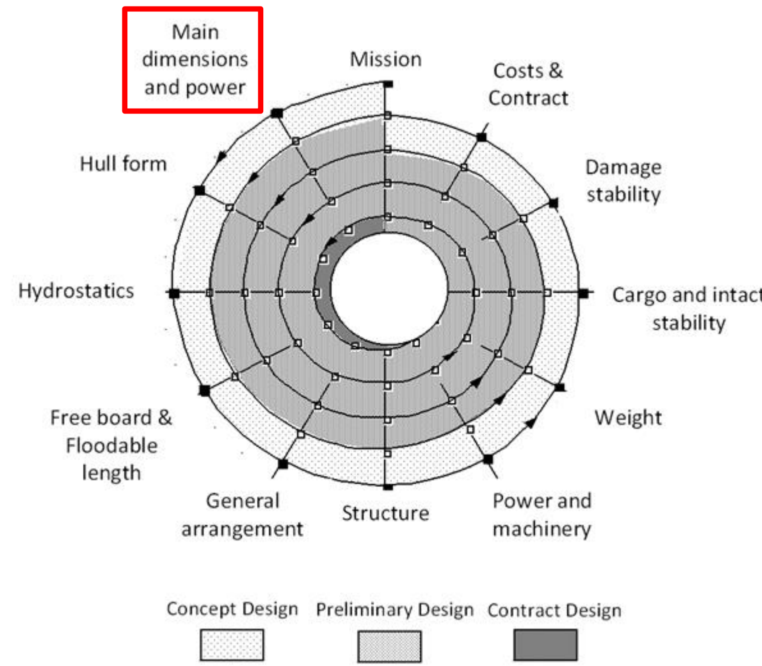
Aalto University
School of Engineering

MEC-E1004 Principles of Naval Architecture

Lecture 3 – Main dimensions

Learning points !

- After the lecture, you will be able to:
  - *List and define terminology related to a ship's main dimensions*
  - *You will become familiar with (and be able to apply) approaches to determine a ship's main dimensions*



Assignment 3 – Main dimensions

- Determine your ship's main dimensions considering her mission & operational profile
  - *Identify size constraints set by the route and ports, and discuss how they affect the design*
  - *Make use of statistics and empirical formulae*
    - ✓ Feel confident on possible deviations from your reference ship
  - *Define whether your ship is limited by weight, volume and/or main dimensions*

TANKER STATISTICS

Name	Launch date	DWT ton	L_{PP} m	B m	T_{WL} m	D m	P_B kW	V_S kn	Engine Speed rpm	Engine Design	Liquid Cargo Capacity m^3
ISOLA VERDE	01.01.93	32 500	169	28,0	10,9	14,9	7 098	14		6RTA52	
DA QING 73	01.07.93	34 000	186	27,5	10,0	15,0	5 852	14		5L50MC	
ACTINIA	01.03.92	34 204	169	32,0	11,2	15,1	7 829	14	117	5L60MC	47962
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RUBIN	01.12.93	39 768		28,0	12,0	16,8	8 421	15		K6SZ70/150	
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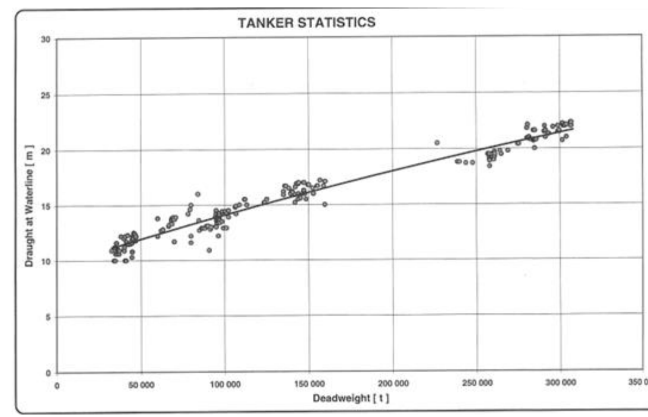


