Estimation Methods for Basic Ship Design

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Ship Design I

MSc in Marine Engineering and Naval Architecture

Summary

- Hull Form
- Lightship Weight
- Deadweight Components
- Propulsive Coefficients
- Propulsive Power
- Subdivision and Compartments
- Capacities

Introduction

- At the beginning of the basic design there is no sufficient data to proceed with accurate computations
- It is necessary to use estimate methods which with the few information available or assumed will allow to obtain approximate values
- These methods are generally based in statistical regressions with data compiled from existing ships

Hull Form Coefficients

Block Coefficient (C_B)

$$C_B = C - 1.68 \cdot F_n$$

C = 1.08 (single screw)
C = 1.09 (twin screw)
C = 1.06

$$C_B = \frac{0.14}{F_n} \cdot \frac{L/B + 20}{26} \qquad 0.48 \le C_B \le 0.85 \qquad 0.14 \le F_n \le 0.32$$

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

$$C_B = -4.22 + 27.8 \cdot \sqrt{F_n} - 39.1 \cdot F_n + 46.6 \cdot F_n^3 \qquad 0.15 < F_n < 0.32$$

Barras (2004)

$$C_B = 1.20 - 0.39 \cdot \left(\frac{V}{\sqrt{L_{PP}}} \right)$$

V [knots]
L_{PP} [m]

Block Coefficient (Cb)

Alexander (1962)

$$C_B = K - 0.5V/\sqrt{L_f}$$

with:

$K = 1.12 \text{ » } 1.03$ $\quad$ *p / navios mercantes*
$= 1.32 \text{ » } 1.23$ $\quad$ *p / navios de guerra*
V : *velocidade* [*knots*]
L_F : *comprimento da linha de flutuaçao* [*ft*]

Van Lameren

$$C_B = 1.37 - 2.02V/\sqrt{L_f}$$

Block Coefficient (Cb)

Ayre

$$C_B = 1.06 - 1.68 V \big/ \sqrt{L_f}$$

Minorsky

$$C_B = 1.22 - 2.38 V \big/ \sqrt{L_f}$$

Munro-Smith (1964)

$$\frac{dC_B}{dT} = \frac{Cw - Cb}{T}$$

Block Coefficient (Cb)

Townsin (1979)

$$C_B = 0.7 + 0.125 \cdot tg^{-1}\left[25 \cdot (0.23 - Fn)\right]$$

Schneekluth (1987)

$$C_B = \frac{0.14}{Fn} \cdot \frac{L_{PP}\big/B + 20}{26}$$

$$C_B = \frac{0.23}{Fn^{2/3}} \cdot \frac{L_{PP}\big/B + 20}{26} \qquad p/ \quad \begin{array}{l} 0.48 < C_B < 0.85 \\ 0.14 < Fn < 0.32 \end{array}$$

Block Coefficient (Cb)

Katsoulis

$$C_B = 0.8217 \cdot f \cdot L_{PP}^{0.42} \cdot B^{-0.3072} \cdot T^{0.1721} \cdot V^{-0.6135}$$

In which *f* is a function of the type of ship:

Ro/Ro **Reefers**	**Gen. Cargo** **Tankers**	**Containers**	**OBO**	**Bulk**	**Gas**	**Products** **Chemicals**	**Ferry**
0.97	0.99	1.00	1.03	1.04	1.05	1.06	1.09

Kerlen (1970)

$$C_B = 1.179 - 2.026 \cdot Fn \qquad p/ \quad C_B > 0.78$$

Midship Section Coefficient (C_M)

Midship Section Coefficient

$$C_M = 1 - \frac{R^2}{2.33 \cdot B \cdot T}$$

Kerlen (1970)

$$C_M = 1.006 - 0.0056 \cdot C_B^{-3.56}$$

Where:

R= Bilge radius [m]

Fn = Froude Number

HSVA

$$C_M = \frac{1}{1 + (1 - C_B)^{3.5}}$$

Meizoso

$$C_M = 1 - 0.062 \cdot Fn^{0.792}$$

RO/RO ships and Container-Carriers

Midship Section Coefficient (C_M)

Parson (2003)

$$C_M = 1 - \left(\frac{0.4292 \cdot R^2}{B \cdot T} \right)$$

Waterline Area Coefficient (C_{WL})

Schneekluth

$$C_{WL} = 0.95 \cdot C_P + 0.17 \cdot \sqrt[3]{1 - C_P}$$

U shape sections

$$C_{WL} = \frac{1}{3}(1 + 2 \cdot C_B)$$

Intermediate shape sections

$$C_{WL} = \sqrt{C_B - 0.025}$$

V shape sections

$$C_{WL} = \frac{1}{3}\left(1 + 2 \cdot \frac{C_B}{\sqrt{C_M}}\right)$$

Torroja

$$C_{WL} = A + B \cdot C_B$$

$$A = 0.248 + 0.049 \cdot G$$

$$B = 0.778 - 0.035 \cdot G$$

$G = 0$ U shaped sections

$= 1$ V shaped sections

Waterline Area Coefficient (C_{WL})

Parson (2003)

$$C_{WL} = \frac{C_B}{0.471 + 0.551 \cdot C_B}$$

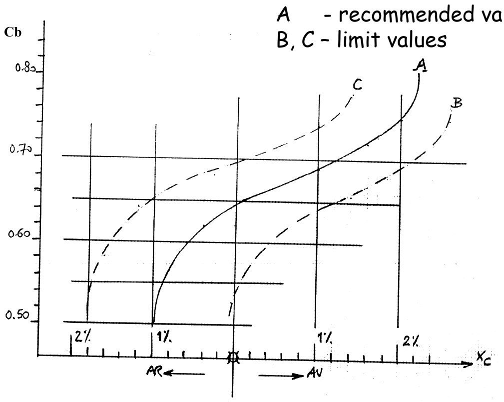
Buoyancy Center Ordinate (KB)

$KB = T\left(\frac{5}{6} - \frac{1}{3}\frac{C_B}{C_{WP}}\right)$	Normand
$KB = T\left(0.9 - 0.36 C_M\right)$	Normand
$KB = T\left(0.9 - 0.3 \cdot C_M - 0.1 \cdot C_B\right)$	Schneekluth
$KB = T\left(0.78 - 0.285\frac{C_B}{C_{WP}}\right)$	Wobig
$KB = \left(0.372 - \frac{0.168 \cdot C_{WL}}{C_B}\right) \cdot T$	Vlasov

Buoyancy Center Abscissa (LCB)

As a first approximation, the abscissa of the buoyancy center can be obtained from the following diagram as a function of the Block Coefficient (C_B):

A - recommended values
B, C - limit values



Buoyancy Center Abscissa (LCB)

Schneekluth

$$lcb = \left(8.80 - 38.9 \cdot F_n\right) / 100$$ [% Lpp AV MS]

$$lcb = -0.135 + 0.194 \cdot C_P$$ (tankers and bulkers)

Transverse Metacentric Radius (BMT)

The Transverse Metacentric Radius is defined by

$$BMT = \frac{I_{XX}}{\nabla}$$

The transverse moment of inertia of the waterplane (I_{XX}) can be approximated by the expression:

$$I_{XX} = k_r \cdot B^3 \cdot L$$

In which the values of the factor k_r are obtained from the following Table:

C_{WL}	K_r	C_{WL}	K_r	C_{WL}	K_r
0.68	0.0411	0.78	0.0529	0.88	0.0662
0.70	0.0433	0.80	0.0555	0.90	0.0690
0.72	0.0456	0.82	0.0580	0.92	0.0718
0.74	0.0480	0.84	0.0607	0.94	0.7460
0.76	0.0504	0.86	0.0634	0.96	0.7740

Transverse Metacentric Radius (BMT)

$$BMT = \frac{f(C_{WP}) \cdot L \cdot B^3}{12 \cdot L \cdot B \cdot T \cdot C_B} = \frac{f(C_{WP})}{12} \cdot \frac{B^2}{T \cdot C_B}$$

Reduction Factor:

$f(C_{WP}) = 1.5 \cdot C_{WP} - 0.5$	Murray
$f(C_{WP}) = 0.096 + 0.89 \cdot C_{WP}^2$	Normand
$f(C_{WP}) = 0.0372 \cdot (2 \cdot C_{WP} + 1)^3$	Bauer
$f(C_{WP}) = 1.04 \cdot C_{WP}^2$	N.N.
$f(C_{WP}) = 0.13 \cdot C_{WP} + 0.87 \cdot C_{WP}^2 \pm 0.005$	Dudszus and Danckwardt

Transverse Metacentric Radius (BMT)

Xuebin (2009)

$$BMT = \left(0.085 \cdot C_B - 0.002\right) \cdot \frac{B^2}{T \cdot C_B}$$ (bulk-carriers)

Xuebin, Li (2009), "Multiobjective Optimization and Multiattribute Decision Making Study of Ship's Principal Parameters in Conceptual Design", Journal of Ship Research, Vol.53, No.2, pp.83-02.

