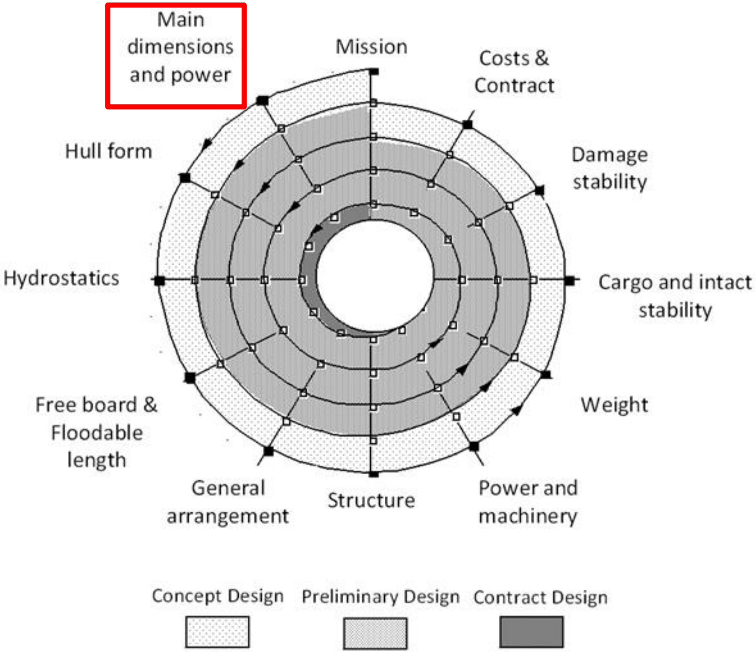
Aalto University
School of Engineering

MEC-E1004 Principles of Naval Architecture

Lecture 3 – Main dimensions

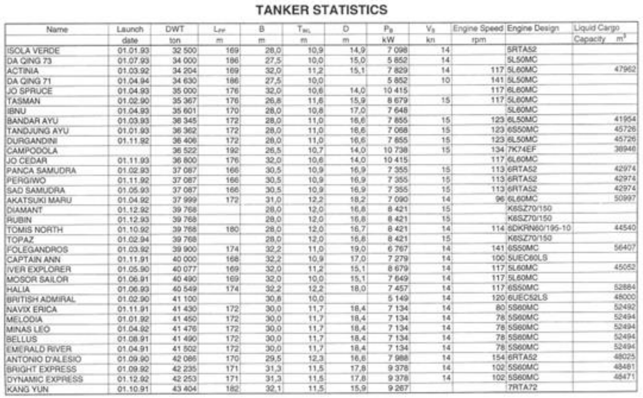
Learning points !

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



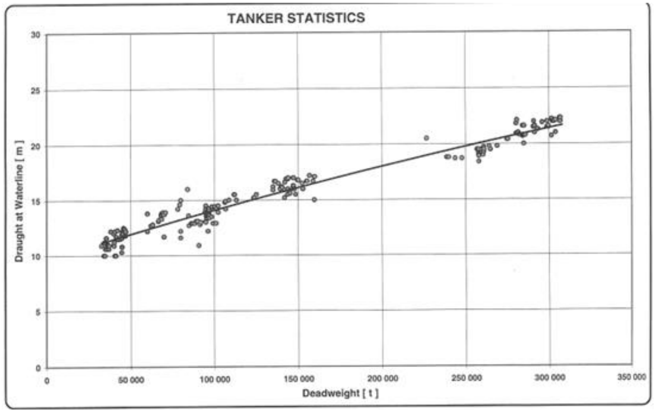
Assignment 3 – Main dimensions

- Determine your ship’s main dimensions considering its mission and operational profile
  - *Identify size constraints set for instance by the route and ports, and discuss how these affect the design of your ship*
  - *Make use of statistics and your reference ship(s)*
    - Motivate possible deviations from your reference ship and or statistics
    - Assess the quality of statistics
  - *Define whether your ship is limited by weight, volume and/or main dimensions*