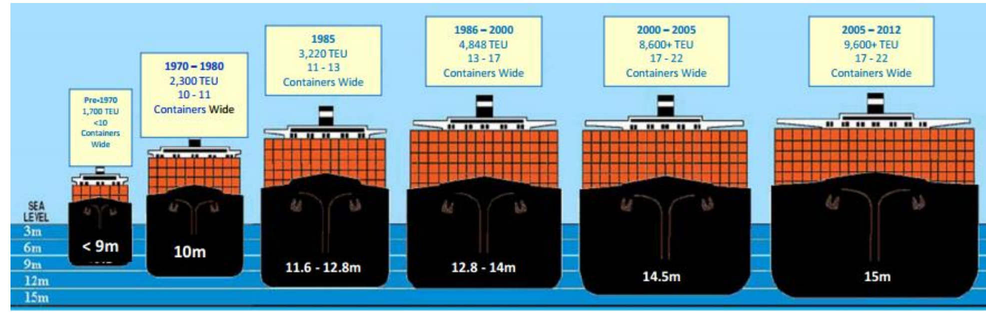
Selection of main dimensions

Question: Why is the selection of a ship's main dimensions important?

Why the selection of main dimensions is key ?

- They define to large extent a ship’s technical and economical performance
  - *Set constraints for ship’s usage*

- Mistakes done in the selection of a ship’s main dimensions are very costly (or impossible) to correct in subsequent design/building phases



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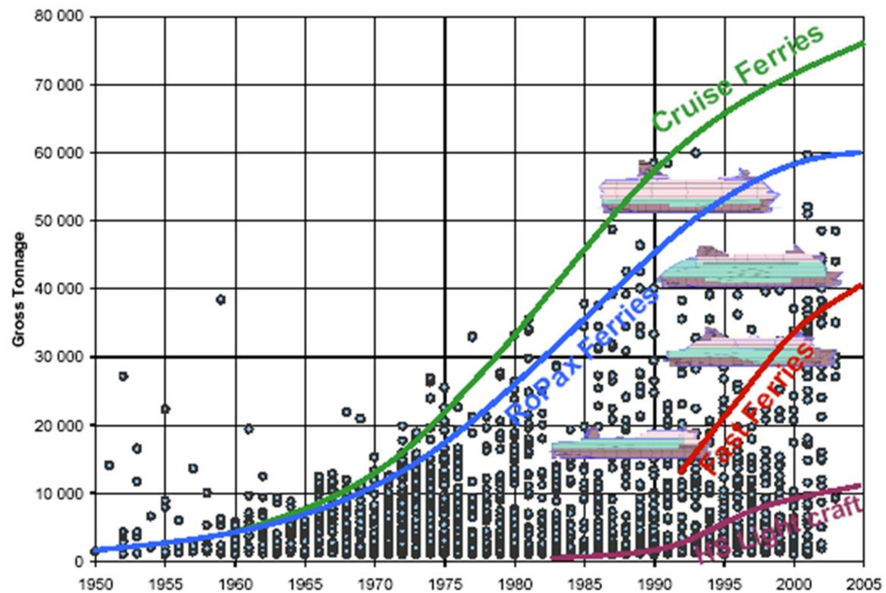
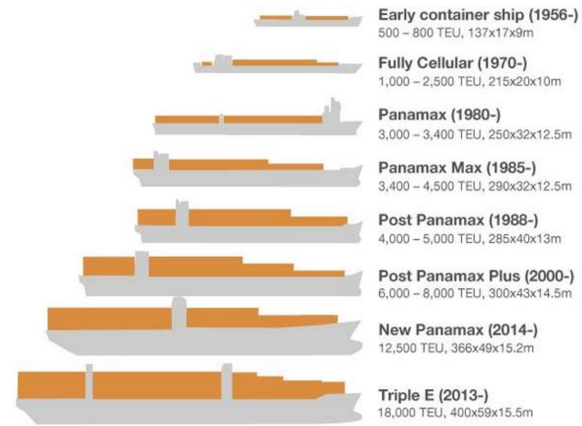
Why the selection of main dimensions is key ? (Examples)

Trend towards larger ships to achieve higher cost-efficiency



Why the selection of main dimensions is key ? (Examples)



