Lecture 3 : Ship Main Dimensions

In early design stage there are two main methods for the estimation of the main dimensions namely (a) the empirical and (b) the parametric. **In the empirical method**, the basis of assessment depends on the utilization of statistical data of similarly built ships. Data may come from an open-source or a commercial/internal databases and are usually represented on graphs. The method is based on two assumptions: (a) data are reliable; (b) ships included in the database are economically and efficiently designed. **In the parametric method**, a study from scratch is conducted seeking for a suitable combination of dimensions and form coefficients that satisfy some selected objectives and design constraints. For instance, a ship's main dimensions can be estimated based on an optimization model for selected economic objectives such as minimum operating or building cost. The parametric method is used when there is a lack of data on the same type and size of the new design.

1. Selection factors

Although the main objective in selecting the main dimensions is to fulfil the owner's requirements in terms of payload and speed, IMO regulations and the Classification requirements may affect design (see Lecture 1, Sections 1.4,1.5). Accordingly, assorted factors should be considered during the selection of ship main dimensions and form coefficients. These factors may help design for (a) hydrodynamic performance (resistance & propulsion, seakeeping, and maneuverability); (b) transverse and longitudinal stability; (c) structural strength; (d) sufficient volume for cargo and also ensure sustainable construction costs. The basic design factors are categorized as follows :

Factors affecting ship length (L). Length is a function of displacement and speed. It has a significant influence on the weight of steel structure and accommodation/outfitting, hence on the construction cost. Also, it strongly affects both the ship's calm water resistance and seakeeping performance (motions, accelerations, dynamic loads, added resistance, and speed loss in seaways).

Factors affecting the Breadth (B), Draught (T), and Depth (D). These dimensions are coupled in fine form coefficients (see Lecture 2, Section 2.3). The volume of a hold depends on the type of cargo, the stowage factor and affects mainly the depth required; **B** has a significant influence on transverse stability and cargo-carrying capacity. Maneuvering and propulsion efficiency are affected by **T**. In rough seas, both breadth and draught affect the wave added resistance while draught affects slamming. The required freeboard affects the selection of both draught and depth of the ship. Consequently, breadth, draught, and depth are key in damage stability pertaining to safety against flooding and capsize. The coupling of the length with the draught has a compelling impact on the longitudinal strength.

Factors affected by physical constraints (e.g. ship route) **operational limitations** (e.g. port drafts and confinement, shipyard dry dock principal particulars, crossing channel width and depth limitations, bridge crossings etc.; e.g. see Table 3.1) that may override an initially set mission and performance objectives.

Canal	Constraints
Kiel	$L_{OA} < 315$m : B < 40m ; T< 9.5m
Panama (old)	$L_{OA} < 290$m: B ≤ 32.24m: T < 13m.
New Panama Canal	$L_{OA} = 427$m; B < 55m ; T< 18.3m.)
St Lawrence	$L_{OA} < 222$m ; B < 23m ; T< 7.6m.
Suez	T < 14.63m. (≈ 1984 increased to 18.29m.)

Table 3.1 Canal constraints on ship design[3]

[3] see : www.pancanal.com/eng/general ; http://www.suezcanal.gov.eg; http://www.greatlakes-seaway.com

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2. Methods for practical design estimates

There are three practical approaches that may be used to decide the main dimensions of a ship. Those are known as Normand's number, statistical and direct calculations approaches. **Normand's number (N) approach** is defined as a factor by which the change in one or various weight components is multiplied to give the change in the total displacement of a ship.

$$N = \frac{d\Delta}{dW} = \frac{\Delta}{\Delta + (W_H + W_O) + \frac{2}{3}(W_M + W_F)} \tag{3.1}$$

where :

dW : is the difference between the deadweight of the new design and the reference ship,

$d\Delta$: is the difference in displacement between the new design and the reference ship,

W_H : is the hull weight of the reference ship,

W_O : is the outfitting weight of the reference ship,

W_M : is the machinery weight of the reference ship, and

W_F : is the fuel weight of the reference ship.

A challenge in Normand's number approach is the lack of available data. Empirical charts are summarized in Figure ,3.2.The main ship dimensions are calculated by setting one or two of the reference ship's characteristics as constant (e.g. C_B).

