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DIMENSIONAL CONSTRAINTS IN SHIP DESIGN

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Abstract

The paper presents general rules for calculations of ship's hull principle dimensions at preliminary stage of design process. There are characterized and defined basic assumptions of design process and limitations for calculations of dimensions and some criteria numbers. Limitations are an outcome of shipping routes what is related to shipping restrictions, diminishing of hull drag, achieving of required strength of hull and safety of shipping requirements. Shipping limitations are because of canals and straits dimensions or harbours drafts. In order to diminish propulsion power, what is related to economically justified solution, selected form and dimensions of hull must ensure minimizing of resistance, including skin friction and wavemaking resistance. That is why proper selection of coefficients of hull shape and dimensional criteria according to ship owner's requirements i.e. deadweight (DWT) or cargo capacity (TEU), speed and seakeeping. In the paper are analyzed dimensional constraints due to shipping region, diminishing of wavemaking and skin friction resistance or application of Froude Number, ships dimensional coefficients (block coefficient, L/B, B/T, L/H) and coefficients expressing relations between capacity and displacement. The scope of applicability above presented values for different modern vessels construction were analyzed.

Keywords*: ship principal dimensions, hull volumetric coefficients, hull design*

1. Methodology of ship's principal dimensions selection at early design stage

Process of ship design consist of several subsequent stages. At each step, more advanced solutions are created. During first stage called preliminary design phase, concept project is elaborated as first, and next is contract project.

First step of that stage is concept design. Base for beginning of design work are client's requirements. That assumptions, in form of technical and economical features of future ship, must be defined very precisely. The concept phase has crucial importance for final project shape and generally is an iteration process. During the process, single analysis and even all cycles are repeated several times. Preliminary determination of principle dimensions of ship is very important sub stage of design. Correct selection of that dimensions has strong impact at project cost and consequently, at construction and exploitation costs. Any changes of main dimensions at that stage, can be done with insignificant changes of project costs, while the same changes at later stages are much more expensive. Preliminary selection of principal dimensions can be carried out in way of analysis or iteration.

Analytical methods are based on empirical equations, which were elaborated using regressive analysis of collected data. That equations present mathematical relations between different parameters and features of specified type of vessel. Accuracy of analytic methods depends on verification based on data base coming from contemporary generation of vessels. Iteration methods relay on straight application of data coming from significant ships list. Collected data enable to determine, basing on statistics methods, relation between dimensions of designed ship. When from one hand, that will be general dimensions of the vessel, and from another preliminary design assumptions, then basing on obtained relations, general dimensions of designed vessel can be determined.

2. Design assumptions

A ship is a complex vehicle. Its production requires the involvement of a wide range of engineering disciplines. Ship design is not an exact science but embraces a mixture of theoretical analysis and empirical data accumulated from previous successful designs. Due to the complex interrelationships between features of the technical design, and the construction of the ship and its operation, the final ship design will often represent a compromise between opposite ship requirements. The development of the overall ship design and its production cannot normally be treated in technical isolation as operational requirements have to be considered. For example, the ship will often form a part of a through transport system; this may range from sophisticated container systems with dedicated ships operating between specified ports, or ferries and RO/RO vessels relying on a regular wheeled through cargo, to tramp vessels on non-regular schedules which rely on carrying various types of cargo between various ports. The route and its environment, type of cargo, quantity to be moved, value of the cargo and port facilities are typical features which will be considered when evolving the size, speed and specification of a suitable ship. Specific service requirements will be similarly considered when evolving vessels such as warships, passenger ships or fishing vessels. Ship owners operate ships to make a satisfactory profit on their investment the evolution of a technical design can therefore be considered as a component part of an overall economic model. In evolving a ship design it is therefore necessary to assess the operating requirements and the environment in which the vessel is to operate, to evolve the feasible technical design and to economical justify the viability of the proposal. In an overall final design process the objectives have to be clearly identified and constraints in the process incorporated. The following discusses some of the alternative objectives. first is design for efficiency and economy: this is normally also a pre-requisite and might take several forms including designing to minimize running costs, maintenance costs, turnaround time for container ships, or turn round time for ferries, all with a view to improve the overall efficiency of the operation. Design for production: in this case producibility is important, and savings in construction costs may be assessed. In this case, the analysis may, for example, be trading increases in steel mass (and hence decrease in deadweight) against decreases in production costs. Design for maintenance: this will often amount to increase in space and improved access for maintenance of tanks or machines. This might entail accepting surplus volume and an increase in ship first cost. Design for the environment: aspects may include pollution, emissions, noise and wave wash. These objectives are becoming increasingly important. Some of these aspects are covered by MARPOL. Before the design process will be initiated, the basic technical data related to the operational requirements have to be defined and specified, or derived or assumed if several alternatives are to be investigated.