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- Load carrying capability (buoyancy)
- Hull resistance in still and deep water and in waves
- Stability (safety)
- Seaworthiness
  - *the motions, the accelerations and the loads from water in rough seas are to be as small as possible*
- Longitudinal Strength
- Cost efficiency
  - *Scale efficiency → Generally, for fully utilized ships, the cost-efficiency (e.g. cost per passenger or cargo unit) increases by size*

Selection of main dimensions – Length (L)

Determined considering

- *Required cargo capacity*
  - L is a general factor of size
- *Hull resistance*
  - Calm water resistance is sensitive to hull length
  - The Length-breadth ratio L/B is typically 4 - 10
- *Longitudinal strength*
  - The length-depth ratio affects the strength of the hull girder
  - $L/D \approx 10 – 18$
- *Physical constraints set by*
  - Shipyard facilities (e.g. Meyer Turku's building dock is 365 m long)
  - Channel docks
  - Port facilities
  - Fairways
  - …

Image credit Meyer Werft

Selection of main dimensions – Drought (T)

- Also referred to as draft

- T is dependent on the Archimedes law
  - *T increases until the weight of the displaced water equals the weight of the ship*
  - *Several load condition specific definitions within the maximum and minimum allowed T values*

- Generally T should be as large as possible to
  - *Enable a large propeller diameter for high energy efficiency*
  - *To minimize slamming in rough seas*
    - Draft-length ratio T/L (≈0,035 - 0,05) affects the bow slamming in rough seas

- Often limited by physical constraints (shallow water)
  - *Restrictions set by ports and the associated waterways are found in port catalogues*

Selection of main dimensions – Breadth (B)

- A general factor of size

- Determined considering
  - *Cargo carrying capacity (e.g. the number of lanes on a RORO ship, or the number of side-by-side containers on a cargo ship)*

  - *Transverse stability*
    - Increase in B → additional stability
    - Both the Breadth-Draft ratio B/T (≈2,3 - 4,5) and the Breadth-Depth ratio B/D (≈1.75 -3), affects the transversal stability of a ship

  - *Hull resistance*
    - Added resistance (e.g. wave resistance) is sensitive to B, calm water resistance not so much

  - *Physical constraints (e.g. set by channels, docks, etc.)*

Image credit Finnlines

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Selection of main dimensions
Depth (D) and Freeboard (F)

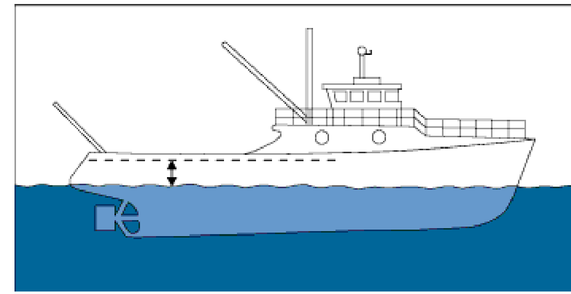
Depth (D)

- A general volume factor
- A strength factor

Freeboard (F)

Sufficient freeboard is essential for stability. If the deck edge goes under the water when the vessel heels, the danger of capsizing is great.