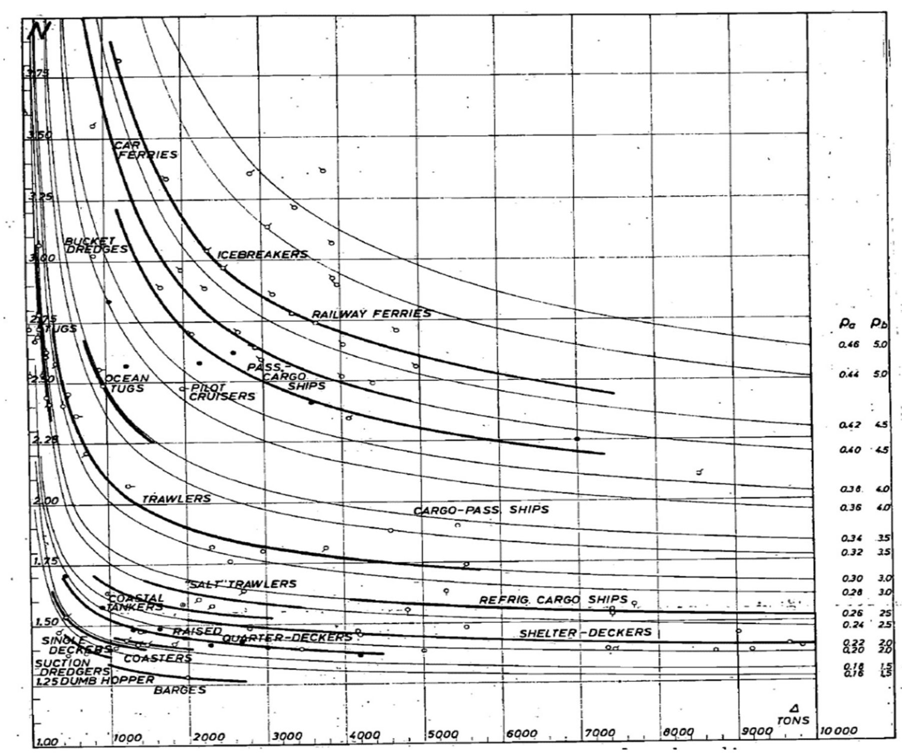

Figure 3.1. Normand's number for merchant ships less than 10,000 tons. Image credits: (Harvaid, 1964)

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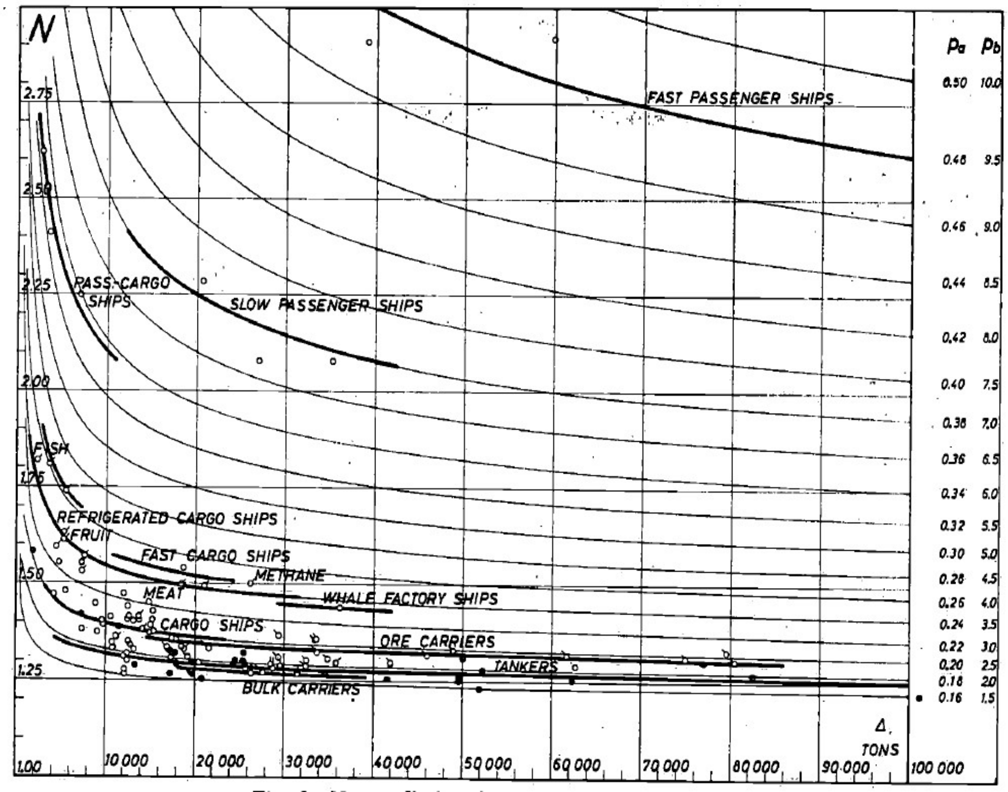