Exemplary design assumptions defines:

- Type of Vessel: for ex. container ship, bulk carrier, etc.,
- Number of Containers or DWT: for ex. 1300 TEU for container ship or 50000DWT for bulk carrier.,
- Speed in service and max speed: 18.0 kn at 85% MCR and 20 kn at 100% MCR,
- Propulsion System: for ex. Low Speed Diesel Engine with fixed propeller,
- Sea Margin: 15%engine power redundancy for heavy condition operating,
- Autonomy: range(for ex.15500 NM)or shipping route,
- Stability: The ship should be able to maintain its stability being loaded at 60% of his max. capacity,
- Classification Society: np. Det Norske Veritas, Germanischer Loyd, PRS,
- Other regulations to apply: SOLAS, Marpol and ILLC.

In Tab. 1 are presented dimensional constraints for specified vessel class and shipping region.

Tab. 1. Some limitations of shipping routes [4]

	B [m]	T [m]	L[m]	Max. height from waterline [m]
Kiel Canal	40	9.5	315	
DanishStraits	48	15	260	
Panama Canal	32.2	12.04	289.5	
Suez Canal	55	18.29	-	
St. Lawrence Seaway	23	7.6	222	57.5
MalaccaStraits	-	21	470	

3. General parameters of ship construction

3.1. Hull principal dimensions

Principal dimensions of the hull are length overall, breadth, draft and depth. Ship's hull is a block which boards have curved areas in all directions. Because of that, several dimensions and coefficients were elaborated in order to describe underwater part of hull as a cubic with dimensions L x B x T.

One of basic general dimensions with impact at reduction of hull resistance is length between perpendiculars $L_{pp.}$ Relation between overall length L_{oa} is expressed by equation:

$$L = \left(\frac{DWT\left(\frac{L}{B}\right)^2 \frac{B}{T}}{\rho \cdot C_B \cdot C_D}\right)^{1/3} \text{[m]}. \quad (1)$$

Length between perpendiculars is a basic dimension related to Froude Number which is related to wavemaking friction. Knowing the Froude Number, the Lpp of our vessel can be obtained as shown below.

$$Fn = \frac{v}{\sqrt{g * L_{pp}}} \cdot \quad (2)$$

Wavemaking friction coefficient reaches maximum value when Froude number is 0.5; and local maxima for values 0.22 and 0.3.

From all values from significant ships′ tables we will take the Froude number (Fn) and the block coefficient (C_B) as constants as values for calculations beginning.

Another main ship's dimensions i.e. breadth, draft, free board height, depends on displacement and range of sailing speed. Proper selection of that coefficients affect ships behavior like stability, speed range or seakeeping. General dimensions influence are not so important like adequate coefficients i.e. L/B, B/T, B/H and T/H and block coefficients.

3.2. Principal dimensions coefficients

Length to breadth relation coefficient L/B depends on type and destination of a vessel. For cargo vessels, tankers and container ships, it takes value amongst 5.5 to 6.5. For passenger vessels and fast vessels the value range is between 6.5 and 8.5 (Molland [7]). Correlation between coefficients L/B and B/T enables defining of impact of specified dimensions at ships, length.

Coefficient B/T has impact at transverse stability of a vessel. Increasing of breadth will result with better stability, but higher resistance of a hull and requirement for higher propulsion power. Relation B/T for different classes of ships takes value from range 2-5. For fast vessels like container ships, which have slim shape of hull, B/T coefficient takes values from 2.3 to 3.6 but most often is equal to 3. One has to notice that container vessel's breadth depends on container unit dimensions and number of loading rows at a deck. For other cargo vessels value of coefficient is 2-2.5. Basing on list of significant ships, hull's breadth for cargo vessels can be calculated according to relation B = L/10

+ (5 – 7.5) [m]. For container vessels the relation is B = L/10 + (7.5 + 10).