Longitudinal Metacentric Radius

The **Longitudinal Metacentric Radius** is defined by

$$BML = \frac{I_{YY}}{\nabla}$$

The longitudinal moment of inertia of the waterplane (I_{YY}) can be obtained approximately by the expression:

$$I_{YY} = k_R \cdot B \cdot L^3$$

In which the values of the factor k_R are obtained from the following Table:

C_{WL}	K_r	C_{WL}	K_r	C_{WL}	K_r
0.68	0.0332	0.78	0.0450	0.88	0.0588
0.70	0.0350	0.80	0.0475	0.90	0.0616
0.72	0.0375	0.82	0.0503	0.92	0.0645
0.74	0.0400	0.84	0.0532	0.94	0.0675
0.76	0.0425	0.86	0.0560	0.96	0.0710

Stability Parameters

Metacentric Height KM

$$KM = B \cdot \left(13.61 - 45.4 \frac{C_B}{C_{WP}} + 52.17 \left(\frac{C_B}{C_{WP}} \right)^2 - 19.88 \left(\frac{C_B}{C_{WP}} \right)^3 \right)$$

Applicable to ships with $0.73 < (C_B/C_{WP}) < 0.95$

$$KM = B \cdot \left(\frac{0.08}{\sqrt{C_M}} \cdot \frac{B}{T} \cdot C + \frac{0.9 - 0.3 \cdot C_M - 0.1 \cdot C_B}{B/T} \right)$$

Schneekluth

If C_{WP} is unknown:

$$C_{WP,N} = \frac{1}{3} \left(1 + 2 \cdot \frac{C_B}{\sqrt{C_M}} \right) \qquad C = 1.0$$

Period of Roll

- An excessively high value of GMT implies a very small period of roll and leads to high accelerations, which are uncomfortable to crew and passengers and also results into higher loads in some equipment
- A maximum value of GMT should therefore be assumed based on na acceptable value of the roll period (T = 10 seconds is typical value)
- The period of roll (T) can be estimated by the expression:

$$T_R = \frac{0.43 \cdot B}{\sqrt{GMT}} \quad [s]$$

where:

B [m]

GMT [m]

Wetted Surface (S_W)

Denny

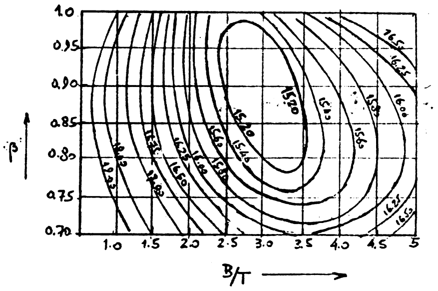
$$S_W = 1.7 \cdot L_{PP} \cdot T + \frac{\nabla}{T}$$

em que:
SW : wetted surface [ft2]
LPP : length bet. perpendiculars [ft]
T : draught [ft]
∇ : displacement volume [ft3]

Taylor

$$S_W = 0.17 \cdot c \cdot \sqrt{\nabla \cdot L_{WL}}$$

em que:
S_W : surface [m2]
∇ : displacement volume [m3]
LPP : length on the waterline [m]
c : f(C_M, B/T)



Wetted Surface (S_W)

Holtrop and Mennen (1978)

$$S_W = Lwl \cdot (2 \cdot T + B) \cdot \sqrt{C_M} \cdot \left(0.453 + 0.4425 \cdot C_B - 0.2862 \cdot C_M - 0.003467 \cdot {}^{B}\!/_{T} + 0.369 \cdot C_{WP}\right) + 2.38 \cdot {}^{A_{BT}}\!/_{C_B}$$

In which:
A_{BT} – transverse section area of the bulb on FWD PP

Schneekluss and Bertram (1998)

$$S_W = \left(3.4 \cdot \nabla^{1/3} + 0.5 \cdot L_{WL}\right) \cdot \nabla^{1/3}$$

Cylindrical Mid-Body

Lindblad (1961)

$$\frac{L_E}{L} = 1.975 - 2.27 \cdot C_B$$

p/ Cb < 0.75

$$\frac{L_R}{L} = 1.12 - C_B$$

$$L_X = L - L_E - L_R$$

Le = length of entry

Lr = length of run

Lx = length of parallel body

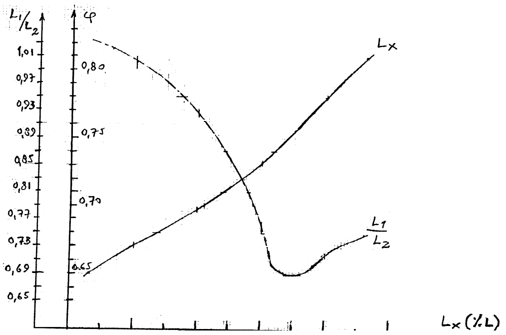
Lindblad, Anders F. (1961), "On the Design of Lines for Merchant Ships" , Chalmers University Books.

Cylindrical Mid-Body

Approximate extent of the cylindrical body:

- Full shape (CB > 0.80) LX = 30% ≈ 35% LPP
- Full shape (0.70 ≤ CB ≤ 0.80) LX = 15% ≈ 20% LPP
- Slender shape (CB < 0.70) LX decreasing to 0

In alternative, the length of the cylindrical body (L_X) and the proportion between the entry and the run bodies (L1/L2) can be obtained from the graphic of the figure, as a function of the block coefficient (C_B)



Freeboard

Tabular Freeboard (ILLC)

- The tabular freeboard can be approximated by a parabolic curve regression of the tabular values from the Load Lines Convention as follows
  - **Ships of Type A**:

$$FB = -0.027415 \times Lfb^2 + 21.007881 \times Lfb - 562.067149 \quad \text{[mm]}$$

  - **Ships of Type B**:

$$FB = -0.016944 \times Lfb^2 + 22.803499 \times Lfb - 691.269920 \quad \text{[mm]}$$

where Lfb = ship length according to the rules [m]

Tonnage

Gross Tonnage

- The Gross Tonnage can be estimated as a function of the Cubic Number (CN = Lpp x B x D), by the following expression:

$$GT = k \cdot CN$$

Type of Ship	K
Tanker, Bulk Carrier	0.26 - 0.30
Product Tanker, Chemical Tanker	0.25 - 0.35
Multi-Purpose	0.25 - 0.40
Fast Container Carrier	0.25 - 0.33

Net Tonnage

- The Net Tonnage can be estimated as a fraction of the Gross Tonnage, as follows:

$$NT = k \cdot GT$$

Type of Ship	K
Container Carrier	0.3 - 0.5
Others	0.5 - 0.7

Compensated Gross Tonnage (1)

- Compensated Gross Tonnage (CGT) is related to the amount of work required to build a ship and it depends on her size, as measured by the GT, and her sophistication, as defined by a coefficient increasing with the ship type complexity.
- Its definition and calculation procedure are set down by the OECD (2007).
- CGT is used to measure and compare the capacity or production of a shipyard, a group, a country etc., for the purpose of statistics and comparisons.