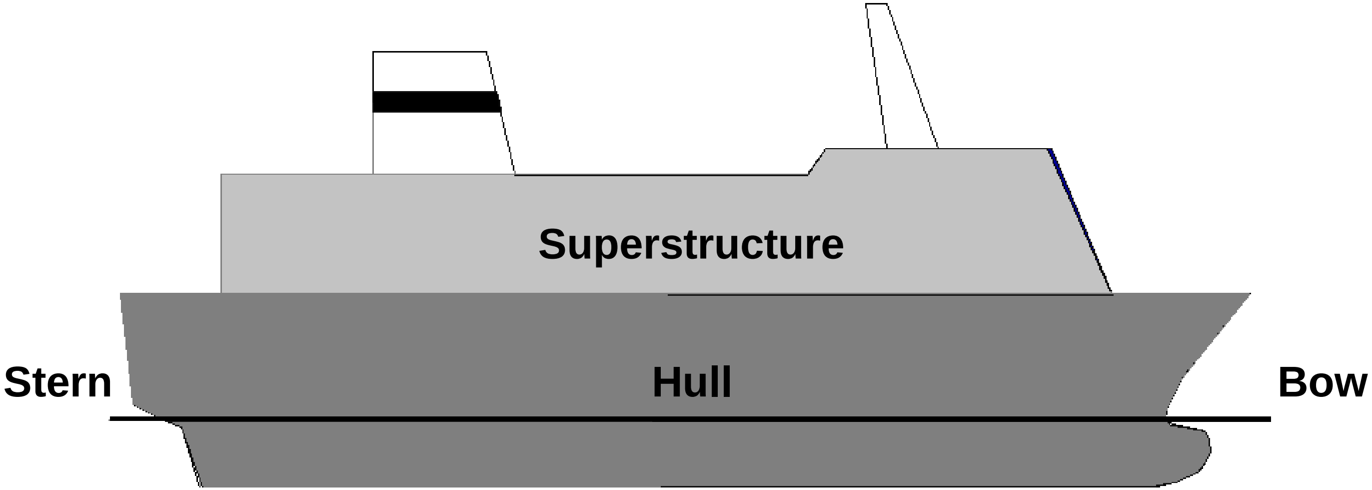
TANKER STATISTICS

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
DA QING 71	01.04.94	34 630	186	27,5	10,0		5 852	10	141	5L50MC	
JO SPRUCE	01.04.93	35 000	176	32,0	10,6	14,0	10 415		117	6L60MC	
TASMAN	01.02.90	35 367	176	26,8	11,6	15,9	8 679	15	117	5L60MC	
IBNU	01.04.93	35 601	170	28,0	10,8	17,0	7 648			5L60MC	
BANDAR AYU	01.03.93	36 345	172	28,0	11,0	16,6	7 855	15	123	6L50MC	41954
TANDJUNG AYU	01.01.93	36 362	172	28,0	11,0	16,6	7 068	15	123	6S50MC	45726
DURGANDINI	01.11.92	36 406	172	28,0	11,0	16,6	7 655	15	123	6L50MC	45726
CAMPODOLA		36 522	192	26,5	10,7	14,0	10 738	15	134	7K74EF	38946
JO CEDAR	01.11.93	36 800	176	32,0	10,6	14,0	10 415		117	6L60MC	
PANCA SAMUDRA	01.02.93	37 087	166	30,5	10,9	16,9	7 355	15	113	6RTA52	42974
PERGIWO	01.11.92	37 087	166	30,5	10,9	16,9	7 355	15	113	6RTA52	42974
SAD SAMUDRA	01.05.93	37 087	166	30,5	10,9	16,9	7 355	15	113	6RTA52	42974
AKATSUKI MARU	01.04.92	37 999	172	31,0	12,2	18,2	7 090	14	96	6L60MC	50997
DIAMANT	01.12.92	39 768		28,0	12,0	16,8	8 421	15		K6SZ70/150	
RUBIN	01.12.93	39 768		28,0	12,0	16,8	8 421	15		K6SZ70/150	
TOMIS NORTH	01.10.92	39 768	180	28,0	12,0	16,7	8 421	14	114	6DKRN60/195-10	44540
TOPAZ	01.02.94	39 768		28,0	12,0	16,8	8 421	15		K6SZ70/150	
FOLEGANDROS	01.03.92	39 900	174	32,2	11,0	19,0	6 767	14	141	6S50MC	56407
CAPTAIN ANN	01.11.91	40 000	168	32,2	10,9	17,0	7 279	14	100	5UEC60LS	
IVER EXPLORER	01.05.90	40 077	169	32,0	11,2	15,1	8 679	14	117	5L60MC	45052
MOSOR SAILOR	01.06.91	40 490	169	32,0	10,0	15,1	7 649	14	117	5L60MC	
HALIA	01.06.93	40 549	174	32,2	12,2	18,0	7 457	14	117	6S50MC	52884
BRITISH ADMIRAL	01.02.90	41 100		30,8	10,0		5 149	14	120	6UEC52LS	48000
NAVIX ERICA	01.11.91	41 430	172	30,0	11,7	18,4	7 134	14	80	5S60MC	52492
MELODIA	01.01.92	41 450	172	30,0	11,7	18,4	7 134	14	78	5S60MC	52494
MINAS LEO	01.04.92	41 476	172	30,0	11,7	18,4	7 134	14	78	5S60MC	52494
BELLUS	01.08.91	41 490	172	30,0	11,7	18,4	7 134	14	78	5S60MC	52494
EMERALD RIVER	01.04.91	41 502	172	30,0	11,7	18,4	7 134	14	78	5S60MC	52494
ANTONIO D'ALESIO	01.09.90	42 086	170	29,5	12,3	16,6	7 988	14	154	6RTA52	48025
BRIGHT EXPRESS	01.09.92	42 235	171	31,3	11,5	17,8	9 378	14	102	5S60MC	48481
DYNAMIC EXPRESS	01.12.92	42 253	171	31,3	11,5	17,8	9 378	14	102	5S60MC	48471
KANG YUN	01.10.91	43 404	182	32,1	11,5	15,9	9 267			7RTA72	



TANKER STATISTICS

Terminology



Main Dimensions

- Length (L)
  - *Horizontal distance between bow and stern*
    - Length over all (L_{OA})
    - Length between perpendiculars (L_{BP})
      - AP = Aft perpendicular
      - FP= Forward perpendicular
    - Design waterline length (L_{WL})

- Breadth / Beam (B)
  - *Horizontal distance between ship sides*
    - Maximum overall breadth B_{MAX}
    - Maximum (design) waterline breadth B_{DWL}

- Draught / Draft (T)
  - *Vertical distance between floating plane and keel*

- Depth (D)
  - *Vertical distance between main deck and keel*

- **Block coefficient (C_B) ??**

- Freeboard (F)
  - *The vertical distance measured from the deck to the waterline*

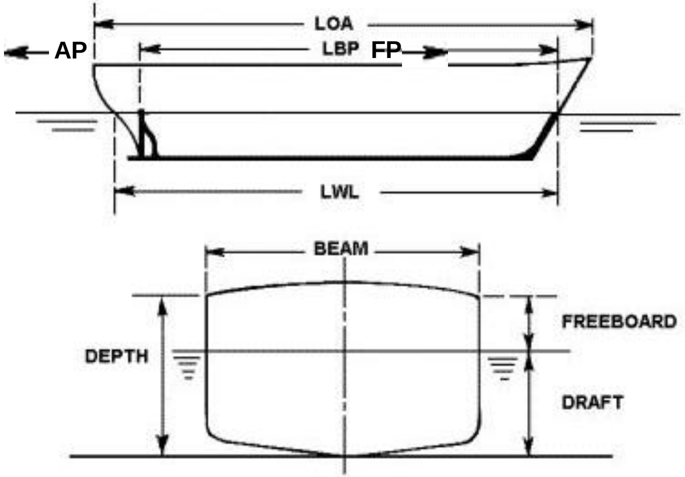


Image credit brighthubengineering.com

Main frame

- Forward facing view (from stern to bow)
  - *Right hand side = starboard*
  - *Left hand side = port side*

