MAIN DIMENSIONS SELECTION METHODOLOGY OF THE CONTAINER VESSELS IN THE PRELIMINARY STAGE

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Abstract

TEU number which the container ship is designed for, directly influences the main hull dimensions that is displacement D, length L, breadth B, draught T, their combinations and block coefficient δ. The main dimensions have a great impact on developing the ships resistant performance. Thus, it is really fundamental to establish the correct dimensions of the hull during the design and ship building process. Estimating the shape of the ships hull, that comprises its main dimensions, is one of the basic tasks as part of the preliminary design stage. The most significant decisions determining ships performance, its duration and building costs are made at the beginning of the preliminary stage, before the contract is signed, when the costs are relatively low, up to 4.5% of total costs of technical and working stage. The results of the decision that has been made at the preliminary design stage are significant for the new building ship including its building costs and what is more important, for the ship owner, the ships operational costs.

It is important to limit the total ship resistance, for instance, by lowering the wave ship resistance as much as possible, especially when the operational speed and TEU number carried by one vessel is increasing. That resistance depends on the operational speed expressed by Froude number.

The resistance criteria and the existing hull dimensions limits, resulting from ships route, must be taken into consideration bearing in mind safety conditions such as ships stability and seaworthiness, when the main ships dimensions are being determined.

Keywords: *contemporary ships, container carriers, main dimensions, hull dimensions*

1. Introduction

The main ship dimensions determined in the preliminary design stage, are not only length L, breadth B, draught T, and side height H, but they also include other parameters characteristic of the designed vessel, which correlate with and affect basic LBT dimensions. These additional parameters mainly include displacement D, block coefficient $\delta = D/LBT$, correlations of the main dimensions $L/D^{1/3}$, L/B, L/H, H/T, B/T as well as speed and Froude number $Fn = v/(gL)^{1/2}$, which is related to it.

Determining main dimensions of a container ship is based on design assumptions, which indicate at least the number of TEU containers, required ship speed and restrictions within a given area of sailing. Such restrictions are taken into consideration in dividing container vessels into classes: panamax, post-panamax, suezmax, post-suezmax, mallaca-max, etc. What is also significant, the restrictions are linked with hull integrity, stability and unsinkability.

2. Designing vessels

Vessels are designed in a process compliant with Evans's rule of design helix, and elaborated by Andrews in terms of helix loops.

The essence of this design approach is illustrated in fig. 1 and it consists in reaching the expected solution in the course of design process by means of verifying design decisions made at the preliminary design stage. That is why it is important to determine as precisely as possible all the main dimensions affecting the resistance characteristics of a vessel, its integrity, stability and unsinkability, as early as at the preliminary design stage.

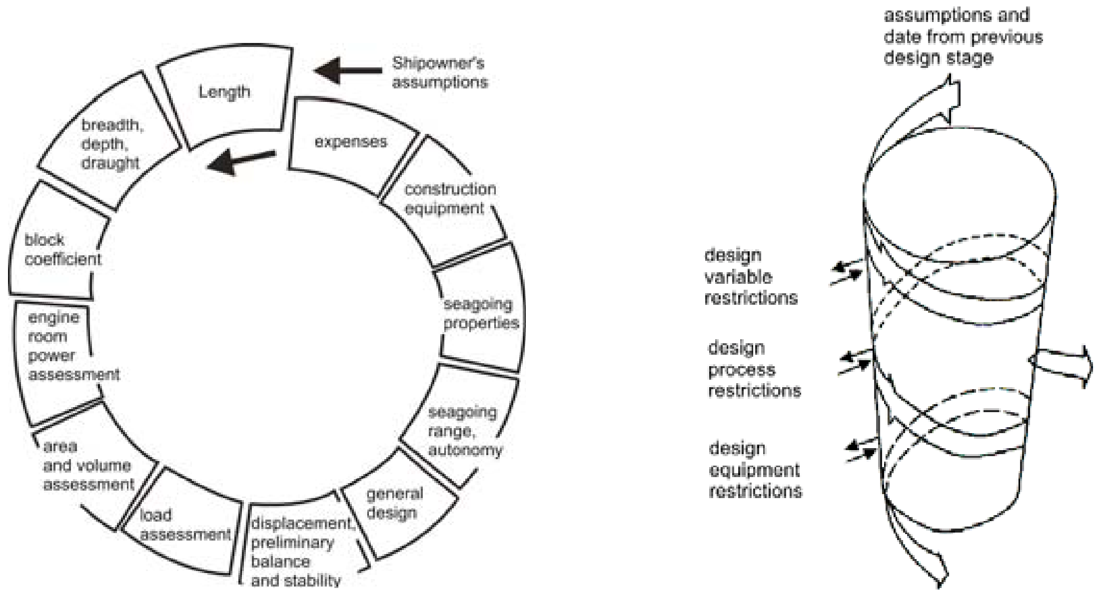

Fig. 1. Andrews-Evans design helix [1, 5, 7]

The most important decisions which determine the vessel characteristics, its cost and construction time are made at the beginning of the design process in the competitive conditions of time-related restrictions.