Compensated Gross Tonnage (2)

- CGT can be estimated by the following expression:

$$CGT = a \cdot GT^b$$

Where:
GT: Gross Tonnage
a, b: coefficients that can be obtained from the Table as a function of the type of ship

Ship Type	a	b
Bulk Carrier	29	0.61
Oil Tanker	48	0.57
Chemical Tanker	84	0.55
Product Tanker	48	0.57
General Cargo	27	0.64
Coaster	27	0.64
Reefer	27	0.68
LPG	62	0.57
Container Carrier	19	0.68

Lightship Weight

Lightship Weight Estimate

- Components of the Lightship Weight
  - Structure
  - Machinery
  - Outfitting
- Centers of Gravity
- Longitudinal distribution of the lightship weight

Displacement and Weights of the Ship

The displacement is computed by:

$$\Delta = \gamma . L_{BP} . B . T . Cb$$

The displacement is equal to the sum of the fixed and variable weights of the ship:

$$\Delta = DW + W_{LS}$$

in which:

DW - deadweight
W_{LS} - lightship weight

$$DW = CDW + DW_S$$

CDW - cargo deadweight
DWs - ship's own deadweight

Lightship Weight

For the purpose of estimate, generally the lightship weight is considered to be the sum of three main components:

$$W_{LS} = W_S + W_E + W_M$$

in which:

W_S - Weight of the structural steel of the hull, the superstructure and of the outfit steel (machinery foundations, supports, masts, ladders, handrails, etc).

$$W_S = W_H + W_{SPS}$$

W_E - Weight of the equipment, outfit, deck machinery, etc.
W_M – Weight of all the machinery located in the engine room

Weight Estimates

A reasonable structure for a generic expression to compute the weights of the ship can be as follows

$$W = k.V^a.\Delta^b$$

in which:

k - constant obtained from similar ships
V - service speed
Δ - displacement
a, b - constants depending from the type of weight under consideration, obtained from statistical regressions

Weight Estimate

Hull Weight

$$W_H = k \cdot V^{0.5} \cdot \Delta$$

Equipment Weight

$$W_E = k \cdot V^{0.9} \cdot \Delta^{3/4}$$

Machinery Weight

$$W_M = k \cdot V^{3} \cdot \Delta^{2/3}$$

Methods to Estimate the Hull Weight

1. Methods that consider the weights as **function of the main characteristics** of the hull
   - Appropriate to be used in processes for the optimization of the main dimensions
2. Methods based in the existence of **data from existing ships**
   - More precise estimates
   - Results not satisfactory when dealing with new types of ships
3. Methods based in **surfaces.**
   - When the hull form, the general arrangement and the subdivision are already roughly known
4. Methods based in the midship section **modulus**.
   - Based on the scantlings of the midship section

Estimate the Hull Weight

NOTES:

- Most estimate methods consider separately the weights of the hull and of the superstructure
- For the purpose of cost estimation, the hull weight should be subdivided into:
  - Weight of structural steel (hull structure)
  - Weight of outfit steel (foundations, ladders, steps, etc.)
- Each of these components should be subdivided into:
  - Weight of plates
  - Weight of stiffeners
- For the purpose of cost estimation, and due to the waste resulting from the cutting process, should be used:

Gross Steel Weight = 1.08 ~ 1.12 x Net Steel Weight

Hull Weight

Quadric Number

$$W_H = k\left[L \cdot (B + D)\right]$$

Cubic Number

$$W_H = k \cdot (L \cdot B \cdot D)$$

In both expressions, *k* is a constant, obtained from similar existing ships

Limitations

- The draught is not considered
- The cubic number gives the same relevance to the three hull dimensions, which is not realistic

Hull Weight

Quadricubic Number (Marsich, Genova)

$$W_H = k \cdot N_{qc}$$

$$N_{qc} = L^{4/3}.B.D^{1/2}.\left(1+\frac{3}{4}Cb\right)^{1/2}$$

Sato (tankers with 150 000 t< DW < 300 000 t), 1967

$$W_H = 10^{-5}\left(\frac{Cb}{0.8}\right)^{1/3}\left[5.11\frac{3L^2B}{D}+2.56\cdot L^2\left(B+D\right)^2\right]$$

Hull Weight

Some methods take advantage of the knowledge of the weight distribution from a similar existing ship (*parent ship*)

LRS Method

$$W_H = W_{HP}\left(1+f_{sl}+f_{sb}+f_{sd}+f_{sc}\right)$$

$$f_{sl} = 1.133\left(LBP-LBP_p\right)/LBP_p$$
$$f_{sb} = 0.688\left(B-B_p\right)/B_p$$
$$f_{sd} = 0.45\left(D-D_p\right)/D_p$$
$$f_{sc} = 0.50\left[1-\left(f_{sl}+f_{sb}+f_{sd}\right)\right]\left(Cb-Cb_p\right)$$

DNV Method

$$W_H = W_{HP}\left(1+f_{sl}+f_{sb}+f_{sd}+f_{sc}+f_{st}\right)$$

$$f_{sl} = 1.167\left(LBP-LBP_p\right)/LBP_p$$
$$f_{sb} = 0.67\left(B-B_p\right)/B_p$$
$$f_{sd} = 0.50\left(D-D_p\right)/D_p$$
$$f_{sc} = 0.17\left(Cb-Cb_p\right)/Cb_p$$
$$f_{st} = 0.17\left(T-T_p\right)/T_p$$

Hull Weight

- From statistical analysis regression (d'Almeida, 2009):

$$W_H = k1 \cdot L_S^{k2} \cdot B^{k3} \cdot D^{k4}$$

	k1	**k2**	**k3**	**k4**
Oil Tankers	0.0361	1.600	1.000	0.220
Bulk Carriers	0.0328	1.600	1.000	0.220
Container Carriers	0.0293	1.760	0.712	0.374
General Cargo	0.0313	1.675	0.850	0.280

Hull Weight

Cudina et al (2010)

(Tankers and Bulk-Carriers)

$$W_H = \left(1 - \frac{f_1}{100}\right)\left\{0.0282\left[Lpp \cdot (B + 0.85D + 0.15T)\right]^{1.36}\left\{1 + 0.5\left[(C_B - 0.7) + (1 - C_B)\frac{0.8D - T}{3}T\right]\right\} + 450\right\}$$

f1 – reduction of the hull weight due to the use of high-tensile steel

Cudina, P.; Zanic, V. and Preberg, P. (2010), "Multiattribute Decision Making Methodology in the Concept Design of Tankers and Bulk-Carriers", 11th Symposium on Practical Design of Ships and Other Floating Structures, PRADS.

Hull Weight Correction

The hull weight estimate can be improved by considering some particular aspects such as the usage of special steels, the need of structural reinforcements for high density cargos or the existence of ice belts.

	Correction [%]
HTS (about 60% of total)	-12.0
HTS (about 35% of total)	-8.0
Systems for corrosion control (tankers)	-4.0
Corrugated bulkheads	-1.7
Reinforcements for Ore Carriers	+4.0
Reinforcements for heavy cargo in alt. holds	+5.5
Reinforcements of holds (general cargo)	+1.5
Reinforcements of decks (general cargo)	+0.5
Ice Class I	+8.0
Ice Class II	+6.0
Ice Class III	+4.0

Weight of Superstructures

- Can be obtained as a function of the hull weight (Pc) and the type of ship:
  - Cargo liners - Wsps = 10 ~ 12 % Pc
  - Tankers - Wsps = 6 ~ 8 % Pc
  - Bulk carriers - Wsps = 6 ~ 7 % Pc
- When the arrangement of the superstructures is already known, a criteria based in the average weight per unit area (Wu) can be used, assuming that the corresponding height of the decks is equal to 2.40 m.

$$W_{SPS} = W_U \cdot A$$

with:

A – covered area of decks
W_u = 190 kg/m2 (castles)
W_u = 210 kg/m2 (superstructures amidships)
W_u = 225 kg/m2 (superstructures aft)

Machinery Weight (1)

The weight of the machinery can be obtained from a similar ship, by alteration of the ship's speed and/or of the displacement.

$$W_M = K \cdot V^3 \cdot \Delta^{2/3}$$

with:

K - obtained from similar ships
V – ship's service speed [knots]
Δ - Displacement

The variation of the weight is obtained by deriving the previous expression:

$$\frac{dW_M}{W_M} = 3.\frac{dV}{V} + \frac{2}{3}.\frac{d\Delta}{\Delta}$$

Machinery Weight (2)

From statistical analysis regression (d'Almeida, 2009):

$$W_M = k1 \cdot P_{MCR}^{k2}$$

P_{MCR}: Propulsive power [bhp]

The coefficients k1 and k2 are characteristic of the type of propulsive plant:

	k1	**k2**
Diesel (2 stroke)	2.41	0.62
Diesel (4 stroke)	1.88	0.60
2 x Diesel (2 stroke)	2.35	0.60
Steam Turbine	5.00	0.54

Weight of the Propeller (1)

Some authors suggest formulas for the estimate of the weight of a propeller as a function of its design parameters such as the diameter (D) and the blade area ratio (A_E/A_0)

Schoenherr

$$W_{PROP} = 1.982 \cdot \left({}^{t}\!/_{D} \right) \cdot \left({}^{A_E}\!/_{A_0} \right) \cdot \gamma \cdot R^3$$

with:

γ - specific weight of the material (ref. to table)
R - hub radius
t - blade thickness ratio
W_{PROP} – weight of the blades, without the hub

Weight of the Propeller (2)

Lamb

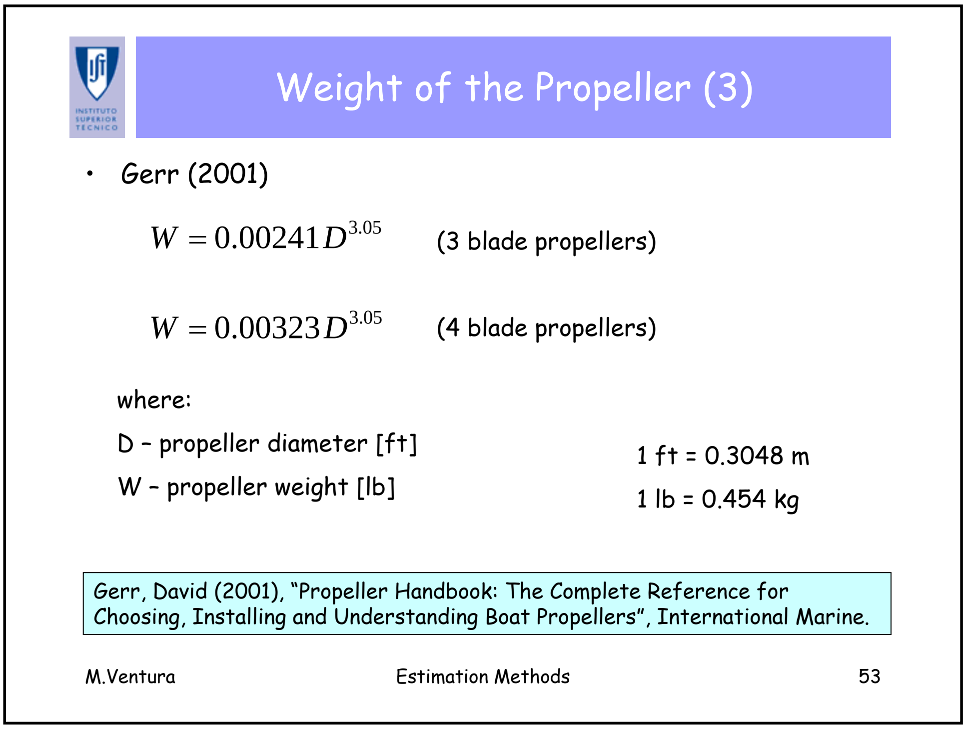
$$W_{PROP} = 0.004 \cdot \left({}^{A_E}\!/_{A_0} \right) \cdot D_{PROP}^3$$ (*fixed pitch propellers*)

$$W_{PROP} = 0.008 \cdot \left({}^{A_E}\!/_{A_0} \right) \cdot D_{PROP}^3$$ (*controllable pitch propellers*)

where:

D_{PROP} - propeller diameter [ft]
W_{PROP} – total weight [ton]

1 ft = 0.3048 m
1 ton US = 0.91 t



Weight of the Propeller (3)

- Gerr (2001)

$$W = 0.00241 D^{3.05}$$ (3 blade propellers)

$$W = 0.00323 D^{3.05}$$ (4 blade propellers)

where:

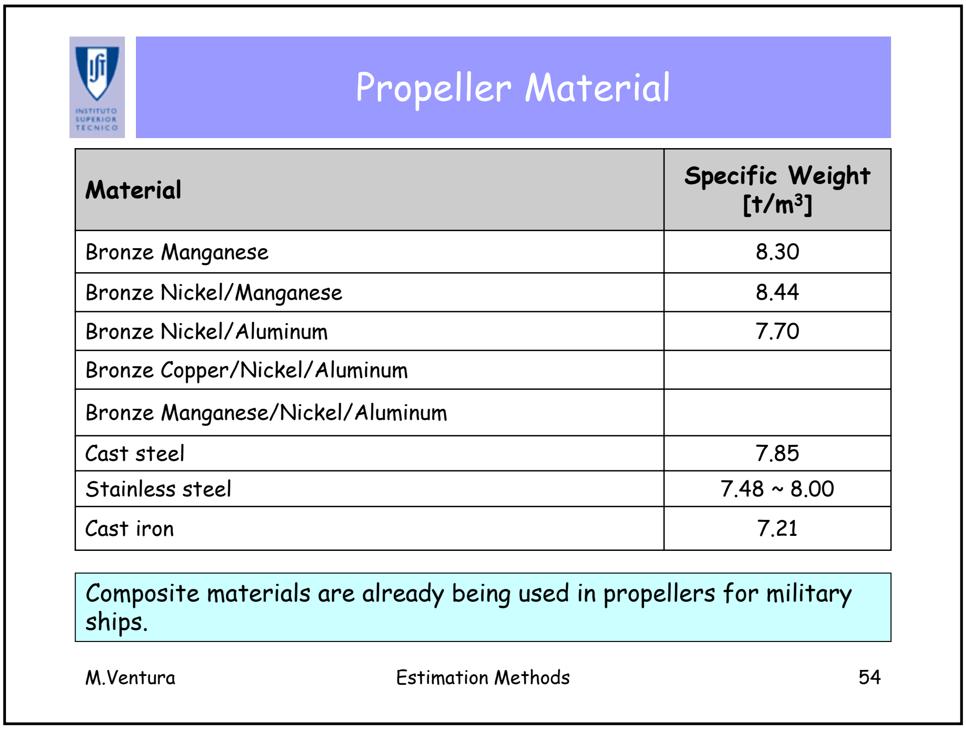
D – propeller diameter [ft]

W – propeller weight [lb]

1 ft = 0.3048 m

1 lb = 0.454 kg

Gerr, David (2001), "Propeller Handbook: The Complete Reference for Choosing, Installing and Understanding Boat Propellers", International Marine.



Propeller Material

Material	**Specific Weight [t/m^3]**
Bronze Manganese	8.30
Bronze Nickel/Manganese	8.44
Bronze Nickel/Aluminum	7.70
Bronze Copper/Nickel/Aluminum	
Bronze Manganese/Nickel/Aluminum	
Cast steel	7.85
Stainless steel	7.48 ~ 8.00
Cast iron	7.21

Composite materials are already being used in propellers for military ships.

Equipment Weight

- From statistical analysis regression (d'Almeida, 2009):

$$W_E = k1 \cdot \left(L \cdot B \cdot D\right)^{K2}$$

	k1	k2
Oil Tankers	10.820	0.41
Bulk Carriers	6.1790	0.48
Container Carriers	0.1156	0.85
General Cargo	0.5166	0.75

Equipment Weight

Cudina et al (2010)

$$W_E = \left(0.28 - \frac{Lpp}{1620}\right) \cdot Lpp \cdot B$$

(Tankers and Bulk-Carriers)

Cudina, P.; Zanic, V. and Preberg, P. (2010), "Multiattribute Decision Making Methodology in the Concept Design of Tankers and Bulk-Carriers", 11th Symposium on Practical Design of Ships and Other Floating Structures, PRADS.

Equipment Weight

Munro-Smith

$$W_E = W_{Eb} \cdot \left(\frac{1}{2} + \frac{1}{2} \frac{L}{L_b} \frac{B}{B_b} \right)$$

W_{Eb} = weight of the equipment of the *parent ship*

Fisher (bulk carriers)

$$W_E = W_{Eb} \cdot \left(\frac{1}{4} + \frac{3}{4} \frac{L}{L_b} \frac{B}{B_b} \right)$$

Parker (tankers)

$$W_E = W_{Eb} \cdot \left(\frac{2}{3} + \frac{1}{3} \frac{L}{L_b} \frac{B}{B_b} \right)$$

Equipment Weight

Lee and Kim

The weight is the result of the average of the 3 values obtained by the following expressions:

$$W_E = \left(W_{E1} + W_{E2} + W_{E3} \right) / 3$$

$$W_{E1} = f_{E1} \cdot L \cdot B$$

$$W_{E2} = f_{E2} \cdot L \cdot \left(B + D \right)$$

$$W_{E3} = f_{E3} \cdot L^{1.3} \cdot B^{0.8} \cdot D^{0.3}$$

with:

f_{E1}, f_{E2}, f_{E3} - constants of proportionality obtained from similar ship

Ordinate of the Centers of Gravity

Steel (Kupras)

$$KG_{S1} = 0.01D\left[46.6 + 0.135(0.81 - Cb)(L/D)^2\right] + 0.008D(L/B - 6.5) \qquad L \geq 120 \text{ m}$$

$$KG_{S2} = KG_{S1} + 0.001D\left[1 - (L - 60)/60\right] \qquad L < 120 \text{ m}$$