Trim

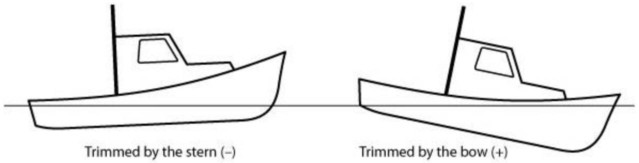
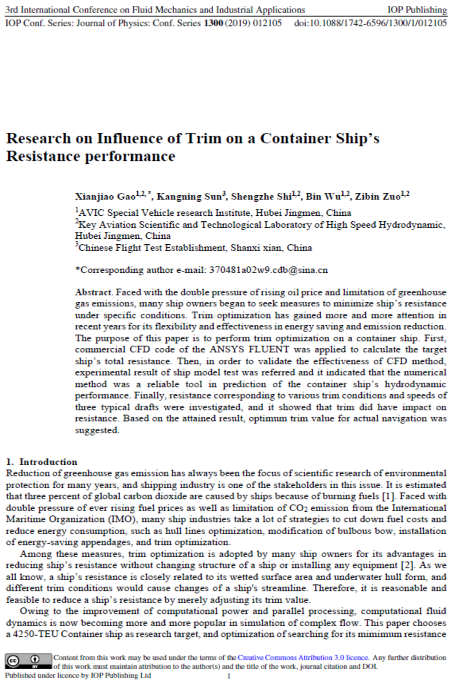


Image credit otenmaritime.com

- Draft (T) is measured both in the stern (aft end) and bow (fwd end) of a ship

- The difference between forward and aft drafts is referred to as <u>trim</u>

- It may have significant impact on ship resistance



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Research on Influence of Trim on a Container Ship's Resistance performance

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Abstract. Faced with the double pressure of rising oil price and limitation of greenhouse gas emissions, many ship owners began to seek measures to minimize ship's resistance under specific conditions. Trim optimization has gained more and more attention in recent years for its flexibility and effectiveness in energy saving and emission reduction. The purpose of this paper is to perform trim optimization on a container ship. First, commercial CFD code of the ANSYS FLUENT was applied to calculate the target ship's total resistance. Then, in order to validate the effectiveness of CFD method, experimental result of ship model test was referred and it indicated that the numerical method was a reliable tool in prediction of the container ship's hydrodynamic performance. Finally, resistance corresponding to various trim conditions and speeds of three typical drafts were investigated, and it showed that trim did have impact on resistance. Based on the attained result, optimum trim value for actual navigation was suggested.

1. Introduction

Reduction of greenhouse gas emission has always been the focus of scientific research of environmental protection for many years, and shipping industry is one of the stakeholders in this issue. It is estimated that three percent of global carbon dioxide are caused by ships because of burning fuels [1]. Faced with double pressure of ever rising fuel prices as well as limitation of CO_2 emission from the International Maritime Organization (IMO), many ship industries take a lot of strategies to cut down fuel costs and reduce energy consumption, such as hull lines optimization, modification of bulbous bow, installation of energy-saving appendages, and trim optimization.

Among these measures, trim optimization is adopted by many ship owners for its advantages in reducing ship's resistance without changing structure of a ship or installing any equipment [2]. As we all know, a ship's resistance is closely related to its wetted surface area and underwater hull form, and different trim conditions would cause changes of a ship's streamline. Therefore, it is reasonable and feasible to reduce a ship's resistance by merely adjusting its trim value.

Owing to the improvement of computational power and parallel processing, computational fluid dynamics is now becoming more and more popular in simulation of complex flow. This paper chooses a 4250-TEU Container ship as research target, and optimization of searching for its mimimum resistance

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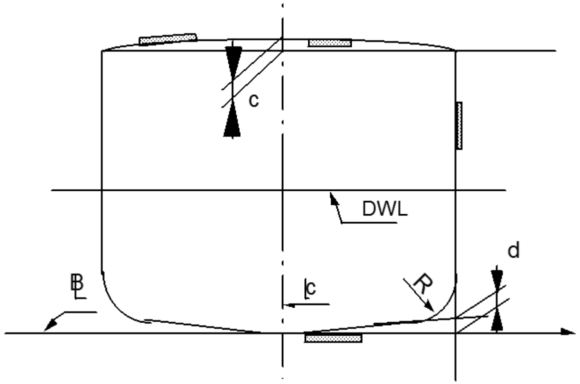
Main frame terminology

- C – Chamber (*kansimutka*)
  - *A measure how the deck's curvature*
  - *Needed to minimize water on deck*

- R – Turn of bilge (*pallepyöristys*)
  - *Measure of the rounding between the ship side and bottom*
  - *It affects the water flow around the hull*

- D – Rise of floor / Deadrise (*pohjannousu*)
  - *A measure of the hull shape*

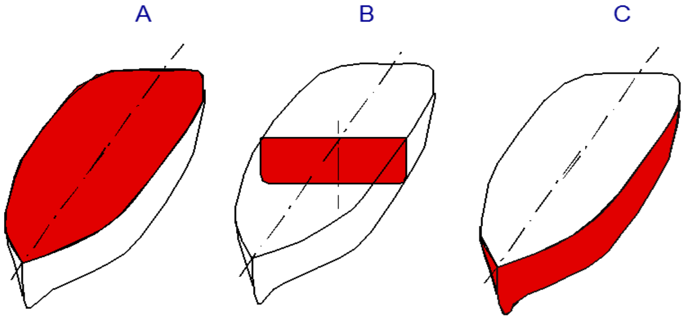


Area measures

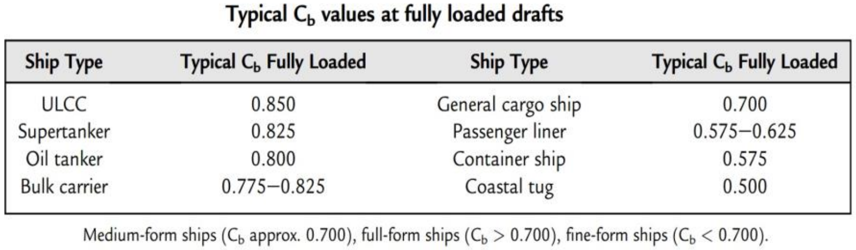
A. Area of waterplane (AWP - *laivan vesiviivan pinta*) is horizontal section cut at floating position