The correlation illustrated in Fig. 2 implies that the significance of the decisions at the preliminary (acquisition) stage (AD) essentially affects the properties of a vessel. The costs of further vessel construction stages, especially those of technical (TD) and working (WD) designs are disproportionately high as compared to the preliminary stage.

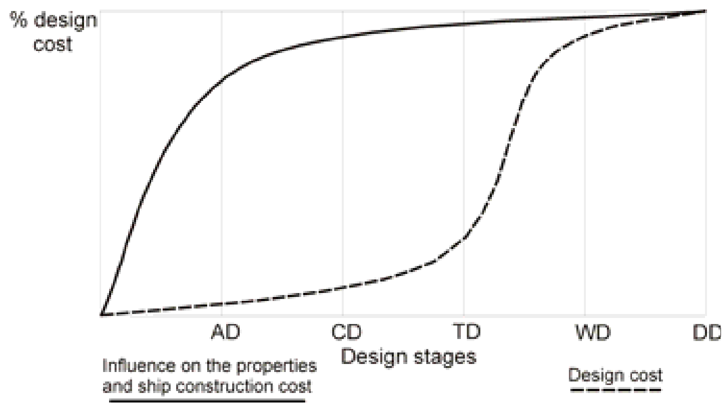

Fig. 2. Design phases expenses and their influence on the technical description and total expenses of the ship [4]

The consequences of the decisions made at the preliminary design stage are critical for the actual vessel not only in terms of its properties, but also in terms of building costs, and – what is crucial for the ship owner – its operational costs.

3. Methodology for selecting main dimensions of container ships

While determining the main dimensions of a container ship, i.e. length, breadth, draught and side height, resistance criteria should be taken into consideration, and so should be those resulting hull unsinkability, stability and integrity conditions. That is why precise determination of vessel main dimensions and basic correlations defining their properties is absolutely crucial in the whole vessel design and building process.

3.1. Design restrictions in selecting main hull dimensions

When a ship owner asks for a quote from a shipyard, they must determine its area of operation in the design assumptions. It is important because main ship dimensions will be linked with fulfilling stability and unsinkability conditions, while being restricted by the size of locks, canals, position of bridges, and other narrow passageways. Tab. 1 presents hull dimension restrictions, breadth B, draught T and length L, respectively, for selected seagoing routes.

Tab. 1. Selected restrictions of ship main dimensions L, B, T [10-11, 14]

	B	T	L
Kiel Canal	40	9.5	315
St. Lawrence Seaway	23	7.6	222
Strait of Malacca	-	21	-
Panama Canal	32.2	12.04	289.5
Suez Canal	55	18,29	-

3.2. Restrictions of main dimensions and their correlations

The ship owner's assumption includes TEU or deadweight, and less frequently – displacement. What is important in further calculations, however, in terms of vessel resistance or power demand for propulsion, is displacement as the measure of the volume of water displaced by the underwater hull part. That is why correlations between TEU and DWT, as well as between displacement and deadweight should be known. According to [9] deadweight/displacement ratio for container ships should be approximately 0.6.

One of the most important main ship dimensions affecting its hull integrity, displacement, and stability is the length between perpendiculars. The selected length of the ship depends on the recommended fineness ratio $L/D^{1/3}$, which should be within the range 5.5-6.5. What is more, the length of a ship also depends on Froude number, whose value essentially determines the value of wave resistance. The maximum wave resistance values occur with Fn = 0.5; 0.32; 0.24.. and minimum wave resistance values occur with Froude number of 0.36; 0.27...

The breadth of a container ship primarily depends on the number of rows of transported containers. What needs to be considered is the number of containers, the space necessary for fixing the containers, etc. In terms of ship resistance, it is important to ensure proper relation between the ship length and breadth. For cargo ships the L/B ratio is in range 6-7.

Hull draught significantly affects ship resistance, stability and unsinkability. B/T ratio for cargo ships should be 2.0-2.5, and the T/H ration should be 0.7-0.8.

Hull integrity and stability considerably influence determining its main dimensions. It is important to maintain an appropriate relation between hull length and breadth, and side height. In terms of hull integrity L/H = 12-13 and in terms of stability, the relation between ship breadth and side height B/H = 1.9.