Sufficient freeboard



Overloaded vessel → Too low freeboard

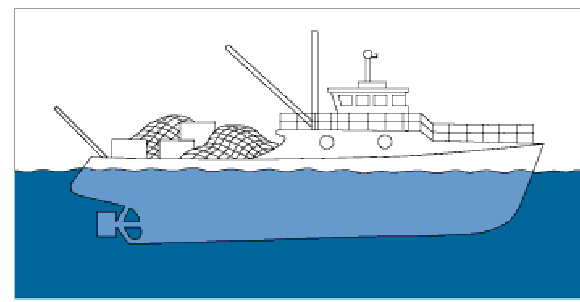


Image credit Transport Canada

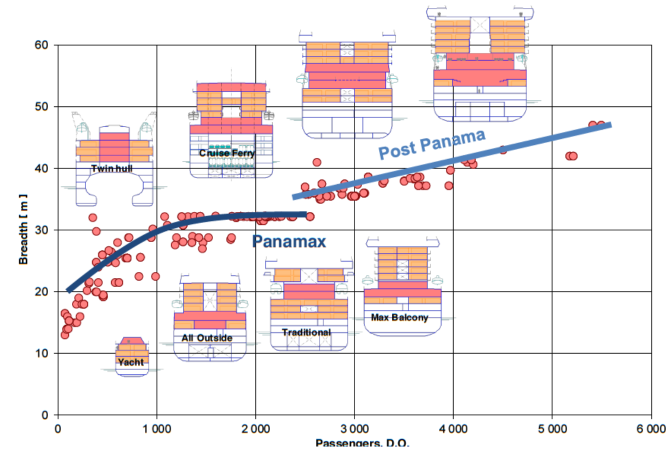
Selection methods for main dimensions

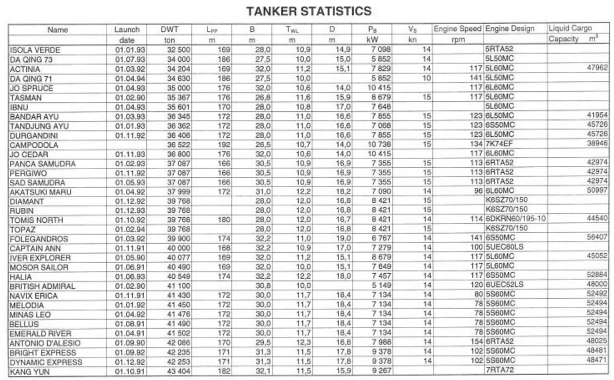
- Based on a reference ship
  - *The main dimensions are determined based on a reference ship*
  - *The dimensions can be modified using the Normand's number approach*

- Based on statistical data
  - *The main dimensions are selected based on statistically determined regression curves*
  - *The statistics should be comprehensive including tens of delivered ships*

- Based on direct calculations
  - *The main dimensions and displacement equilibrium are determined based on direct calculations*

Regardless of method, the selection of the main dimension is an iterative process





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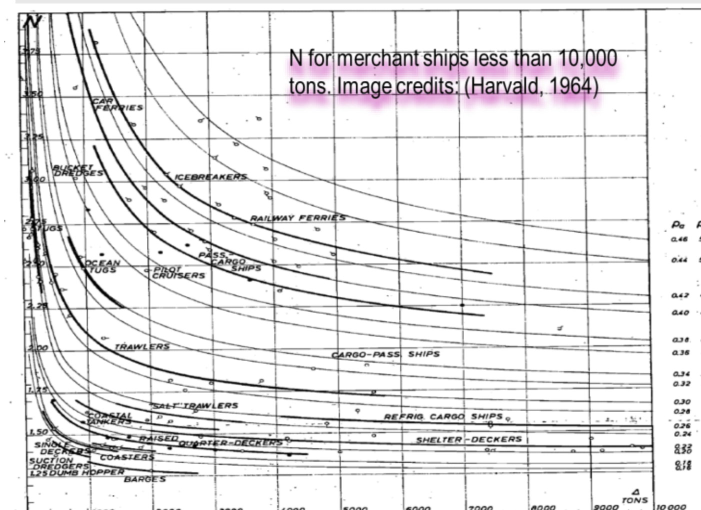
Normand's no. (N)

Can be used to estimate the change in a ship's total weight i.e. the displacement change dΔ, caused by scaling the size of a ship to accommodate extra/reduced weight dW

- *Is defined as a ratio between the displacement and weight changes*
- *Starting point is the equilibrium between displacement and ship's weight*
- *The added weight dW causes the displacement change dΔ*



N for merchant ships less than 10,000 tons. Image credits: (Harvald, 1964)

Reference Ship + Normand's no.

- Let's assume that the weight W_i can be defined as a function of displacement Δ having the following format:

$$W_i = C_i \Delta^{k_i} \quad (1)$$

- The derivation of the equation in terms of the displacement results:

$$\frac{dW_i}{d\Delta} = k_i C_i \Delta^{k_i - 1} = k_i \frac{W_i}{\Delta} \quad (2)$$

- When the both sides of the expression is multiplied by dΔ and the result is substituted into the weight equation, we get

$$d\Delta = dW + \frac{d\Delta}{\Delta} \sum k_i W_i \quad (3)$$

Reference Ship + Normand's no.