B. Area at amidships (AM - *pääkaaren pinta*) is the area closed by molded hull line and the floating plane, usually equaling the main frame area at midship

C. Wetted surface, (S - *märkäpinta*), is the area in touch with surrounding water



Block Coefficient (C_B)



Typical C_b values at fully loaded drafts

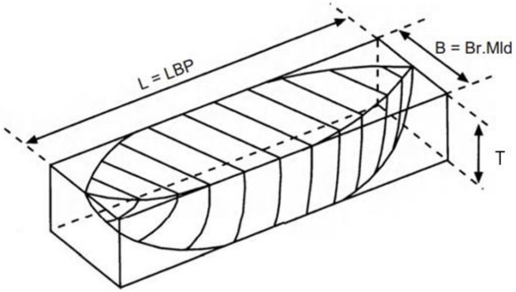
Ship Type	Typical C_b Fully Loaded	Ship Type	Typical C_b Fully Loaded
ULCC	0.850	General cargo ship	0.700
Supertanker	0.825	Passenger liner	0.575–0.625
Oil tanker	0.800	Container ship	0.575
Bulk carrier	0.775–0.825	Coastal tug	0.500

Medium-form ships (C_b approx. 0.700), full-form ships ($C_b > 0.700$), fine-form ships ($C_b < 0.700$).

It is the ratio of the underwater volume of a ship to the volume of a rectangular block, the dimensions of which are the length between perpendiculars, the mean draught and the breadth extreme. The relationship is expressed as a decimal figure.

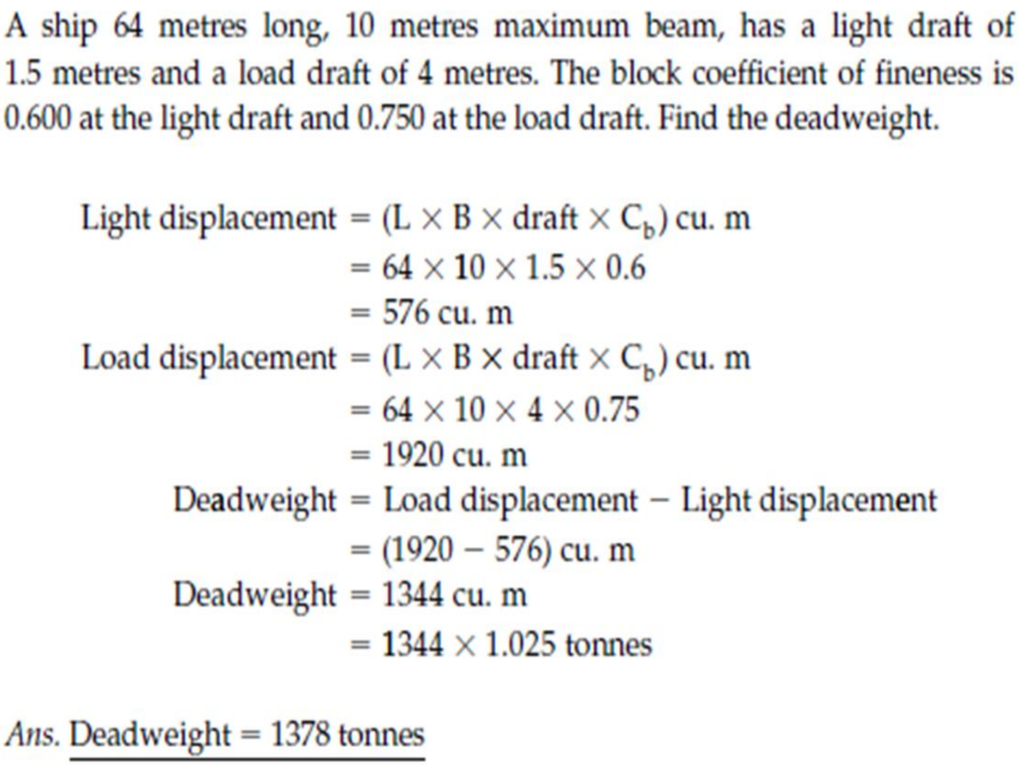
$$C_B = \frac{\nabla}{LBT}$$

- **Determined considering**
  - *Resistance and speed*
    - In passenger ship C_B≈0,55 while in slow bulk-carrier C_B≈0,85
  - *Buoyancy*
    - An increased higher C_B value provides an increased buoyancy
  - *Manufacturing related factors*



Block Coefficient (C_B)

$$C_B = \frac{\nabla}{LBT}$$



A ship 64 metres long, 10 metres maximum beam, has a light draft of 1.5 metres and a load draft of 4 metres. The block coefficient of fineness is 0.600 at the light draft and 0.750 at the load draft. Find the deadweight.

$$\begin{aligned}
\text{Light displacement} &= (\text{L} \times \text{B} \times \text{draft} \times C_b)\ \text{cu. m} \\
&= 64 \times 10 \times 1.5 \times 0.6 \\
&= 576\ \text{cu. m} \\
\text{Load displacement} &= (\text{L} \times \text{B} \times \text{draft} \times C_b)\ \text{cu. m} \\
&= 64 \times 10 \times 4 \times 0.75 \\
&= 1920\ \text{cu. m} \\
\text{Deadweight} &= \text{Load displacement} - \text{Light displacement} \\
&= (1920 - 576)\ \text{cu. m} \\
\text{Deadweight} &= 1344\ \text{cu. m} \\
&= 1344 \times 1.025\ \text{tonnes}
\end{aligned}$$

Ans. Deadweight = 1378 tonnes

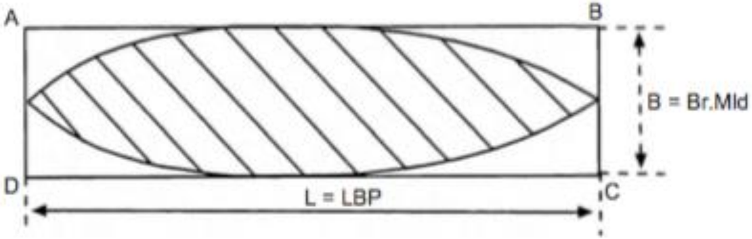
Waterplane area coefficient (C_W)