Equipment (Kupras)

$$KG_E = D + 1.25 \qquad p/ \quad L \leq 125\, m$$

$$KG_E = D + 1.25 + 0.01(L - 125) \qquad p/ \quad 125 \leq L < 250\, m$$

$$KG_E = D + 2.50 \qquad p/ \quad L \geq 250\, m$$

Machinery (Watson and Gilfillan)

$$KG_M = h_{DB} + 0.35(D - h_{DB})$$

in which

hDB – height of double-bottom

Lightship Weight Distribution (1)

Ships with Parallel middle-body

- Defining the unit hull weight (w_H) by:

$$w_H = \frac{W_H}{L_{FF}}$$

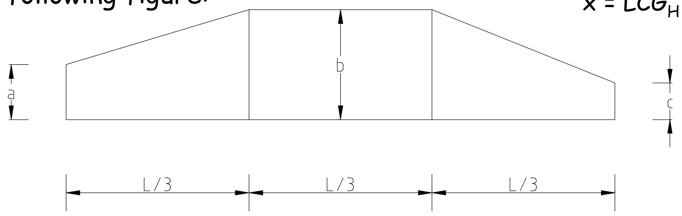
The distribution of the hull weight, in a ship with parallel mid-body, can be represented in accordance with the following figure:

with:

b = 1.19 w_H

a = $(0.62 \pm 0.077x).w_H$

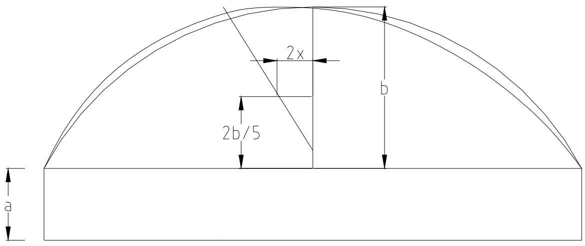
x = LCG_H [% Lff]



Lightship Weight Distribution (2)

Ships without parallel middle-body

- The distribution can be considered as the sum of a rectangular distribution with a parabolic distribution (Muckle).



with:

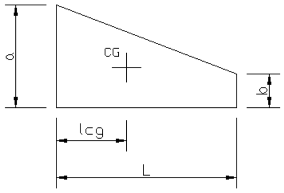
$a = w_H/2$

$b = 3w_H/4$

x = value of the required LCG_H shift

Trapezoidal Distribution

- Na approach quite common is to assume a trapezoidal distribution of the weight components.



The weight is represented by the area of the trapezoid that is given by:

$$W = \frac{a+b}{2} \cdot L \qquad lcg = \frac{b-a}{a+b} \cdot \frac{L}{6}$$

Knowing the weight and the LCG of the component, the trapezoid is defined by:

$$a = \frac{W}{L} - \frac{6 \cdot W \cdot lcg}{L^2}$$

$$b = \frac{W}{L} + \frac{6 \cdot W \cdot lcg}{L^2}$$

Deadweight Components

Deadweight Components

- The deadweight is the sum of all the variable weights on board and is generally assumed to have two main components:

$$DW = CDW + DWs$$

- The first approximation, when almost everything is unknown or undefined is to assume:

$$DW = 1.05 \times CDW$$

- As the knowledge about the ship characteristics and systems increases the 5% DW approximation of the component non-dependent of the cargo can be replaced by the estimate of the several individual contributions:

$$DWs = W_{FO} + W_{LO} + W_{SPARES} + W_{FW} + W_{CREW}$$

Deadweight

- The Deadweight Coefficient is a concept useful in the first steps of the design process and is defined by the expression:

$$C_{DW} = \frac{DW}{\Delta}$$

- Typical values of the Deadweight Coefficient for different types of ships are presented in the table (Barras, 2004):

Ship Type	C_{DW}	Ship Type	C_{DW}
Oil Tanker	0.800 - 0.860	Container Carrier	0.600
Ore Carrier	0.820	Passenger Liner	0.35 – 0.40
General Cargo	0.700	Ro/Ro Vessel	0.300
LNG/LPG	0.620	Cross-Chanel Ferries	0.200

Cargo Capacity

- When dealing with cargo holds (solid cargoes) it is common to use different measures of the volume:
  - **Moulded capacity** – gross volume computed directly from the moulded lines of the hull
  - **Grain capacity** – net volume, discounting the volume occupied by the hull structures
  - **Bale capacity** – net volume, discounting the volume occupied by the hull structures and irregular shaped volumes not usable by packed cargo
  - **Insulated capacity** – discounting all the above plus the thickness of the insulation, if any, which can range from 200 to 350 mm (refrigerated spaces)
- These capacities can be approximated as follows:
  - Grain Capacity = 0.985 x Moulded Capacity
  - Bale Capacity = 0.90 x Moulded Capacity
  - Insulated capacity = 0.75 x Moulded Capacity

Fuel Oils

Fuel Oils

- The total capacity of fuel oil on board is a function of the required autonomy, the service speed (Vs) and the propulsive power (Pcsr)

$$W_{FO} = \frac{Autonomy}{V_S} \times P_{CSR} \times SFOC \times 10^{-6} \quad [t]$$

- The daily consumption is computed by the expression

$$Daily\ Consumption = P_{CSR} \times SFOC \times (24+6) \times 10^{-6} \quad [t]$$

with a tolerance of 6 hours and:

$$SFOC \equiv Specific\ Fuel\ Oil\ Consumption \quad \left[g \cdot kW \cdot h^{-1} \right]$$

Fuel Oil Tanks

- The fuel oil system includes the following types of tanks:
  - Storage tanks (*Tanques de armazenamento*)
  - Settling tanks (*Tanques de decantação*)
  - Daily tanks (*Tanques diários*)

Fuel Oils - Storage Tanks

$$V_t = \frac{f_s}{\left(f_e \cdot \rho_{op} \cdot 10^6\right)}\left(C_s BHP \cdot A + N_{MCA} \cdot C_{SMCA} \cdot BHP_{MCA} \cdot A + N_p \cdot C_c \cdot Q_{up} \cdot T_{cd} + N_p \cdot C_c \cdot Q_{um} \cdot T_{man}\right)$$

VT – volume total do tank (90%) [m3]

Fs – specific FO consumption factor (1.03)

Fe – expansion factor (0.96)

ρ_{OP} – specific weight of the HFO [t/m3]

BHP – máx. power of the main engine

Cs – specific FO consumption [g/kW/h]

A – autonomy [horas]

N_{MCA} – number of Aux. Engines

N_P – number of ports

Cc – aux. Boiler consumption

Qup – consumo de vapor em porto [kg/h]

T_{CS} – time for load/unload

Q_{UM} – steam consumption manoeuv. [kg/h]

Tman – time for manoeuv. [h]

Fuel Oils - Daily Tanks (Settling and Service)

Settling Tank

$$V_t = \frac{f_s}{f_e * \rho_{op} * 10^6}\left(C_s * BHP * T\right)$$

T – time for settling (24 + 6 hours)

Cs – specific FO consumption

fs – service factor (margin)

fe – FO expansion factor

P – FO density

Service Tank

Capacity identical to the settling tank.

Deadweight Estimate (2)

Lubricating Oils

$$W_{LO} = 0.03 \cdot (W_{FO} + W_{DO} + W_{BO})$$

The weight of the Lub. Oils can be estimated as a function of the FO, DO and BO weights

Spares

For the purpose of its maintenance there is onboard the ship a set of *spare parts* of the main machinery and of other equipment of the engine room, whose weight can be assumed as proportional to the machinery weight

$$W_{spar} = 0.03 \cdot W_M$$

HFO, DO, BO and LO Densities

For the weight estimates the following values can be used:

	Specific Gravity [t/m3]
Heavy Fuel Oil (HFO)	0.935 ~ 0.996
Diesel Oil (DO)	0.86 ~ 0.90
Boiler Fuel Oil (BO)	0.94 ~ 0.96
Lubricating Oil (LO)	0.90 ~ 0.924

Fresh Water

There are different types of fresh water onboard, associated to different systems:

- Cooling Water Systems (Main, aux. engines, central cooling)
- Feed Water Systems (Main and aux. boilers)
- Sanitary Water Systems
- Drinking Water Systems

To estimate tank capacity of the Sanitary and Drinking Water systems, a typical consumption of about 200 liter/person/day can be used.