- After separating the variables, the following expression is obtained:

$$\left(\Delta - \sum \boldsymbol{k_i W_i}\right) \boldsymbol{d}\Delta = \Delta \boldsymbol{dW} \qquad (\mathbf{4})$$

- When the derivative of the displacement with respect to the added weight is solved, the following expression is obtained for Normand's number N:

$$\boldsymbol{N} = \frac{\boldsymbol{d}\Delta}{\boldsymbol{dW}} = \frac{\Delta}{\Delta - \sum_{i=1}^{n} \boldsymbol{k_i W_i}} \qquad \mathbf{(5)}$$

Reference Ship + Normand's no.

- Lightship weight is composed of:
  - Hull weight W_H, outfitting weight W_O and machinery weight W_M.

- Ship deadweight composed of:
  - Fuel weight W_F and cargo weight W_G.

- Let's derive the relationships between the weights and the displacement:

  - Hull and outfitting weight W_{H+O} can be assumed to be function of the product of the ship length L, breadth B and depth D:

    $$W_{H+O} = C_{H+O} * LBD \qquad (6)$$

  - Displacement as a function of the length L, breadth B and draught T gets

    $$\Delta = constant * LBT \qquad (7)$$

  - Assuming that the ratio between depth and draught D/T is constant, the relation between the weights and displacement is:

    $$W_{H+O} = C_{H+O} * \Delta \qquad (8)$$

Selection of main dimensions

- Assumption that machinery weight is related power P, the following expression can be written:

$$P = \frac{v^3 \Delta^{\frac{2}{3}}}{C_A}$$

- And thus, the machinery weight is

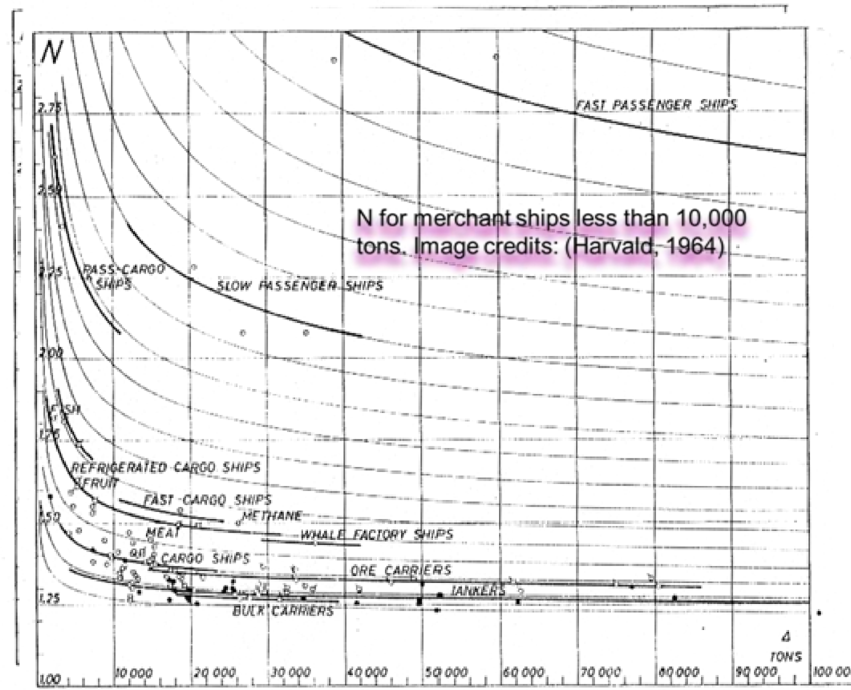
$$W_M = C_M \Delta^{\frac{2}{3}}$$

- Fuel weight is related to the fuel consumption, which can be calculated based on power and operation time

$$W_F = C_F \Delta^{\frac{2}{3}}$$

- Based on the relation between the weights and displacements, Normand's number is:

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



N for merchant ships less than 10,000 tons. Image credits: (Harvald, 1964)

Statistical approach

- Different procedures can be followed to obtain first estimation of main dimensions
- The selection of the appropriate procedure depends on the available data, curves, empirical formula, etc.
- For example, if we are given: DWT, Speed (owner requirements) and we need to define the main particulars:
  - ✓ Get displacement from the tabular values of deadweight displacement ratios.
  - ✓ Length, C_b and L/B can be calculated using regression-based equations, suitable empirical formulas or tabular data.
  - ✓ Draft can be calculated using C_b , B, L and displacement
  - ✓ Depth can be calculated based on the L/D ratio from statistical data.