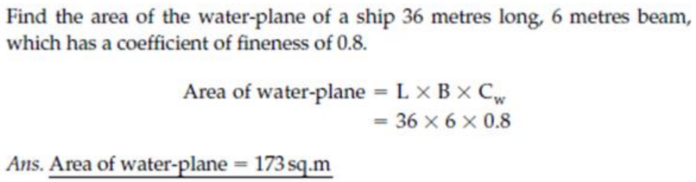
It is the ratio of the actual area of the waterplane to the product of the length and breadth of the ship.

$$C_W = \frac{\text{Area of water-plane}}{\text{Area of rectangle ABCD}}$$

$$= \frac{\text{Area of water-plane}}{L \times B}$$

Area of the water-plane = L x B x Cw




Find the area of the water-plane of a ship 36 metres long, 6 metres beam, which has a coefficient of fineness of 0.8.

$$\text{Area of water-plane} = L \times B \times C_W$$
$$= 36 \times 6 \times 0.8$$

Ans. Area of water-plane = 173 sq.m

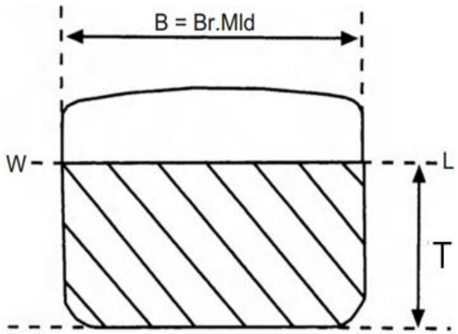
Mid ship section area coefficient (C_M)

It is the ratio of the actual area of the immersed portion of the ship’s midship section to the product of the breadth and the draught of the ship.

$$Cm = \frac{\text{Midships area (Am)}}{\text{Area of rectangle}}$$

$$= \frac{\text{Midships area (Am)}}{B \text{ x } d}$$

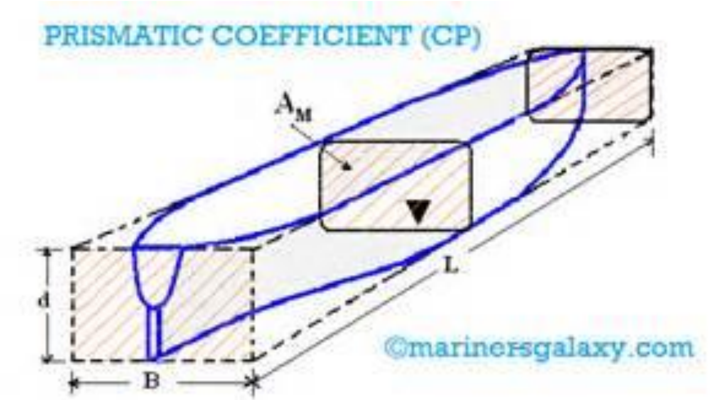
Midships area (Am) = L x B x C**m**



The Midships Coefficient

Prismatic coefficient (C_P)

The ratio of the volume of displacement at that draft to the volume of a prism having the same length as the ship and the same cross-sectional area as the ship's midships area.



$$Cp = \frac{\text{Volume of ship}}{\text{Volume of prism}}$$

$$= \frac{\text{Volume of ship}}{L \times Am}$$

$$\text{Volume of ship} = L \times Am \times \mathbf{Cp}$$

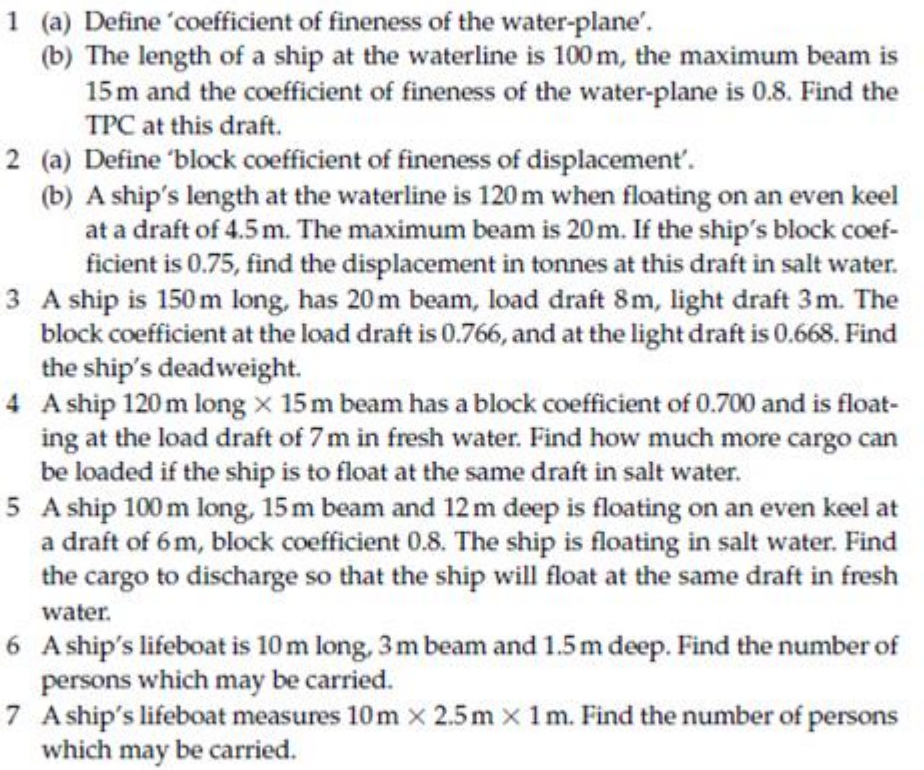
Relationship between coefficients

$$C_m \times C_p = \frac{A_m}{B \times d} \times \frac{\text{Volume of ship}}{L \times A_m}$$

$$= \frac{\text{Volume of ship}}{L \times B \times d}$$

So, $C_m \times C_p = C_b$

Home exercises



1 (a) Define 'coefficient of fineness of the water-plane'.
  (b) The length of a ship at the waterline is 100 m, the maximum beam is 15 m and the coefficient of fineness of the water-plane is 0.8. Find the TPC at this draft.