Hull block coefficient significantly affects the economics of ship operation. As it is linked with hull shape and length of the ship, it influences the resistance and speed of a ship. According to [9] optimum block coefficient can be estimated with the use of the formula:

$$\delta = 1.23 - 0.395 \left. V \middle/ L^{0.5} \right. , \tag{1}$$

where:
V - speed of a ship [kn],
L - length between perpendiculars [m].

3.3. Displacement of a container ship

One of the basic parameters determining the size of a sea vessel is its displacement, defined as the volume of the underwater part of the hull or the mass of water displaced by the ship at a given water temperature.

$$D = \rho V[t], \tag{2}$$

where:
V - volume of the underwater part of the hull,
ρ - density of water.

The more containers a ship can carry the greater is its displacement, so the ship's hydrodynamic resistance will increase, thus the power demand for the propulsion of the ship will increase as well.

The displacement of a ship can be determined on the grounds of data collected in the container ship data base according to [2, 6, 11-14] and the conducted analyses. Displacement can be calculated for a given TEU container number with the use of the correlation in the form of a linear equation y = 15.06x+1832.6 (Fig. 3). Parameter x in this linear equation is defined as the number of 20ft (TEU) containers, which container ships are designed for.

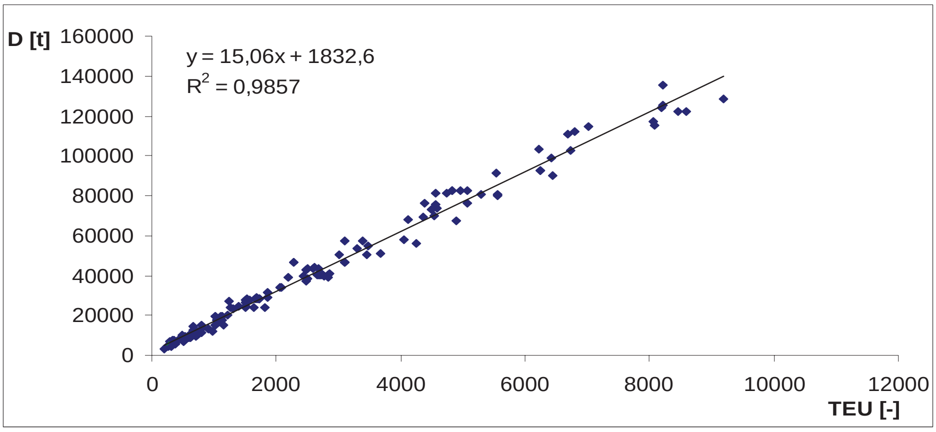

Fig. 3. Linear regression of the container ships displacement and the number of TEU

3.4. Length of a container ship

In order to determine the length of a ship, Froude number can be used, which enables determining if, for an assumed speed of sailing v, the chosen length of a ship corresponds to recommended Fn numbers in terms of minimizing wave resistance.

For contemporary container ships, the Froude number includes values within 0.24-0.26 range, i.e. excludes the range of the local maximum in the characteristics of wave resistance coefficient illustrated in Fig. 4.

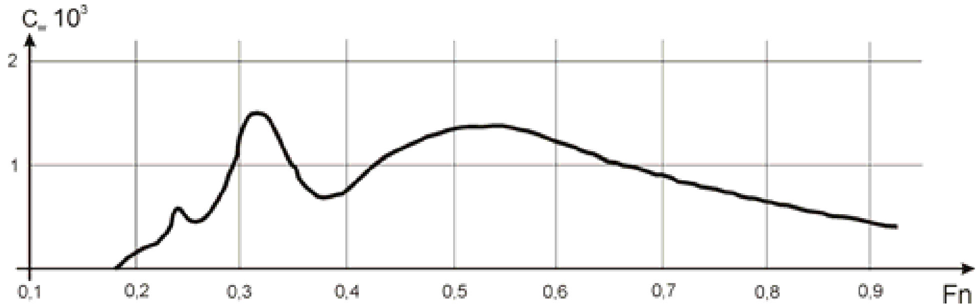

Fig. 4. Wave resistance coefficient and Froude number relation [3]

Tab. 2 presents mean values of Froude number for particular classes of contemporary container ships.

Tab. 2. Froude number in figures

Class (TEU)	Fn
do 1000	0.26
1001-2500	0.25
2501-5000	0.25
5001-10000	0.24
Mean	**0.25**

The maximum value of Fn=0.26 is used for the small feeder class, i.e. container ships of the capacity up to 1000 TEU. The vessels of the capacity from 5000 to 10000 containers in the so-called post-panamax class have the lowest Fn value.