Figure 3.2. Normand's number for merchant ships up to 100,000 tons. Image credits: (Harvaid, 1964)

In the statistical approach, the empirical method is used to select the main dimensions. There are various procedures, curves, and regression-based equations that may be used to decide on selecting a ship's main characteristics. An example of the procedure to be followed is given as follows:

- The displacement of the new design is calculated based on tabular values of deadweight displacement ratios. Deadweight should be known as an owner requirement.
- The length of the ship is calculated using regression-based equations.
- The block coefficient is calculated using regression-based equations.
- The length to breadth ratio is estimated based empirical formulae or tabular values. Hence, breadth is calculated.
- The draught is calculated based on displacement, breadth, length, and the block coefficient. Any limitations on the draught, D/T or B/T ratios should be considered.
- The length to depth ratio is calculated based on tabular values from statistical data.
- The depth is obtained.

Direct calculations may be used when there is a lack of data from similar type or size of ships or when the new design is uncommon in shape and/or size, it is crucial to start the design from scratch based on objectives, requirements, and constraints. In such cases the purpose of the designer is to seek the best combination of dimensions and form characteristics that will satisfy the given objectives. However, at preliminary design stages definition of accurate relationships between the different ship parameters and design economic objectives may be challenging. Thus solutions are implemented at detailed design stage through the use of a mathematical optimization model embedded in a commercial software (e.g. NAPA, Rhinoceros, etc).

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3. Practical examples

Let us assume that you are required to design a general cargo ship for a shipping line company operating a fleet of Passenger vessels. The ship is approximately similar to the last built ship in the fleet; however, for economic reasons her deadweight needs to be increased by 5,000 tonnes. Based on the sister ship's operational profile, the draught limit is 9m. Additionally, for minimizing the fuel consumption, the length to breadth ratio should be increased (L/B=7.5) Calculate the displacement and the main characteristics of the new design using Normand's number and the statistical approaches. In your calculations you may assume that the block coefficient is constant. The data of the reference ship are given below:

Item	Reference Ship data
Length, L (m)	300
Beam, B (m)	42
Draft, T (m)	18
Block Coefficient, C_B	0.72
Hull weight W_H (tonne)	8000
Machinery Weight W_M (tonne)	3000
Outfitting weight W_O (tonne)	2000
Fuel weight W_F (tonne)	3000
Deadweight (tonne)	24824
Length to Beam ratio, L/B	7.14

Table 3.1 Reference ship data for a cargo vessel

3.1 Solution (Normand's number approach)

1. Open spreadsheet T3_Main dimensions.xlsx sheet 1 entitled ''*Normand No*''
2. Calculate the displacement of the reference ship based on the main dimensions and C_B; λ is the shell and appendage allowance=1.006; ρ is the density of seawater=1.25 $t/_{m^3}$

$$\Delta = \rho . L . B . T . C_B . \lambda = 20534 \text{ t}$$

3. Calculate Normand's number based on equation (3.1) and the given reference ship data.

$$N = \frac{20534}{20534 - (4000 + 1000) - \frac{2}{3}(1500 + 1500)} = 1.517$$

4. Based on the deadweight change required and Normand's number, the displacement of the new design can be calculated as :

$$\Delta_{new} = \Delta + NdW = 20534 + (1.52 \times 5000) = 28120 \text{ tonnes}$$

5. To determine the main dimensions L/B, C_B, and T are assumed to be unchanged.
6. Since C_B and T do not change; $L \times B = \frac{\Delta}{C_B . T}$ and $L/B = 7.14$, therefore, L, B can be deduced.
7. Using T3_maindimensions.xlsx you will get the following results :

Item	New Ship data
L (m)	176,1
B (m)	24,65
T (m)	9
C_B	0,72
Δ (tonne)	28120
Cargo Deadweight (tonne)	17534

Table 3.2 Ship dimension estimates for cargo vessel

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3.2 Solution (statistical approach)

1. Open spreadsheet T3_Main dimensions.xlsx sheet 1 entitled ''*Statistical Method*''
2. To estimate the ship displacement for the required deadweight, the deadweight to displacement ratio should be used. Table 3.3 summarizes this for different types of ships.

