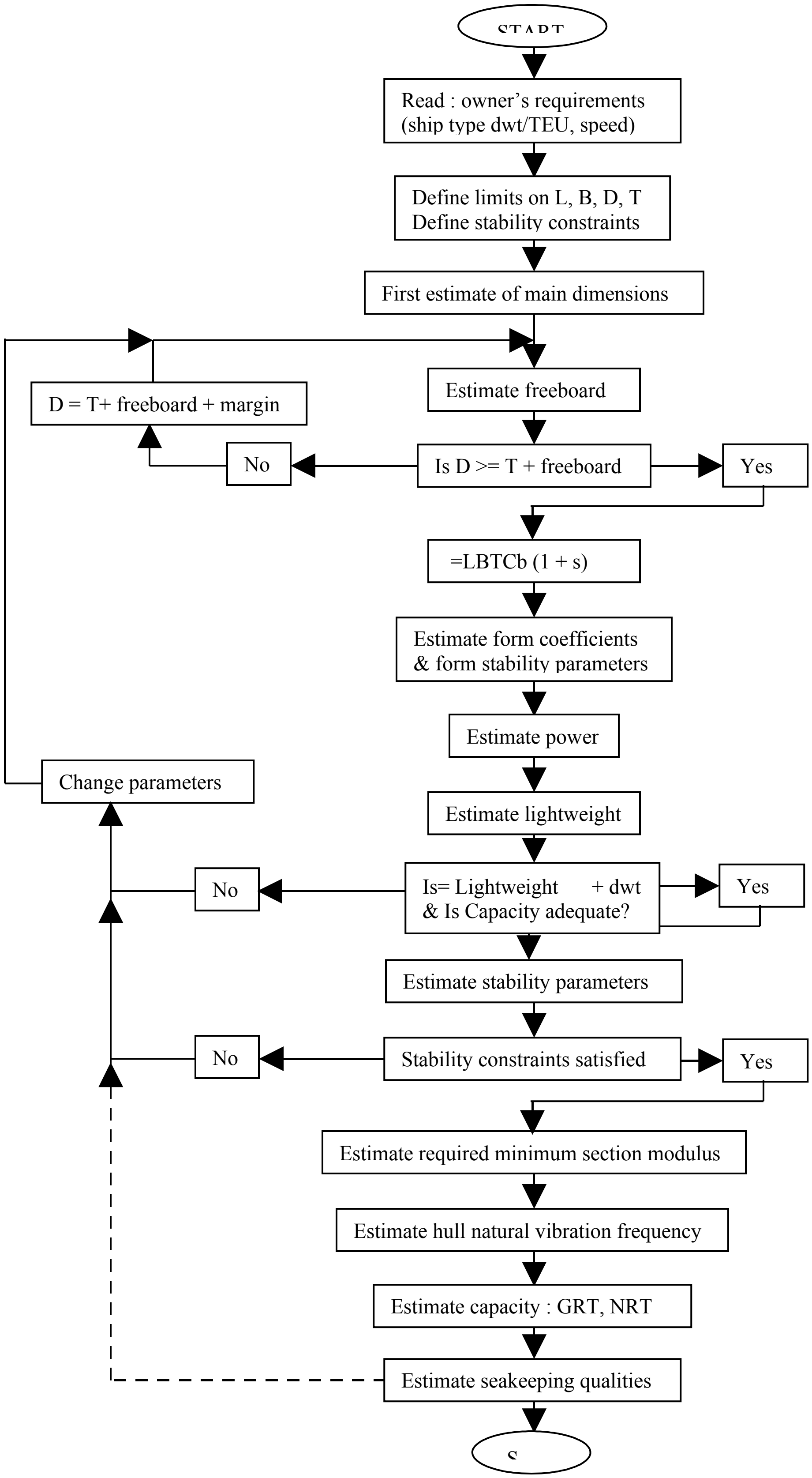
PRELIMINARY SHIP DESIGN PARAMETER ESTIMATION



Ship design calculations – Selection of Main parameters

1.0 The choice of parameters (main dimensions and coefficients) can be based on either of the following 3 ship design categories (Watson & Gilafillon, RINA 1977)

A. Deadweight carriers where the governing equation is

$$\Delta = C_B \times L \times B \times T \times \rho\ (1+s) = deadweight + lightweight$$

where s : shell plating and appendage displacement (approx 0.5 to 0.8 % of moulded displacement)

and ρ : density of water (= 1.025 t/m^3 for sea water)

Here T is the maximum draught permitted with minimum freeboard. This is also the design and scantling draught