Reducing the wave resistance of the designed ship mainly involves the analysis of potential reduction possibility of Froude number value by means of increasing the length of a ship so that the local maximums of wave resistance coefficient can be avoided. Fig. 5 illustrates the correlation of the length of container ships in the function of TEU container number.

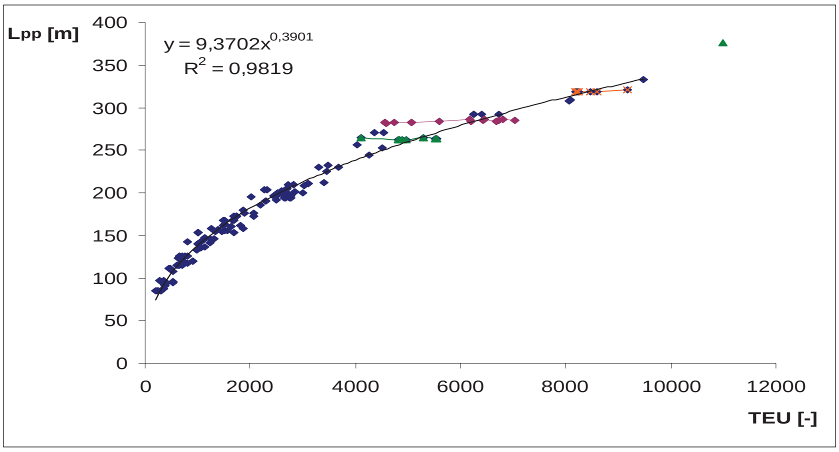

Fig. 5. Length between perpendiculars and TEU number relation

The correlation illustrated in Fig. 5 implies that up to the value of 5000 TEU restrictions of sailing routes do not affect the length of a hull. For this TEU number value range, the length of a ship can be determined with the $y = 9.3702x^{0,3901}$ equation. For greater container capacities, the length of a ship should be verified with regard to restrictions resulting from ship owner's assumptions relating to the expected sailing routes.

3.5. Breadth and draught of a container ship

The subsequent stages of determining main dimensions of the designed container ship, breadth B and draught T of a ship are determined respectively.

Vessel hull breadth directly depends on TEU container number which a given ship is designed for. Increasing the breadth of a ship results in an increase in hull resistance and, consequently, an increase in main propulsion power. With the lack of sailing restrictions, the value of ship's breadth B results from the stability condition and can be determined with the use of the correlation illustrated in Fig. 6, amounting to the exponential equation: $y = 2.6375x^{0,3116}$. For a larger number of containers, when the breadth of a ship exceeds 30 m, it is not the number of containers that is critical in determining the breadth value, but restrictions resulting from the sailing area. The restriction in the ship's breadth at around 32 meters results from the fact that ship owners include the Panama Canal in their design assumptions.

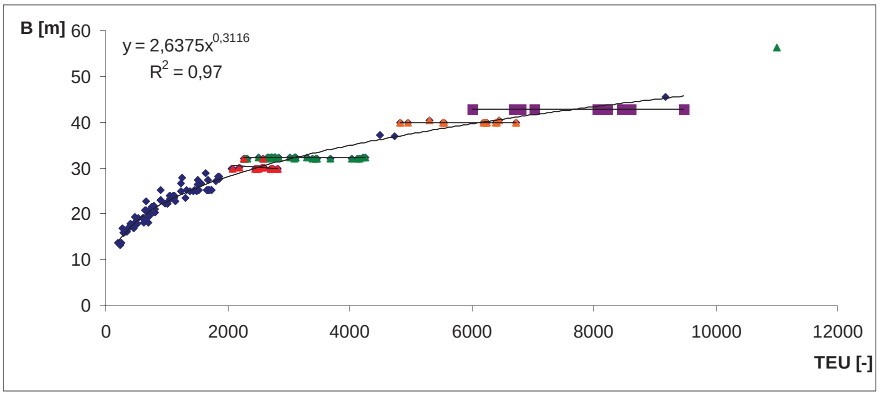

Fig. 6. Exponent relation between ship breadth and TEU number

The situation is similar as far as ships of larger container capacity are concerned. It is observed that subsequent groups of ships are 40 and 43 m wide, respectively. There are no breadth and draught restrictions for container ships of very large capacity, whose forerunner, Emma Maersk, can carry 11000 containers, as these ships are expected to sail in the areas of unrestricted breadth and depth.

Just as it is the case for the breadth of a ship, there are also value ranges of container capacity for draught, which do not involve any change in the design draught value. STab. draught ranges begin with values exceeding 10 m.