2 (a) Define 'block coefficient of fineness of displacement'.
  (b) A ship's length at the waterline is 120 m when floating on an even keel at a draft of 4.5 m. The maximum beam is 20 m. If the ship's block coefficient is 0.75, find the displacement in tonnes at this draft in salt water.

3 A ship is 150 m long, has 20 m beam, load draft 8 m, light draft 3 m. The block coefficient at the load draft is 0.766, and at the light draft is 0.668. Find the ship's deadweight.

4 A ship 120 m long × 15 m beam has a block coefficient of 0.700 and is floating at the load draft of 7 m in fresh water. Find how much more cargo can be loaded if the ship is to float at the same draft in salt water.

5 A ship 100 m long, 15 m beam and 12 m deep is floating on an even keel at a draft of 6 m, block coefficient 0.8. The ship is floating in salt water. Find the cargo to discharge so that the ship will float at the same draft in fresh water.

6 A ship's lifeboat is 10 m long, 3 m beam and 1.5 m deep. Find the number of persons which may be carried.

7 A ship's lifeboat measures 10 m × 2.5 m × 1 m. Find the number of persons which may be carried.

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

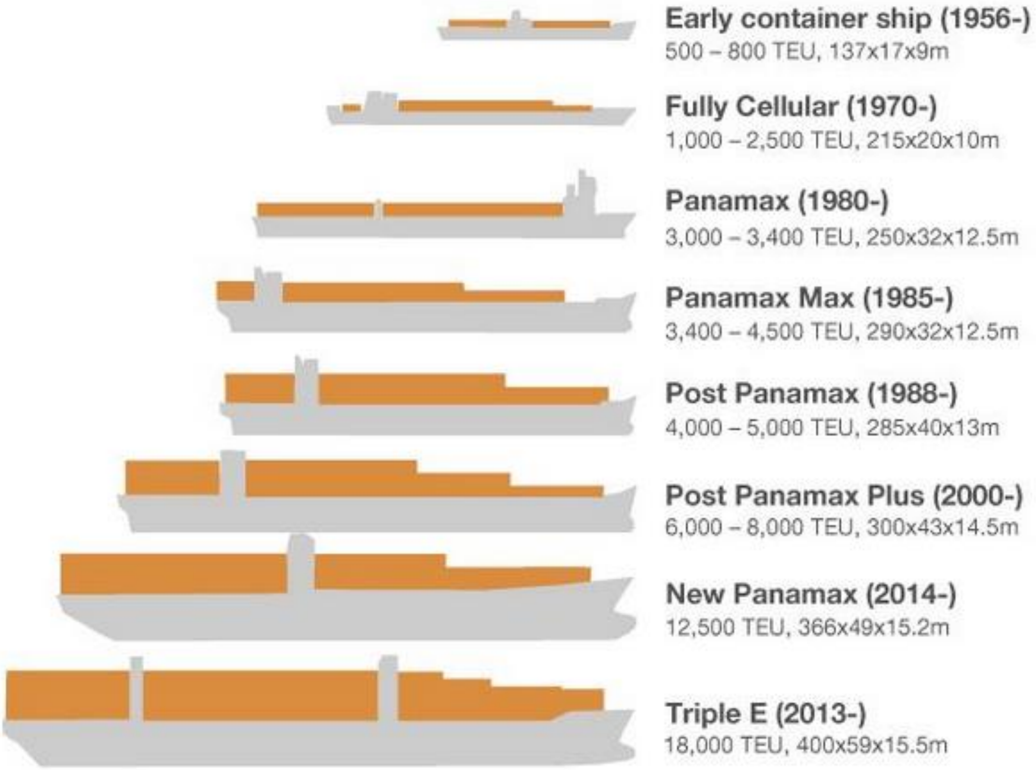
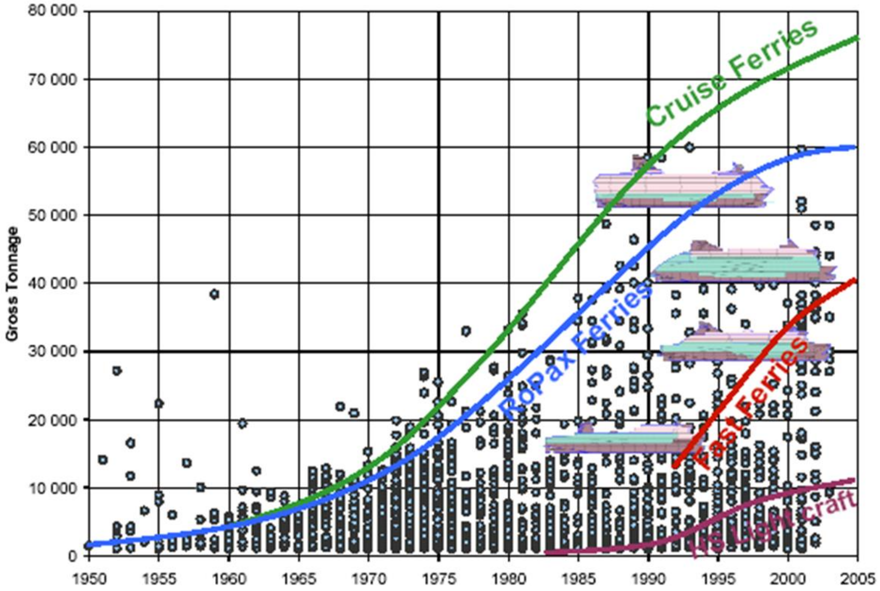


Image credit J-P Rodrigue

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)