B. Capacity carriers where the governing equation is

$$V_h = C_{BD}\,.L.\,B.\,D' = \frac{V_r - V_u}{1-s_s} + V_m$$

where

D' = capacity depth in m $= D + C_m + S_m$

C_m = mean camber $= \frac{2}{3}.C\ [for\ parabolic\ camber]$

$$= \tfrac{1}{2}C \quad \begin{bmatrix} for\ straight\ line\ camber \\ \text{where C : Camber at C . L .} \end{bmatrix}$$

S_m = mean sheer $= \tfrac{1}{6}(S_f + S_a) \quad \begin{bmatrix} for\ parabolic\ shear \\ S_f = ford\ shear \\ S_c = aft\ shear \end{bmatrix}$

C_{BD} = block coefficient at moulded depth

$$= C_B + (1 - C_B)[\,(0.8D - T)/3T] \qquad [1]$$

V_h = volume of ship in m^3 below upper deck and between perpendiculars

V_r = total cargo capacity required in m^3

V_u = total cargo capacity in m^3 available above upper deck

V_m = volume required for m/c , tanks, etc. within V_h

S_s = % of moulded volume to be deducted as volume of structurals in cargo space [normally taken as 0.05]

Here T is not the main factor though it is involved as a second order term in C_{BD}

C. Linear Dimension Ships : The dimensions for such a ship are fixed by consideration other than deadweight and capacity.

e.g.

Restrictions imposed by St. Lawrence seaway

$6.10 \text{ m} \leq \text{Loa} \leq 222.5 \text{ m}$

$\text{Bext} \leq 23.16 \text{ m}$

Restrictions imposed by Panama Canal

$B \leq 32.3$ m; $T \leq 13$ m

Restrictions imposed by Dover and Malacca Straits

$T \leq 23$ m

Restrictions imposed by ports of call.

Ship types (e.g. barge carriers, container ships, etc.) whose dimensions are determined by the unit of cargo they carry.

Restrictions can also be imposed by the shipbuilding facilities.

2.0 **Parameter Estimation**

The first estimates of parameters and coefficients is done

(a) from empirical formulae available in published literature, or

(b) from collection of recent data and statistical analysis, or

(c) by extrapolating from a nearly similar ship

The selection of parameters affects shipbuilding cost considerably. The order in which shipbuilding cost varies with main dimension generally is as follows:

The effect of various parameters on the ship performance can be as shown in the following table [1]

Speed
Length
Breadth
Depth
Block coefficient

Table: Primary Influence of Dimension

Parameter	*Primary Influence of Dimensions*
Length	resistance, capital cost, maneuverability, longitudinal strength, hull volume, seakeeping
Beam	transverse stability, resistance, maneuverability, capital cost, hull volume
Depth	hull volume, longitudinal strength, transverse stability, capital cost, freeboard
Draft	displacement, freeboard, resistance, transverse stability

2.1 Displacement

A preliminary estimate of displacement can be made from statistical data analysis, as a function of deadweight capacity. The statistical $\frac{dwt}{\Delta}$ ratio is given in the following table [1]

Table: Typical Deadweight Coefficient Ranges

Vessel Type	$C_{cargo\ DWT}$	$C_{total\ DWT}$
Large tankers	0.85 – 0.87	0.86 – 0.89
Product tankers	0.77 – 0.83	0.78 – 0.85
Container ships	0.56 – 0.63	0.70 – 0.78
Ro-Ro ships	0.50 – 0.59	–
Large bulk carriers	0.79 – 0.84	0.81 – 0.88
Small bulk carriers	0.71 – 0.77	–
Refrigerated cargo ships	0.50 – 0.59	0.60 – 0.69
Fishing trawlers	0.37 – 0.45	–
where $C = \dfrac{Cargo\ DWT\ or\ Total\ DWT}{Displacement}$		

2.2 Length

A. Posdunine's formulae as modified by Van Lammeran :

$$L_{BP}\left(ft\right)=C\left[\frac{V_T}{2+V_T}\right]^2 \qquad \Delta^{1/3}$$

C = 23.5 for single screw cargo and passenger ships where V = 11 to 16.5 knots
= 24 for twin screw cargo and passenger ships where V = 15.5 to 18.5 knots
= 26 for fast passenger ships with V$\geq$ 20 knots

B. Volker's Statistics :

$$\left(\frac{L}{\nabla^{1/3}}-C\right)=3.5+4.5\ \frac{V}{\sqrt{g\nabla^{1/3}}} \qquad , \quad V\ in\ m/s$$

$$L \rightarrow m$$

$$\nabla \rightarrow disp\ in\ m^3$$

where C = 0 for dry cargo ships and container ships

= 0.5 for refrigerated ship and

= 1.5 for waters and trawler

C. Schneekluth's Formulae : This formulae is based on statistics of optimization results according to economic criteria, or length for lowest production cost.