The correlation of draught in meters in the function of ship TEU container capacity is represented with logarithmic formula in Fig. 7. Up to the value of approximately 2000 TEU, the limitations of sailing routes do not affect the value of draught. For this range of TEU number, draught of a ship can be represented with the following formula: $y = 9.3702x^{0,3901}$.

3.6. Verifying main dimensions

Hull shapes, even if some of their measurements are similar, can be very dissimilar. Due to the existing measurement-related restrictions of a hull, the condition of stability and unsinkability, as well as resistance-related criteria, it is recommended to consider appropriate measurement ratios of mainly B/T, L/B values, fineness ratio and block coefficient in order to determine the optimum hull shape. Proper determination of hull shape affects resistance properties, mobility and manoeuvrability of a ship. Only after quotients of particular values are compared, can differences be seen in the hull shape.

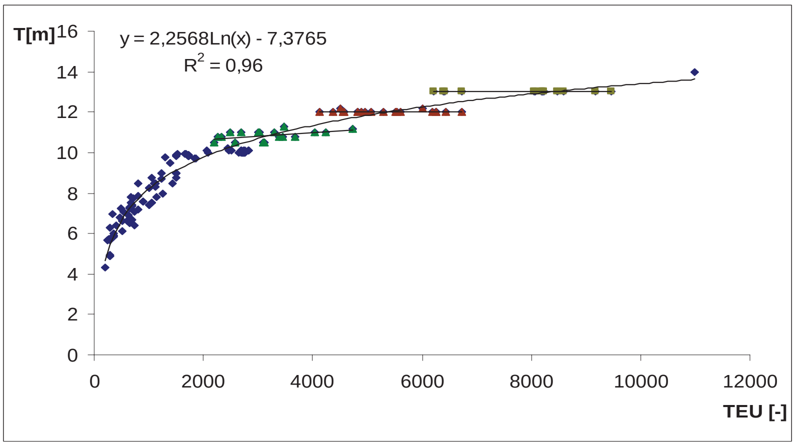

Fig. 7. Relation between ship draught and TEU number

While operating these quotients, the dimensions of a hull can be selected to meet at least the majority of restrictions. Where no restrictions apply to breadth B, the value will be determined by the limitations resulting from stability-related calculations. For fine form ships, and container ships are in this category, the B/T quotient usually exceeds 2.4. For contemporary container ships B/T value is within the range presented in Tab. 3.

Tab. 3. Ships breadth B and draught T quotient in figures

Value	B/T
Minimum	2.3
Maximum	3.6
Mean	2.9

The analysis of contemporary container ships implies that, especially for the ships of large carrying capacity, the B/T ratio usually exceeds the recommended cargo ships values within the range 2-2.5 [9].

Unlike B/T quotient, L/B ratio is not as critical for vessel stability, but it considerably affects the integrity of a hull and value of resistance, thus the speed of the vessel and, essentially, the economics of its exploitation.

The design length-breadth (L/B) ratio is within the 5.3-8.8 range for contemporary container ships. These values are also dissimilar from those recommended for cargo ships (6-7). For ships of smaller TEU container number capacity, the L/B quotient will have diverse values. The larger vessel the smaller quotient value range which is illustrated in Tab. 4.

Tab. 4. Length between perpendiculars and breadth quotient for different container carriers classes

TEU	Lpp/B
up to 4000	5.3-7.2
4000-6000	6.6-8.8
6000-10000	6.6-7.8

In the last stage of selecting main dimensions of a container carrier D displacement and LBT measurements are verified. In order to do that hull block coefficient $\delta = D / LBT$ can be used. The finer the form of the hull, i.e. smaller block coefficient value, the greater the speed of a vessel can be, but its displacement decreases, and so does the carrying capacity. For contemporary container carriers of all capacities the value of the coefficient is within the range of 0.60-0.69.

4. Conclusions

In the case of small numbers of TEU containers, there are no restrictions for hull dimensions, and they are chosen according to resistance criteria, with regard to safety conditions, i.e. stability, unsinkability and integrity of a hull.

Stable values of hull length, breadth and draught for various TEU carrying capacities result from restrictions included in design assumptions concerning sailing areas. For the Kiel Canal it is mainly the breadth value of 40 m, for the Panama Canal, where locks are used in vessel transport, the restrictions stem from block measurements, in this case: L = 290 m, B = 32 m, T = 12 m.

Other measurements exceeding the restrictions stemming from the sailing area can be caused by the value of wave resistance, safety conditions, limitations concerning the technology aspects of the shipyard or other entities cooperating in ship construction.

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