Because of Hull strength requirements, crucial relation is coefficient L/H, where H is board height, and due to stability important is coefficient B/H. For cargo vessels coefficient L/H takes values from 12 to 13. B/H coefficient for tankers and bulk carriers is around 1.9 and for fast ships like container vessels its limit value is 1.7.

Considering free board criteria, important is coefficient T/H, which for typical cargo vessels takes value 0.7 – 0.8 and for container vessels around 0.55.

3.3. Calculation of displacement (Δ)

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:

$$DWT/\ \Delta = C_D. \tag{3}$$

Exemplary recommended values of that coefficient defining share of hull mass, propulsion mass, crew and stores mass according to [ ] 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. 1 is presented function DWT = f (TEU) for container vessel 5000 TEU.

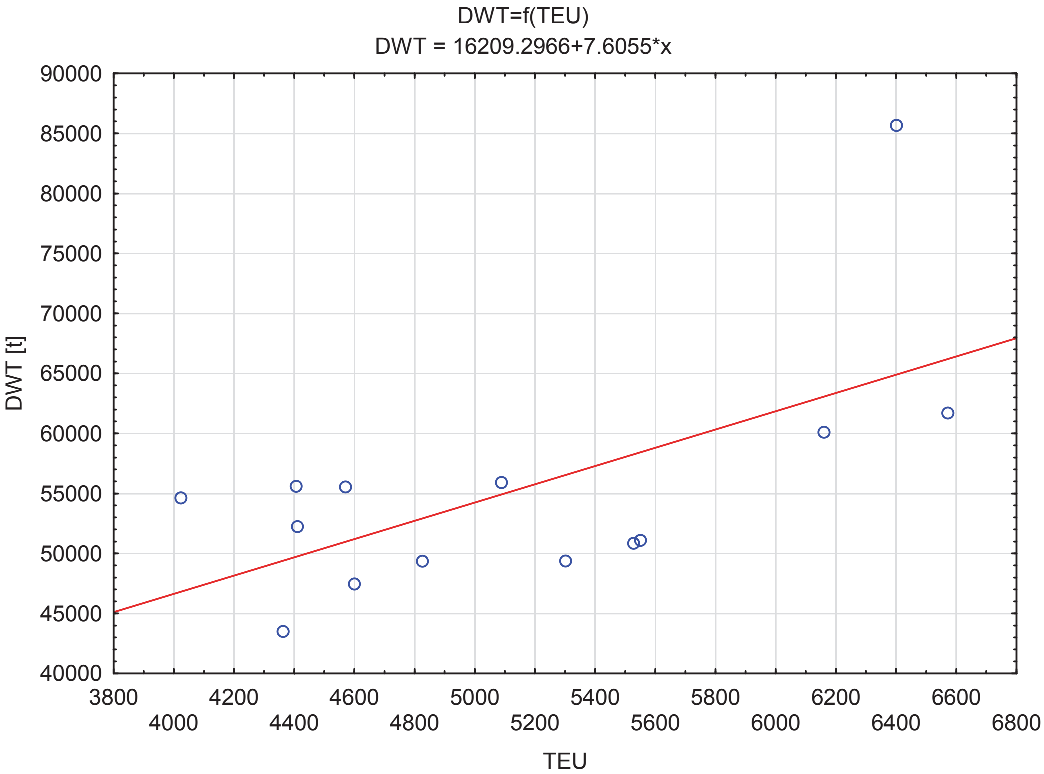

Fig. 1. Cargo capacity function $DWT = f(TEU)$

Expressing it as volume displacement (∇), we obtain:

$$\Delta = \nabla * \rho_{SeaWater}, \tag{4}$$

where:
∇ - capacity displacement [m^3],
Δ - mass displacement[t],
for $\rho_{SeaWater}$ (seawater´s density at 15ºC) = 1025.6 $\frac{kg}{m^3}$ [4].

4. Principle dimensions coefficients

Hull's shape is described by coefficients including displacement, linear dimensions, area of transverse frame and waterline. Some relations between parameters were elaborated which creates coefficients taken as criteria directions for hull selection.