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

Lpp in metres, Δ is displacement in tonnes and V is speed in knots

C = 3.2, if the block coefficient has approximate value of
$C_B = {0.145}/{Fn}$ within the range 0.48 – 0.85

It the block coefficient differs from the value ${0.145}/{Fn}$, the coefficient C can be modified as follows

$$C=3.2\ \frac{C_B+0.5}{\left({0.145}/{Fn}\right)+0.5}$$

The value of C can be larger if one of the following conditions exists :

(a) Draught and / or breadth subject to limitations
(b) No bulbous bow
(c) Large ratio of undadeck volume to displacement

Depending on the conditions C is only rarely outside the range 2.5 to 2.8. Statistics from ships built in recent years show a tendency towards smaller value of C than before.

The formulae is valid for $\Delta \geq 1000$ tonnes, and
F_n between 0.16 to 0.32

2.3 Breadth

Recent trends are:

L/B = 4.0 for small craft with L $\leq$ 30 m such as trawlers etc.

= 6.5 for L $\geq$ 130.0 m

= 4.0 + 0.025 (L - 30) for 30 m $\leq$ L $\leq$ 130 m

B = L/9 + 4.5 to 6.5 m for tankers

= L/9 + 6.0 m for bulkers

= L/9 + 6.5 to 7.0 m for general cargo ships

= L/9 + 12 to 15 m for VLCC.

or B = L/5 – 14m for VLCC

$$B = 10.78\left[\frac{Dwt}{1000}\right]^{0.2828} m$$

2.4 Depth

For normal single hull vessels

$$1.55 \leq B/D \leq 2.5$$

B/D = 1.65 for fishing vessels and capacity type vessels (Stability limited)

= 1.90 for dwt carries like costers, tankers, bulk carriers etc. such vessels have adequate stability and their depth is determined from the hull deflection point of view. (3)

$$D = \frac{B-3}{1.5} \text{ m for bulk carriers} \qquad (5)$$

Recent ships indicate the following values of B/D

B/D = 1.91 for large tankers
= 2.1 for Great Lakes ore carriers
= 2.5 for ULCC
= 1.88 for bulk carriers and
= 1.70 for container ships and reefer ships

2.5 Draught

For conventional monohull vessels, generally

$$2.25 \leq B/T \leq 3.75$$

However, B/T can go upto 5 in heavily draught limited vessels.

For ensuring proper flow onto the propeller

$$B/T \leq [9.625 - 7.5 \; C_B]$$

Draught – depth ratio is largely a function of freeboard :

T/D = 0.8 for type A freeboard (tankers)
($T/D < 0.8$ for double hull tankers)
= 0.7 for type B freeboard

= 0.7 to 0.8 for B – 60 freeboard

$$T = 4.536 \left[\frac{dwt}{1000}\right]^{0.290} m$$

T = 0.66 D + 0.9 m for bulk carriers

2.6 Depth – Length Relationship

Deadweight carriers have a high B/D ratio as these ships have adequate stability and therefore, beam is independents of depth. In such case, depth is governed by L/D ratio which is a significant term in determining the longitudinal strength. L/D determines the hull deflection because b.m. imposed by waves and cargo distribution.

L/D =10 to 14 with tankers having a higher value because of favourable structural arrangement.

3.0 Form Coefficients

$$C_B = C_P \, . \, C_M$$

and $C_B = C_{VP} \, . \, C_{WP}$

where C_p : Longitudinal prismatic coefficient

and C_{VP}: Vertical prismatic coefficient

$$C_P = \frac{\nabla}{A_M \, .L}$$

$$C_{VP} = \frac{\nabla}{A_{WP} \, .T}$$

3.1 Block Coefficients

$$C_B = 0.7 + \tfrac{1}{8} \tan^{-1}\left[25\left(0.23 - F_n\right)\right]$$

where $F_n = \dfrac{V}{\sqrt{gL}}$: Froude Number

A. Ayre's formulae

$C_B = C - 1.68\ F_n$

where $C = 1.08$ for single screw ships

$= 1.09$ for twin screw ships

Currently, this formulae is frequently used with C = 1.06

It can be rewritten using recent data as

CB = 1.18 – 0.69 $V/\sqrt{L}$ for 0.5 $\le V/\sqrt{L} \le$ 1.0 ,

V: Speed in Knots and

L: Length in feet

$$C_B = \frac{0.14}{F_n}\left[\frac{L/B + 20}{26}\right] \quad \text{or}$$

$$C_B = \frac{0.14}{F_n^{2/3}}\left[\frac{L/B + 20}{26}\right]$$

The above formulae are valid for $0.48 \le C_B \le 0.85$, and $0.14 \le F_n \le 0.32$

Japanese statistical study [1] gives C_B for

$0.15 \le F_n \le 0.32$ as

$$C_B = -4.22 + 27.8\sqrt{F_n} - 39.1\,F_n + 46.6\,F_n^3$$

3.2 Midship Area Coefficient

C_B	= 0.55	0.60	0.65	0.70
C_M	= 0.96	0.976	0.980	0.987

Recommended values of C can be given as

C_M = 0.977 + 0.085 (C_B – 0.60)

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

$=\left[1+(1-C_B)^{3.5}\right]^{-1}$ [1]

Estimation of Bilge Radius and Midship area Coefficient

(i) Midship Section with circular bilge and no rise of floor

$$R^2 = \frac{2(1-C_M)\,B.T.}{4-\pi}$$

$=2.33\ (1 - C_M)$ B.T.