	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)	$L \cong 80$ m	16,000 t DWT	50–60	68–78	12–19	10–20
Reefers[d] (ft³) of net ref. vol.	300,000	500,000	45–55	51–62	21–28	15–26
Passenger Ro-Ro/ferries/ RoPax	$L \cong 85$ m	$L \cong 120$ m	16–33	56–66	23–28	11–18
Large passenger ships (cruise ships)	$L \cong 200$ m	$L \cong 360$[e] m	23–34	52–56	30–34	15–20
Small passenger ships	$L \cong 50$ m	$L \cong 120$ m	15–25	50–52	28–31	20–29
Stern Trawlers	$L \approx 44$ m	$L \cong 82$ m	30–58	42–46	36–40	15–20
Tugboats	$P_B \cong 500$ KW	3,000 KW	20–40	42–56	17–21	38–43
River ships (towed)	$L \cong 32$ m	$L \cong 35$ m	22–27	58–63	19–23	16–21
River ships (self-propelled)	$L \cong 80$ m	$L \cong 110$ 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

Table 3.3 Upper and lower bound DWT to displacement ratios for different designs (Papanikolaou, 2014).

3. The L_{pp} of the ship is to be calculated based on Schneekluth's (1998) formula as follows:

$$L_{PP} = \Delta^{0.3} V^{0.3} C$$

where

V is the vessel speed in knots and $C = 3.4 - \frac{\Delta - 10^3}{10^6}$ for $1000\ \mathrm{t} \le \Delta \le 201{,}000\ \mathrm{t}$ or C=3.2 for $\Delta \ge 201{,}000$ t

4. Froude's no. (F_n) can be calculated using Eq.(2.7), i.e. $Fn = \frac{V(m/s)}{\sqrt{gL(m)}}$
5. C_B can be obtained using one of the following empirical formulae:

$$C_B = 0.7 + 0.125 \tan^{-1}\left[(23 - 100Fn)/4\right] \quad \text{[Watson \& Gilfillan]}$$

$$C_B = -4.22 + 27.8\sqrt{Fn} - 39.1Fn + 46.6Fn^3 \quad \text{for } 0.15 \le \mathrm{Fn} \le 0.32$$

6. L/B ratio can be estimated based on the following empirical formulae:

$$L/B = 4 \ \ for\ L \le 30\ m \quad L/B = 4 + 0.025(L - 30) \ \ for\ 30\ m \le L \le 130\ m$$
$$L/B = 6.5 \ \ for\ L \ge 130\ m \quad \text{[Watson \& Gilfillan]}$$

7. Draft then can be obtained based on the ship's breadth using the following formula:

$$T = \frac{\nabla}{L \times B \times C_B}$$

8. Recommendations on the L/D ratio which is important for longitudinal strength and through which you can calculate the depth of the ship are provided by Papanikoloau (2014) as follows :

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Ship type	Ratio of main dimensions
	L_{pp}/D
Fast seagoing cargo ships	9.9–13.5
Slow seagoing cargo ships	
Coastal cargo ships	10.0–12.0
Small short sea passenger ships	10.4–11.6
Ferries	8.6–10.3
Fishing vessels	8.2–9.0
Tugboats	7.7–10.0
Bulk carriers	10.5–12.8
Tankers F_n=0.15	12.0–14.0
Tankers F_n=0.16–0.18	10.5–12.8
Fast seagoing reefers	−11.0

4. Questions

1. A shipowner has a fleet of old tankers. He requested from your firm to support them with a new tanker which has a 2% increase in the deadweight in comparison to the last tanker. As the fleet is very old, some weight data estimates are missing. The length of the dock at which the ship will be built limits the length to 200 meters. The maximum breadth to draught ratio (B/T) required is estimated based on the formula :

$$(B/T)_{max} = 9.625 - 7.5 \times C_B$$

The main characteristics of the reference tanker are given in the table. If the block coefficient is constant, calculate the displacement and the main characteristics of the new design using both Normand's number approach and the statistical design method.

Item	Reference ship data
L (m)	200
B (m)	33.3
T (m)	12
C_B	0.84
Deadweight (tonne)	55,737

2. You are working in a design office, and your task is to select the main dimensions of a new container ship based on concise owner requirements. According to a feasibility study, the ship owner expects that a deadweight of 25,000 tonnes, and a design speed of 12 Knots will achieve the required return on investment. Calculate the ship's main characteristics using a statistical method.
3. Describe the factors associated with the use of statistics in the definition of ship main dimensions?
4. What can be done with clustering of data when you use of statistics in the definition of ship main dimensions? What kind of restrictions you can explain by clustering process?
5. Which issues should be considered when you use statistics in the definition of ship main dimensions?
6. Explain the idea of Normand's number. How can you apply that in selection of main dimensions?

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