In passenger ships, due to the high number of people on board, the capacity of the FW tanks is complemented with the installation of evaporators, that extract FW from SW

Crew and Passengers

Crew and belongings

The total weight of the crew and their personal objects on board can be estimated by the expression

$$W_{Crew} = N_{Crew} \times 500 \ [kg]$$

N_{Crew} = number of crew members

Passengers and belongings

The total weight associated with the passengers can be estimated using a smaller vale for the luggage, due to their shorter staying on board

$$W_{pass} = N_{pass} \times 200 \ [kg]$$

N_{Pass} = number of passengers

Propulsive Coefficients

Wake Fraction (w)

Definition

$$Va = (1 - w) \cdot V$$

$$w = 1 - \frac{Va}{V}$$

Taylor

$$w = -0.05 + 0.50 \cdot Cb$$

Telfer

$$w = \frac{3C_{WL}}{C_{WL} - C_P{}^2} - \frac{B(T - Z_P)}{L_{WL} \cdot T}\left(0.9 - \frac{3 \cdot D_P}{2B}\right)$$

Wake Fraction (w)

Schoenherr

$$w = 0.10 + \frac{4.5 \cdot \frac{C_B \cdot C_P}{C_{WL}} \cdot \frac{B}{Lpp}}{\left(7 - \frac{6 \cdot C_B}{C_{WL}}\right) \cdot \left(2.8 - 1.8 \cdot C_P\right)} + \frac{1}{2}\left(\frac{Z_H}{T} - \frac{D}{T} - 0.175 \cdot k\right)$$

with:

Zh = average immersion of the propeller shaft

K = 0.3 (ships with normal bow)

Holtrop and Mennen (1978)

$$w = \frac{B\,S\,C_V}{D\,T_A}\left(\frac{0.0661875}{T_A} + \frac{1.21756\,C_V}{D\left(1-C_P\right)}\right) +$$

$$+0.24558\sqrt{\frac{B}{L\left(1-C_P\right)}} - \frac{0.09726}{0.95-C_P} + \frac{0.11434}{0.95-C_B}$$

Wake Fraction (w)

Holtrop and Mennen (1982)

$$w = c_9 \cdot C_V \cdot \frac{L_{WL}}{T_{aft}}\left(0.0661875 + 1.21756 \cdot c_{11} \cdot \frac{C_V}{1-C_{P1}}\right) +$$

$$+0.24558\sqrt{\frac{B}{L_{WL} \cdot \left(1-C_{P1}\right)}} - \frac{0.09726}{0.95-C_P} + \frac{0.11434}{0.95-C_B} +$$

$$+0.75 \cdot C_{stern} \cdot C_V + 0.002 \cdot C_{stern}$$

where:

$$C_{P1} = 1.45 \cdot C_P - 0.315 - 0.0225 \cdot lcb$$

$$c_8 = \frac{B \cdot S_W}{L \cdot D \cdot T_{AFT}} \qquad \text{if } B/T_{AFT} \le 5.0$$

$$c_8 = \frac{S_W \cdot \left(\frac{7 \cdot B}{T_{AFT}} - 25.0\right)}{L_{WL} \cdot D_P \cdot \left(\frac{B}{T_{AFT}} - 3.0\right)} \qquad \text{if } B/T_{AFT} > 5.0$$

$$C_{stern} = +10.0$$

Wake Fraction (w)

Bertram

Linear interpolation in the following table, as a function of C_B and the number of propellers.

Cb	0.50	0.60	0.70	0.80
w (1 propeller)	0.14	0.23	0.29	0.35
w (2 propellers)	0.15	0.19	0.19	0.23

Thrust Deduction Factor (t)

Definition

$$R_T = (1-t)\cdot T_P$$

$$t = 1 - \frac{R_T}{T_P}$$

Schronherr

$$t = k \cdot w$$

with:
- k = 0.50 ~ 0.70 w/ hydrodynamic rudder
- k = 0.70 ~ 0.90 w/ double plate rudder and stern post
- k = 0.90 ~ 1.05 w/ simple plate rudder

Holtrop and Mennen (1978)

$$t = 0.001979\frac{L}{B - B\cdot C_P} + 1.0585\frac{B}{L} - 0.00524 - 0.1418\frac{D_P^2}{B\cdot T}$$

Thrust Deduction Factor (t)

Holtrop and Mennen (1982)

$$t = 0.001979 \cdot \frac{L_{WL}}{B - B \cdot C_{P1}} + 1.0585 \cdot c_{10} + 0.00524 -$$

$$0.1418 \cdot \frac{D_P^2}{B \cdot T} + 0.0015 \cdot C_{stern}$$

where:

$$C_{P1} = 1.45 \cdot C_P - 0.315 - 0.0225 \cdot lcb$$

$$c_{10} = B / L_{WL} \qquad \text{if } L_{WL}/B > 5.2$$

$$c_{10} = \frac{0.25 - 0.003328402}{\frac{B}{L_{WL}} - 0.134615385} \qquad \text{if } L_{WL}/B \le 5.2$$

$$C_{stern} = +10.0$$

Hull Efficiency (η_C)

Definition

$$\eta_C = \frac{1 - t}{1 - w}$$

Volker

Linear interpolation in the following table, as a function of C_B and the number of propellers.

Cb	0.50	0.60	0.70	0.80
η_C (1 hélice)	1.00	1.05	1.10	1.15
η_C (2 hélices)	0.96	1.00	1.03	1.07

Propulsive Power

Propulsive Power

The propulsive power is given by:

$$P_D = \frac{P_E}{\eta_G \, \eta_M \, \eta_H \, \eta_R \, \eta_O} \quad \text{[kW]}$$

where:

P_E = effective power:

$$P_E = R_T V \quad \text{[kW]}$$

R_T = Total hull resistance [kN]

V = Ship speed [m/s]

η_G	Efficiency of the gear box: = 0.99 (non-reversible) = 0.98 (reversible)
$\eta_M = 0.995$	Mechanical efficiency of the shaft line
$\eta_H = \frac{1-t}{1-w}$	Efficiency of the hull
$\eta_R = 1.01$	Rotation relative efficiency
η_O	Open water efficiency of the propeller

Estimate of the Total Hull Resistance

- At the initial design stage, the estimate of the total hull resistance R_T can be done mainly using methods based in statistical analysis of results from towing tank tests.
- There are several published methods:
  - Oossanen (*small high-speed displacement craft*)
  - Keunung and Gerritsma (*planing hull forms*)
  - Savitsky (*planing hull forms*)
  - Sabit (Series 60)
  - Keller
  - Harvald
  - Holtrop & Mennen (1978, 1980), Holtrop (1982)
- The method of Holtrop & Mennen has proved to give good results for merchant ships

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Method of Holtrop & Mennen (1)

The total resistance is the sum of the following components

$$R_T = R_F + R_W + R_V + R_B \qquad \text{[kN]}$$

The viscous resistance (that includes form + appendages)

$$R_V = \frac{1}{2}\rho V^2 C_F (1+k) S_{tot} \qquad \text{[kN]}$$

The frictional resistance coefficient, C_F is computed by

$$C_F = \frac{0.075}{(\log R_n - 2)^2}$$

Method of Holtrop & Mennen (2)

The form coefficient *(1+k)* is the sum of the form coefficient of the naked hull *(1+k1)* with a contribution due to the resistance of the hull appendages *(1+k2)*

$$1+k = 1+k_1 + \left[\left(1+k_2\right)-\left(1+k_1\right)\right] {S_{app}}/{S_{tot}}$$

The form coefficient of the naked hull can be estimated by the expression:

$$1+k_1 = 0.93+\left(T/L\right)^{0.22284}\left(B/L_R\right)^{0.92497}\left(0.95-C_P\right)^{-0.521448}\left(1-C_P+0.0225\right)^{0.6906}$$

The value of *(1+k2)* is obtained from the following table, in accordance with the configuration of the hull appendages

Method of Holtrop & Mennen (3)

Configuration of the Hull Appendages	**$1+k_2$**
Rudder (1 propeller)	1.1~1.5
Rudder (2 propellers)	2.2
Rudder + structs (1 propeller)	2.7
Rudder + boss (2 propellers)	2.4
Stabilizer Fins	2.8
Bilge Keels	1.4
Domes	2.7