4.1. Block coefficients C_B

Relations between ship's displacement and basic dimensions are expressed by Block coefficient $\mathbf{C_B}$:

$$C_B = \nabla / LBT. \tag{5}$$

Block coefficient $\mathbf{C_B}$ can be calculated on relation:

$$C_B = \frac{0.23\frac{L}{B} + 20}{26 \cdot F_n^{2/3}}. \tag{6}$$

In Fig. 2 are presented hull dimensions, necessary for determining of hull's shape coefficients.

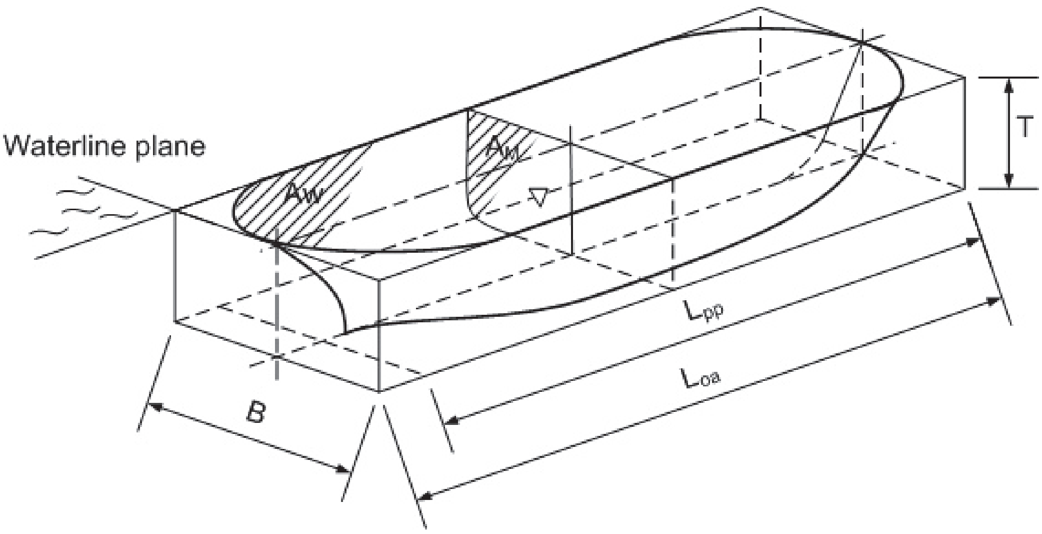

Fig. 2. Principal dimensions of a hull

4.2. Another coefficients of hull's shape determination

– Volumetric Coefficient (C_∇),

$$C_\nabla = \frac{\nabla}{L^3} \quad \text{for slender coefficient } L/\nabla^{1/3}, \tag{7}$$

– Midship Section Coefficient (C_M),

$$C_M = A_M / BT, \tag{8}$$

– Waterplane Coefficient (C_{WP}),

$$C_{WP}=A_W/BL, \tag{9}$$

– Vertical Prismatic Coefficient (C_{VP}).

$$C_{VP}=\nabla/LA_W. \tag{10}$$

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

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 [2]:

$$C_{B_{\min.Schneekluth}} = \frac{0,145}{Fn}. \tag{11}$$

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

In Tab. 2 are presented recommended values of selected coefficients for different types of ships.

Tab. 2. Recommended values of selected coefficients for different types of ships

	Load DWT/(TEU)	V_{max}/ V_{min} [kn]	V_{expl} [kn]	Fn	$\mathbf{C_B}$	C_D	B/T	L/B
Bulk carriers	100000	≤16/	14-16	0.16	0.7-0.86	0.82	2.35	5.75
Tankers VLCC	315000	≤16/	15.7-	0.16	0.825	0.8-0.85	2.65	5.55
Containerships Feeder	35000/ 2500	22/≥16	20-22	0.22	0.6	0.76	2.3	6.4
Container ships Panamax	70000/ 5000	25/≥16	20-25	0.24	0.57-0.65	0.7	3	6.5
Container ships Suesmax	140000/ 10000	25/≥16	20-25	0.25	0.57-0.65	0.6	3.22	7.5
Container ships Malaccamax	250000/ 18000	28/≥16	20-25	0.24-0.27	0.57-0.65	0.6	3.61	7.1

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