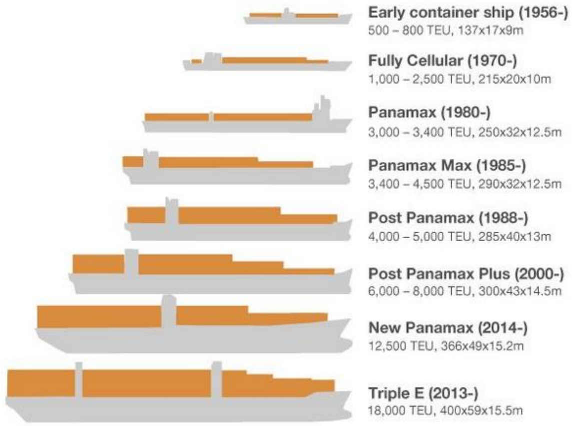


Image credit J-P Rodrigue

- 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 ≈ 10 – 18
- *Physical constraints set by*
  - Shipyard facilities (e.g. Meyer Turku's building dock is 365 m long)
  - Channel docks
  - Fairways
  - …

Image credit Meyer Werft

Selection of main dimensions – Drought (T)

- Also referred to as draft

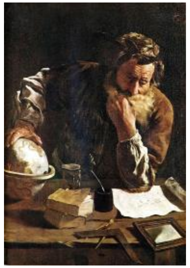
- T is dependent on the Archimedes law
  - *T increases until the weight of the displaced water equals the weight of the ship*
  - *Several load condition specific definitions within the maximum and minimum allowed T values*

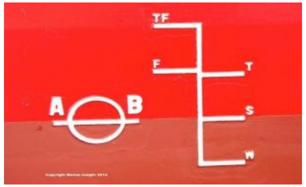
- Generally T should be as large as possible to
  - *Enable a large propeller diameter for high energy efficiency*
  - *To minimize slamming in rough seas*
    - Draft-length ratio T/L (≈0,035 - 0,05) affects the bow slamming in rough seas

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

Load line mark

- Define he maximum legal limit to which a ship can be loaded for various operating conditions
  - *Salt/sea water*
    - T – Tropical waters
    - S – Summer temperate water
    - W – Winter temperate water
  - *Fresh water*
    - F – Fresh water
    - TF – Tropical fresh water
- Plimsoll mark”
  - *Summer salt water line*
  - The maximum legal limit to which a ship can be loaded in salt water in “summer” conditions





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

Image credit mjolnershipping.com

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

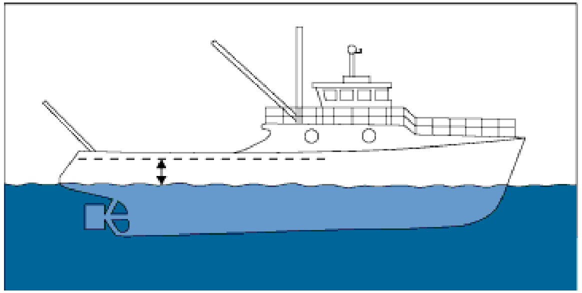
Depth (D)