	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] (ft^3) 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

Ship type	Hull form coefficients				Ratios of main dimensions		
	C_P	C_M	C_B	C_{WP}	L_{PP}/B	B/T	$L_{PP}/\nabla^{1/3}$
Fast seagoing cargo ships	0.57–0.65	0.97–0.98	0.56–0.64	0.68–0.74	5.7–7.8	2.2–2.6	5.6–5.9
Slow seagoing cargo ships	0.66–0.74	0.97–0.995	0.65–0.73	0.80–0.86	4.8–8.5	2.1–2.3	5.2–5.4
Coastal cargo ships	0.69–0.73	−0.985	0.58–0.72	0.78–0.83	4.5-5.5	2.5–2.7	4.2–4.8
Small short sea passenger ships	0.61–0.63	0.82–0.85	0.51–0.53	0.65–0.70	5.8-6.5	3.3–3.9	6.3–6.6
Ferries	0.53–0.62	0.91–0.98	0.50–0.60	0.69–0.81	5.9–6.2[a] 5.2–5.4[b]	3.7–4.0	6.2–6.9[a] 5.7–5.9[b]
Fishing vessels	0.61–0.63	0.87–0.90	0.53–0.56	0.76–0.79	5.1–6.1	2.3–2.6	5.0–5.4
Tugboats	0.61–0.68	0.75–0.85	0.50–0.58	0.79–0.84	3.8–4.5	2.4–2.6	4.0–4.6
Bulk carriers	0.79–0.84	0.990–0.997	0.72–0.86	0.88–0.92	5.0–7.1[a]	2.1–3.2	4.7–5.6
Tanker $F_n=0.15$	0.835–0.855	0.992–0.996	0.82–0.88	0.88–0.94	5.1–6.8	2.4–3.2	4.5–5.6
Tankers $F_n=0.16-0.18$	0.79–0.83	0.992–0.996	0.78–0.86	0.88–0.92	5.0–6.5	2.2–2.9	4.5–5.2
Fast seagoing reefers	(0.55)[c] 0.59–0.62	0.96–0.985	(0.53)[c] 0.57–0.59	0.68–0.72	6.7–7.2	2.8–3.0	6.1–6.5

Note on tutorial

- **Exercise 1** : Three basic exercises on ship form coefficients to build up your knowledge and experience from Lecture 2
- **Exercise 2 :** An example on reference ship and Normands No.
- **Exercise 3 :** A step by step example on how to apply the statistical approach
- **Exercise 4 :** An example on how to apply direct calculations
- Bonus information on statistical relationships between main dimensions (empirical charts)

Tools

- **Explanatory note on how to use the xls tools**
- Database with information on statistical data for different ship types (not perfect but can be useful !)
- Calculation tool for Normand's no.

Summary and conclusions

The main dimensions consist of

- Linear dimensions: length, breadth,…
- Area based dimensions
- Volume based dimensions

The selection of appropriate main dimensions is very important as they define to a large extent a ship's technical and economical performance

- Can be selected/determined in various ways
  - *Based on a reference ship*
    - The dimensions can be scaled using the Normand's number
  - *Based on statistical data*
  - *Based on direct calculations*

Image credit pancanal.com

Summary and conclusions

- Ship hydrodynamic performance, seakeeping, maneuvering, stability, strength, etc. depend on the selection of the main dimensions and their ratios.

- There are different methods to obtain the first estimation of the main dimensions
  - ✓ *Based on a reference ship (Normand's number can be used to define the new displacement)*
  - ✓ *Based on statistical data*
  - ✓ *Based on direct calculations*

- Regardless of method, the selection of the main dimension is an iterative process that is sensitive to data availability and design novelty

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Thank you !