Method of Holtrop & Mennen (4)

The length of the aft body, *L*L_R, can be approximated by

$$L_R / L = 1 - C_P + 0.06\, C_P\, Lcb / \left(4 C_P - 1\right)$$

When the wetted surface is still unknown, it can be approximated

$$S = L\left(2T + B\right)\sqrt{C_M}\left(0.453 + 0.4425 C_B - 0.2862\, C_M - 0.003467\, {}^{B}\!/_{T} + 0.3696\, C_{WP}\right)$$
$$+2.38\, A_{BT} / C_B$$

The wave resistance R_W (generated wave + broken wave) is

$$\frac{R_W}{\Delta} = c_1\, c_2 \exp\left[m_1\, F_n^d + m_2 \cos\left(\lambda\, F_n^{-2}\right)\right] \qquad d = 0.9$$

Method of Holtrop & Mennen (5)

in which the coefficients are computed by the following expressions:

$$\lambda = 1.446\, C_P - 0.03\, {}^{L}\!/_{B}$$

$$c_1 = 2223105 \left({}^{B}\!/_{L}\right)^{3.78613} \left({}^{T}\!/_{B}\right)^{1.07961} \left(90 - 0.5\alpha\right)^{-1.37565}$$

α = semi-angle of entrance of the load waterline [degrees]

$$c_2 = \exp\left(-1.89\sqrt{c_3}\right)$$

$$m_1 = 0.0140407\, {}^{L}\!/_{T} - 1.75254\, {}^{\nabla^{1/3}}\!/_{L} - 4.79323\, {}^{B}\!/_{L} - 8.07981 C_P$$
$$+13.8673 C_P^2 - 6.984388 C_P^3$$

$$m_2 = -1.69385 C_P^2 \exp\left(-0.1 / F_n^2\right)$$

$$c_3 = \frac{0.56\, A_{BT}^{1.5}}{BT\left(0.56\sqrt{A_{BT}} + T_F - h_B - 0.25\sqrt{A_{BT}}\right)}$$

Method of Holtrop & Mennen (6)

When still unknown, the half-angle of entrance (α) of the design waterline can be estimated by

$$0.5\alpha = 125.67\,{}^{B}\!/\!{}_{L} - 162.25C_P^2 + 234.32C_P^3 +$$
$$+0.155087\left(Lcb + \frac{6.8\left(T_A - T_F\right)}{T}\right)^3 \quad [\text{degrees}]$$

The bulb resistance R_B is computed from the expression

$$R_B = \frac{c\,F_{ni}^3}{\sqrt{1+F_{ni}^2}} \quad [\text{kN}]$$

$$i = T_F - h_B - 0.25\sqrt{A_{BT}}$$

$$F_{ni} = \frac{V}{\sqrt{g\,i + 0.15V^2}} \quad \text{V [m/s]}$$

$$p_B = \frac{0.56\sqrt{A_{BT}}}{T_F - 1.5h_B}$$

Method of Holtrop & Mennen (7)

The bulb resistance R_B is

$$R_B = \frac{0.11\cdot\exp\left(-3p_B^{-2}\right)\cdot F_{ni}^3\cdot A_{BT}^{1.5}\cdot\rho\cdot g}{1+F_{ni}^2} \quad [\text{kN}]$$

The model-ship correlation defined by

$$C_A = \frac{R_A}{{}^{1}\!/\!{}_{2}\,\rho\,S_{tot}\,V^2}$$

can be determined from the expression

$$C_A = 0.006\left(L_S + 100\right)^{-0.16} - 0.00205 + 0.003\sqrt{{}^{L_S}\!/\!{}_{L_M}}\,C_B^4\cdot c_2\left(0.04 - c_4\right)$$

$$c_4 = {}^{T_F}\!/\!{}_{L_S} \qquad p/\ {}^{T_F}\!/\!{}_{L_S} \le 0.04$$

$$c_4 = 0.04 \qquad p/\ {}^{T_F}\!/\!{}_{L_S} > 0.04$$

Subdivision and Compartments

Length of the Ship

Alternatives:

- Formulas based in the economical performance
- Statistics from existing ships
- Procedures of control to define limits of variation

Length of the Ship

Schneekluth and Bertram (1998)

$$L_{pp} = \Delta^{0.3} \cdot V^{0.3} \cdot 3.2 \cdot \frac{C_B + 0.5}{\left(0.145 / F_n \right) + 0.5}$$

with:

Lpp – Length bet. Perpendiculars [m]
V – Ship Speed [knots]
Cb – Block Coefficient
Fn – Froude Number
g = 9.81 m/s^2

$$F_n = \frac{V}{\sqrt{g\,L}}$$

- Based on statistical analysis from the results of optimizations with economical criteria
- Applicable to ships with

$$\Delta \geq 1000\,t$$
$$0.16 \leq F_n \leq 0.32$$

Length of the Ship

- The length of the ship can also be obtained from the Deadweight Coefficient (C_{DW}) and some common dimensional ratios and form coefficients obtained from similar ships:

$$L = \sqrt[3]{\frac{DW \cdot \left(\frac{L}{B}\right)^2 \cdot \left(\frac{B}{T}\right)}{\rho \cdot C_B \cdot C_{DW}}} \quad [\text{m}]$$

where:

P = 1.025 t/m3

$C_{DW} = DW/\Delta$

Relations From Statistical Analysis of Existing Ships (1)

Formula of Ayre

$$\frac{L}{\Delta^{1/3}} = 3.33 + 1.67 \cdot \frac{V}{\sqrt{L}}$$

Posdunine (Wageningen)

$$L = C \cdot \left(\frac{V}{V+2} \right)^2 \cdot \nabla^{1/3}$$

$$C = 7.25 \qquad ships\ with\ 15.5 \le V \le 18.5\ knots$$

$$V \quad [knots]$$

$$\nabla \quad [m^3]$$

Relations From Statistical Analysis of Existing Ships (2)

Volker (Statistics 1974)

$$\frac{L}{\nabla^{1/3}} = 3.5 + 4.5 \cdot \frac{V}{\sqrt{g \cdot \nabla^{1/3}}}$$

with:

V [m/s]

Applicable to cargo ships and container-carriers

Validation/Comparison of Formulas

- Example: Container Carrier "Capiapo"
  Δ = 91.187 t
  V = 25.92'
  Cb = 0.703

Lpp = 263.80 m
B = 40.00 m
T = 12.00 m
DW = 50.846 t

Source: "Significant Ships 2004"

Formulas	L_{PP} [m]	Obs.
Schneekluth	N/A	Fn=0.55
Ayre	153.38	
Posdunine	278.94*	V > 18.5'
Volker	284.24	

Limitative Factors for the Length

- Physical Limitations
  - Shipbuilding
    - Length of the building ramp or of the dry dock
  - Ship Operation
    - Locks
    - Port limitations

- Check the interference between the bow and stern wave systems, in accordance with the Froude Number
  - The wave resistance begins to present considerable values starting at Fn = 0.25
  - The intervals 0.25 < Fn < 0.27 and 0.37 < Fn < 0.50 shall be avoided (Jensen, 1994)

Collision Bulkhead

- The location of the collision bulkhead is established in the IMO Convention for the Safety of Life at Sea (SOLAS)

Length of the Engine Room

- The length of the Engine Room <L_{ER}> can be estimated as a function of the power of the main machinery
- With the current trend of the decrease of the length (L_{ENG}) of the Diesel engines used it is acceptable to estimate:

$$L_{ER} = 2 \sim 3 \times L_{ENG}$$

- The resulting length should be rounded to a value multiple of the frame spacing in the Engine Room

Height of Double-Bottom

- The minimum height of the double-bottom is established by the Classification Societies taking into consideration only the longitudinal resistance of the hull girder
- For DNV the minimum height is:

$$H_{DB} = 250 + 20 \cdot B + 50 \cdot T \qquad \text{[mm]}$$

with:

H_{DB} - height of double-bottom [mm]
B - breadth, molded [mm]
T - draught [mm]

The actual value of the double-bottom height must represent a compromise between the volume of ballast required (due to ballast voyage condition, stability, etc.) and the associated decrease of the cargo volume. In tankers, MARPOL requirements establish in addition

H_{DB} = MIN(B/15, 2.0 m)

Height of the Superstructure

- The total height of the superstructure can be estimated based on the IMO SOLAS visibility requirements (Burgos, 2008)

$$H_{SPST} = \left(\frac{0.85 \cdot L_{WL}}{L_{VIS}} \right) \cdot \left(D - T_M + H_{DK} \right) + H_{DK} + 1.5$$

where:

Lvis = MIN(2Lpp, 500)
Hdk = average height of the superstructure decks
Tm = average draught

Estimate of Capacities

Cubic Efficiency Factor (CEF)

- The CED is a useful ratio defined by

  CEF = C_{CRG}/(LBD)

  Typically presents values of [0.50,0.65] and it can be estimated for similar ships by the expression:

$$CEF = k1 \cdot Cb^{k2} \cdot C_{CRG}^{k3} \cdot P_{MCR}^{k4}$$

C_{CRG} [m3]
P_{MCR} [Hp]

	k1	k2	k3	k4
Oil Tankers	0.6213	0.80	0.094	-0.10
Bulk Carriers	0.7314	0.66	0.079	-0.10
Multi-Purpose	1.2068	0.60	0.077	-0.15
General Cargo (*box-shaped*)	1.9640	0.60	0.075	-0.20

Capacities of Cargo Holds and Tanks

Knowing CEF from similar ships, the cargo capacity of a ship can be computed by

$$C_{CRG} = L \cdot B \cdot D \cdot CEF$$

The Depth required to obtain a certain cargo capacity can be obtained also with CEF by the expression:

$$D = \frac{C_{CRG}}{L \cdot B \cdot CEF}$$

Volumes of Cargo Holds and Tanks (1)

Volume of Cargo Holds

Can be estimated from the midship section geometry, deducting insulations

$$V_H = f_{ps} \cdot A_{MS} \cdot L_H \cdot C_b$$

with:

f_{PS} = factor obtained from a similar ship

A_{MS} = area of the midship section

L_H = length of the cargo zone

Volumes of Cargo Holds and Tanks (2)

Volume of Ballast Tanks

The volume of the ballast tanks in the cargo area can be estimated from a similar ship

$$V_{WB} = f_{ps} \cdot A_{MS} \cdot L_H$$

The volume of the ballast tanks in the aft and fore bodies can be estimated by the expression:

$$V_{WBaft} = 0.13 f_{ps} \cdot B \cdot (T + 0.5) \cdot L_{aft}$$

$$V_{WBfwd} = 0.35 \cdot T \cdot B$$

Volumes of Cargo Holds and Tanks (3)

Hull Volume (excluding FWD Peak)

$$Vol = 0.987 \cdot Lpp \cdot B \cdot D \cdot C_{BD}$$

$$C_{BD} = 0.086 \cdot \left(\frac{D}{T} - 1.0 \right) + 0.0475 \cdot (0.7 - C_B) + C_B$$

Volume of Double-Bottom

$$Vol = 0.987 \cdot Lpp \cdot B \cdot H_{DB} \cdot C_{BDB}$$

$$C_{BD} = 1.88 \cdot \left(\frac{H_{DB}}{T} \right)^{0.5} - 1.364 \cdot \left(\frac{H_{DB}}{T} \right) + 1.15 \cdot (C_B - 0.7)$$

Volumes of Cargo Holds and Tanks (4)

Volume of the Engine Room and Aft Peak

$$Vol = Lpp \cdot B \cdot D \cdot C_{Bm} + dC_{Bm}$$

$$C_{Bm} = 0.042 \cdot \left(\frac{D}{T}\right) - 0.04 \cdot C_B + \left(\frac{L_{cm}}{Lpp}\right) \cdot \left(C_B - 0.02\right) - 0.08$$

$$dC_{Bm} = \left(\frac{H_{DB}}{T} - 0.1\right) \cdot \left(0.133 \cdot C_B - 0.048\right)$$

- Kupras, L. K. (1976), "Optimisation Method and Parametric Design in Precontracted Ship Design", International Shipbuilding Progress.

Volumes of Cargo Holds and Tanks (5)

Total Hull Volume (Lamb, 2003)

$$C_{BD} = C_B + \left(1 - C_B\right) \cdot \left(\frac{0.8D - T}{3T}\right)$$

$$Vol = Lpp \cdot B \cdot D \cdot C_{BD}$$

Engine Room Volume

$$Vol = L_{CM} \cdot B \cdot D \cdot C_B \cdot k$$

$$L_{CM} = 0.002 \cdot P_D + 5.5$$

with:

L_{CM} - Length of Engine Room

P_D - Propulsive power

K = 0.85 (Engine Room aft)

Volumes of Cargo Holds and Tanks (6)

Volume of the Double Bottom

$$Vol = L_{DB} \cdot B \cdot H_{DB} \cdot C_{BDB}$$

$$C_{BD} = C_B \cdot \left(\frac{H_{DB}}{T} \right)^a \qquad a = \frac{C_{FF}}{C_B} - 1.0$$

$$C_{FF} = 0.70 \cdot C_B + 0.3 \quad p/ \quad C_B < 0.75$$

$$= \sqrt{C_B} \qquad p/ \quad C_B \geq 0.75$$

Volume of Peak

$$Vol = 0.037 \cdot Lpk \cdot B \cdot D \cdot C_B$$

$$L_{pk} = 0.05 \cdot Lpp$$

Volumes of Wing and Hopper Tanks

- Kupras, L. K. (1976), "Optimisation Method and Parametric Design in Precontracted Ship Design", International Shipbuilding Progress.

Volume of the Wing Tanks

$$Vol = 2 \cdot f \cdot (0.82 \cdot C_B + 0.217) \cdot L_C$$

$$f = 0.02 \cdot B \cdot B_W + 0.5 \cdot B_W{}^2 \cdot tg(\alpha)$$

Volume of the Hopper Tanks

$$Vol = 2 \cdot f \cdot (0.82 \cdot C_B + 0.217) \cdot L_C$$

$$f = 0.02 \cdot B \cdot B_H + 0.5 \cdot B_H{}^2 \cdot tg(\beta)$$

Capacity of Containers (Ships with Cell Guides)

Containers in Holds

for Lpp < 185 m

$$N_{HOLD} = 15.64 \cdot \left(N_B \cdot N_D\right)_{MS}^{0.6589} \cdot N_L^{0.5503} \cdot C_B^{0.598} - 126$$

for Lpp > 185 m

$$N_{HOLD} = 15.64 \cdot \left(N_B \cdot N_D\right)_{MS}^{1.746} \cdot N_L^{1.555} \cdot C_B^{3.505} + 704$$

with:

N_B - Number of transverse stacks
N_D - Number of vertical tiers
N_L - Number of longitudinal stacks

Capacity of Containers (Ships with Cell Guides)

The number of stacks can be estimated by the expressions:

$$N_B = \left(B - 2 \cdot B_{DH}\right) / 2.54$$
$$N_D = \left(D + H_{DK} + H_{HA} - H_{DB} - H_{MRG}\right) / 2.60$$
$$N_L = L_{HOLDS} / 6.55$$

with:

B_{DH} - Breadth of the double-hull
H_{DK} - Height of the deck (*salto do convés*)
H_{HA} - Height of the hatch
H_{DB} - Height of the double-bottom
H_{MRG} - Distance from the top of the upper container to the hatch cover
L_{HOLDS} - Total length of the cargo holds [m]

Capacity of Containers (Ships with Cell Guides)

- Assuming the margins between stacks of containers

Δb_{TEU} = 100 mm (transverse direction)
Δl_{TEU} = 900 mm (longitudinal direction)
Δh_{TEU} = 13 mm (vertical direction)

- From the statistical analysis of recent ships, the number of <u>longitudinal stacks</u> of containers inside the holds can be estimated by the expression:

$$N_L = 0.0064 \cdot Lpp^{0.414} \cdot L_{HOLDS}{}^{0.806} + 4.22$$

Capacity of Containers (Ships with Cell Guides)

<u>Containers On Deck</u>

$$N_B = {B}/{2.464}$$
$$N_L = {L_{DK}}/{6.55}$$

The number of vertical stacks depends on the stability and also from the bridge visibility.

In ships with Engine Room aft, the height of the bridge can be approximated by:

$$H_{BDG} = 0.22 \cdot L_{PP} + 0.28 \cdot D^{1.56} - 0.02 \cdot L_{PP}{}^{0.806} \cdot D^{1.1}$$

The total number of containers on deck, based in recent statistics, can be approximated by the expression:

$$N_{DK} = 145 \cdot L_{PP}^{0.36} \cdot B^{0.18} + 0.032 \cdot BHP^{1.18} - 1074$$

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