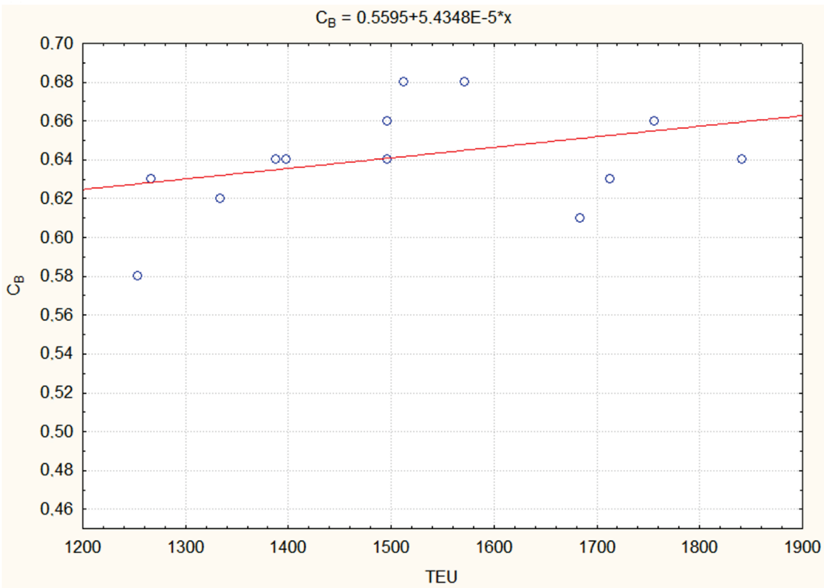

Fig. 4. Block capacity function C_B = f(TEU)

3. Selection of reliable coefficients characterizing ship's propulsion

Coefficients related to main dimensions of the ship are necessary for rough calculation of dimensions and power requirement of propulsion set. At preliminary stage of design, or during conducting of pre-project analysis, very often is necessary to do quick evaluation of necessary propulsion power. Having significant ships list, rough calculation can be carried out with formulas presented in publications, traditional Admiralty Method or basing at relations Ne/D. All way can give acceptable results under condition that database consist of ships similar in terms of propulsion set configuration and mass coefficient. Mass coefficient is essential because lets evaluate ship's displacement what is not typical value given in ships datasheet but is critical for value of resistance force and subsequently decides about power f propulsion.

3.1. Power coefficient

Power coefficient describes relations between effective power and ship's displacement. Common mistake is taking load capacity instead of displacement, what results with omitting ships specifics i.e. constructional solution of a hull, propulsion and sailing range sailing region. In Fig. 5 is presented function Ne/D = f(TEU) for container vessel about 1500 TEU.

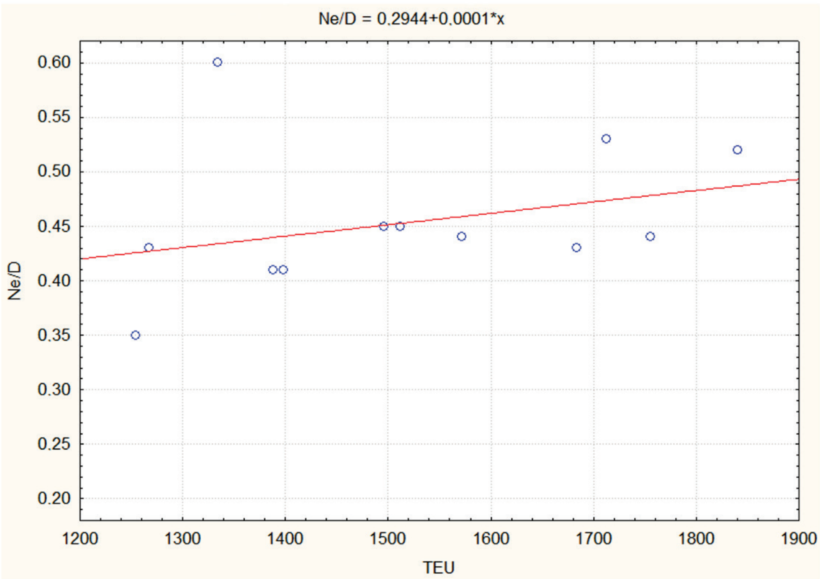

Fig. 5. Block capacity function Ne/D = f(TEU)

3.2. Admiralty Coefficient

Admiralty Coefficient formula given by Admiral Taylor in 1899 is always in use and gives good level of estimation at early stage of propulsion design [5]. That formula was based at similar ships list and was considering displacement, speed, and propulsion power. Despite of fact that was elaborated for military ships, its spectrum of implementation is quite broad, under condition that similarity criteria are followed. In Fig. 6 is presented function C_A = f(TEU) for container vessel about 1500 TEU.

4. Conclusion

Analysis of dimensional parameters related to ship's hull and attached to that analysis of calculated power of propulsion at preliminary stage of design is one of most important problems of considered task of propulsion estimation. Very often, undertaken assumptions done at early stage of designing, affect final effect i.e. fulfilling contract statements and expectations and divergence between contracted parameters and sea trial results. Because of that, seems to be crucial, very careful taking of criterions from database, especially mass coefficient and Froude number, and for power calculation – coefficient Ne/D. In case of impossibility of displacement determination, one can use mass coefficient or relation between TEU number and load capacity.

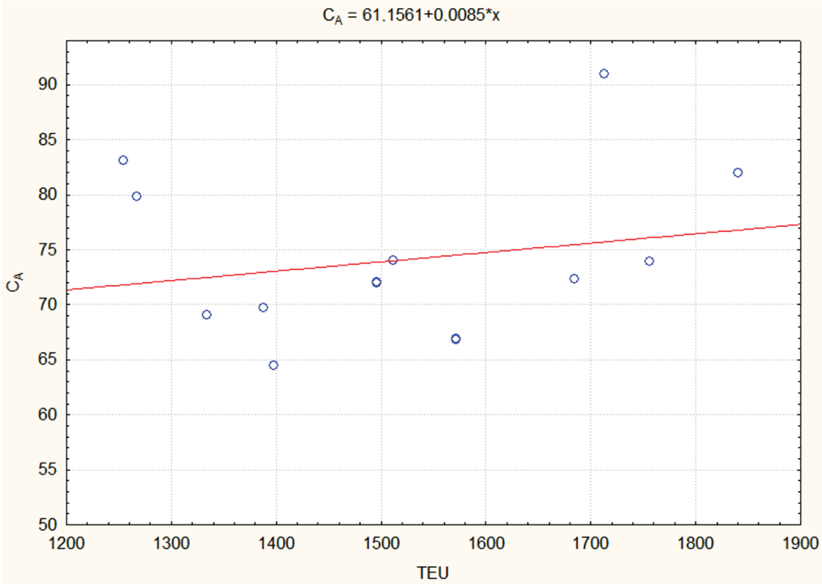

Fig. 6. Block capacity function C_A = f (TEU)

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