- 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

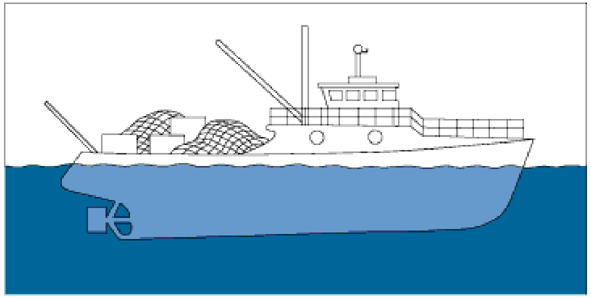


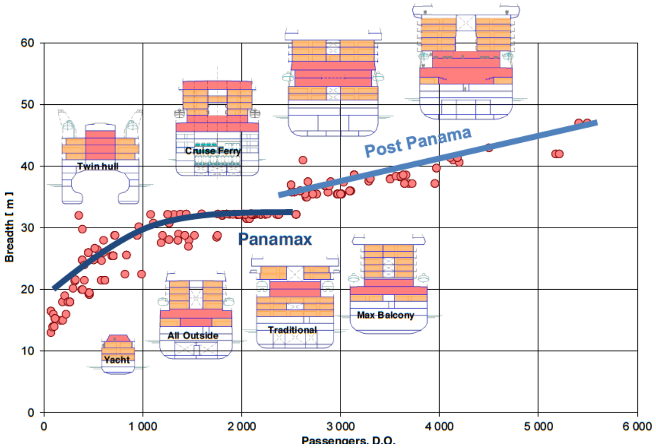
Image credit Transport Canada

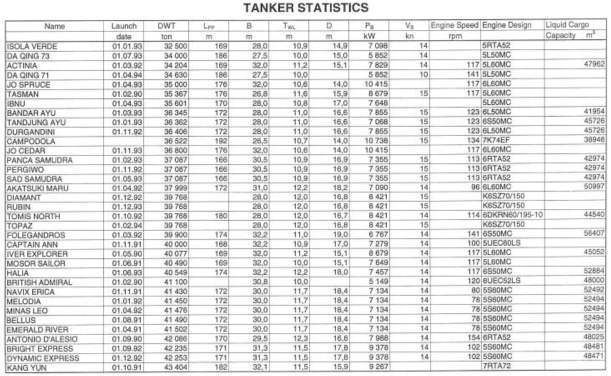
Selection methods for main dimensions

- 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*





TANKER STATISTICS

Name	Launch	DWT	L_{PP}	B	T_{WL}	D	P_B	V_S	Engine Speed	Engine Design	Liquid Cargo Capacity
	date	ton	m	m	m	m	kW	kn	rpm		m^3
ISOLA VERDE	01.01.93	32 500	169	28,0	10,9	14,9	7 098	14		5RTA52	
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
DA QING 71	01.04.94	34 630	186	27,5	10,0		5 852	10	141	5L50MC	
JO SPRUCE	01.04.93	35 000	176	32,0	10,6	14,0	10 415		117	6L60MC	
TASMAN	01.02.90	35 367	176	26,8	11,6	15,9	8 679	15	117	5L60MC	
IBNU	01.04.93	35 601	170	28,0	10,8	17,0	7 648			5L60MC	
BANDAR AYU	01.03.93	36 345	172	28,0	11,0	16,6	7 855	15	123	6L50MC	41954
TANDJUNG AYU	01.01.93	36 362	172	28,0	11,0	16,6	7 068	15	123	6S50MC	45726
DURGANDINI	01.11.92	36 406	172	28,0	11,0	16,6	7 855	15	123	6L50MC	45726
CAMPODOLA		36 522	192	26,5	10,7	14,0	10 738	15	134	7K74EF	38946
JO CEDAR	01.11.93	36 800	176	32,0	10,6	14,0	10 415		117	6L60MC	
PANCA SAMUDRA	01.02.93	37 087	166	30,5	10,9	16,9	7 355	15	113	6RTA52	42974
PERGIWO	01.11.92	37 087	166	30,5	10,9	16,9	7 355	15	113	6RTA52	42974
SAD SAMUDRA	01.05.93	37 087	166	30,5	10,9	16,9	7 355	15	113	6RTA52	42974
AKATSUKI MARU	01.04.92	37 999	172	31,0	12,2	18,2	7 090	14	96	6L60MC	50997
DIAMANT	01.12.92	39 768		28,0	12,0	16,8	8 421	15		K6SZ70/150	
RUBIN	01.12.93	39 768		28,0	12,0	16,8	8 421	15		K6SZ70/150	
TOMIS NORTH	01.10.92	39 768	180	28,0	12,0	16,7	8 421	14	114	6DKRN60/195-10	44540
TOPAZ	01.02.94	39 768		28,0	12,0	16,8	8 421	15		K6SZ70/150	
FOLEGANDROS	01.03.92	39 900	174	32,2	11,0	19,0	6 767	14	141	6S50MC	56407
CAPTAIN ANN	01.11.91	40 000	168	32,2	10,9	17,0	7 279	14	100	5UEC60LS	
IVER EXPLORER	01.05.90	40 077	169	32,0	11,2	15,1	8 679	14	117	5L60MC	45052
MOSOR SAILOR	01.06.91	40 490	169	32,0	10,0	15,1	7 649	14	117	5L60MC	
HALIA	01.06.93	40 549	174	32,2	12,2	18,0	7 457	14	117	6S50MC	52884
BRITISH ADMIRAL	01.02.90	41 100		30,8	10,0		5 149	14	120	6UEC52LS	48000
NAVIX ERICA	01.11.91	41 430	172	30,0	11,7	18,4	7 134	14	80	5S60MC	52492
MELODIA	01.01.92	41 450	172	30,0	11,7	18,4	7 134	14	78	5S60MC	52494
MINAS LEO	01.04.92	41 476	172	30,0	11,7	18,4	7 134	14	78	5S60MC	52494
BELLUS	01.08.91	41 490	172	30,0	11,7	18,4	7 134	14	78	5S60MC	52494
EMERALD RIVER	01.04.91	41 502	172	30,0	11,7	18,4	7 134	14	78	5S60MC	52494
ANTONIO D'ALESIO	01.09.90	42 086	170	29,5	12,3	16,6	7 988	14	154	6RTA52	48025
BRIGHT EXPRESS	01.09.92	42 235	171	31,3	11,5	17,8	9 378	14	102	5S60MC	48481
DYNAMIC EXPRESS	01.12.92	42 253	171	31,3	11,5	17,8	9 378	14	102	5S60MC	48471
KANG YUN	01.10.91	43 404	182	32,1	11,5	15,9	9 267			7RTA72	

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

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*

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:

$$W_i = C_i \Delta^{k_i}$$

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

$$\frac{dW_i}{d\Delta} = k_i C_i \Delta^{k_i-1} = k_i \frac{W_i}{\Delta}$$

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

$$d\Delta = dW + \frac{d\Delta}{\Delta} \sum k_i W_i$$

Reference Ship + Normand's no.

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

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

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

$$\boldsymbol{N} = \frac{\boldsymbol{d}\Delta}{\boldsymbol{dW}} = \frac{\Delta}{\Delta - \sum_{i=1}^{n} \boldsymbol{k_i W_i}}$$

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:

    $W_{H+O} = C_{H+O} * LBD$
  - Displacement as a function of the length L, breadth B and draught T gets

    $\Delta = constant * LBT$
  - Assuming that the ratio between depth and draught D/T is constant, the relation between the weights and displacement is:

    $W_{H+O} = C_{H+O} * \Delta$

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

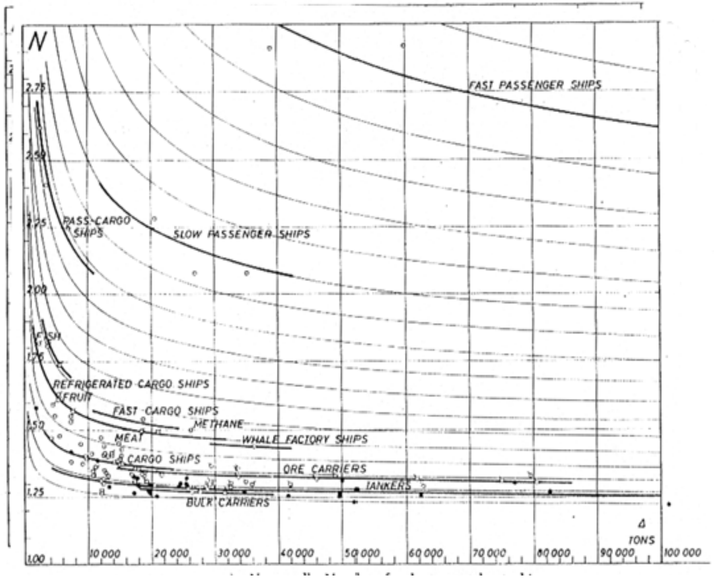
$$W_M = C_M \Delta^{\frac{2}{3}}$$

- 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:

$$N = \frac{d\Delta}{dW} = \frac{\Delta}{\Delta + W_{H+O} + + \frac{2}{3}(W_M + W_F)}$$



Aalto University
School of Engineering

Thank you !