(ii) Midship Section with rise of floor (r) and no flat of keel

$$R^2 = \frac{2BT(1-C_M) - B.r}{0.8584}$$

(iii) Schneekluth's recommendation for Bilge Radius (R)

$$R = \frac{BC_k}{\left(\frac{L}{B}+4\right)C_B^2}$$

C_k : Varies between 0.5 and 0.6 and in extreme cases between 0.4 and 0.7

For rise at floor (r) the above C_B can be modified as

$$C'_B = \frac{C_B T}{\left(T - \frac{r}{2}\right)}$$

(iv) If there is flat of keel width K and a rise of floor F at $B/2$ then,

$$C_M = 1 - \left\{ F \left[\left(B/2 - K/2 \right) - r^2 / \left(B/2 - K/2 \right) \right] + 0.4292\, r^2 \right\} / BT$$

From producibility considerations, many times the bilge radius is taken equal to or slightly less than the double bottom height.

3.3 Water Plane Area Cofficient

Table 11.V

Equation	Applicability/Source
$C_{WP} = 0.180 + 0.860\ C_P$	Series 60
$C_{WP} = 0.444 + 0.520\ C_P$	Eames, small transom stern warships (2)
$C_{WP} = C_B/(0.471 + 0.551\ C_B)$	tankers and bulk carriers (17)
$C_{WP} = 0.175 + 0.875\ C_P$	single screw, cruiser stern
$C_{WP} = 0.262 + 0.760\ C_P$	twin screw, cruiser stern
$C_{WP} = 0.262 + 0.810\ C_P$	twin screw, transom stern
$C_{WP} = C_P^{\ 2/3}$	schneekluth 1 (17)
$C_{WP} = (1 + 2\ C_B/C_m^{\ ½})/3$	Schneekulth 2 (17)
$C_{WP} = 0.95\ C_P + 0.17\ (1 - C_P)^{1/3}$	U-forms hulls
$C_{WP} = (1 + 2\ C_B)/3$	Average hulls, Riddlesworth (2)
$C_{WP} = C_B^{\ ½} - 0.025$	V-form hulls

4.0 Intial Estimate of Stability

4.1 Vertical Centre of Buoyancy, KB [1]

$\frac{KB}{T} = \left(2.5 - C_{VP}\right) / 3$:Moorish / Normand recommend for hulls with $C_M \le 0.9$

$\frac{KB}{T} = \left(1 + C_{VP}\right)^{-1}$:Posdumine and Lackenby recommended for hulls with $0.9 < C_M$

Regression formulations are as follows :

$$\frac{KB}{T} = 0.90 - 0.36\ C_M$$

$$\frac{KB}{T} = (0.90 - 0.30\ C_M - 0.10\ C_B)$$

$$\frac{KB}{T} = 0.78 - 0.285\ C_{VP}$$

4.2 **<u>Metacenteic Radius</u> : BM_T and BM_L**

Moment of Inertia coefficient C_I and C_{IL} are defined as

$$C_I = {I_T}/{LB^3}$$

$$C_{TL} = {I_L}/{LB^3}$$

The formula for initial estimation of C_I and C_{IL} are given below

Table 11.VI Equations for Estimating Waterplane Inertia Coefficients

Equations	*Applicability / Source*
$C_I = 0.1216\ C_{WP} - 0.0410$	D' Arcangelo transverse
$C_{IL} = 0.350\ C_{WP}^2 - 0.405\ C_{WP} + 0.146$	D' Arcangelo longitudinal
$C_I = 0.0727\ C_{WP}^2 + 0.0106\ C_{WP} - 0.003$	Eames, small transom stern (2)
$C_I = 0.04\ (3C_{WP} - 1)$	Murray, for trapezium reduced 4% (17)
$C_I = (0.096 + 0.89\ C_{WP}^2) / 12$	Normand (17)
$C_I = (0.0372\ (2\ C_{WP} + 1)^3) / 12$	Bauer (17)
$C_I = 1.04\ C_{WP}^2) / 12$	McCloghrie + 4% (17)
$C_I = (0.13\ C_{WP} + 0.87\ C_{WP}^2) / 12$	Dudszus and Danckwardt (17)

$$B_{MT} = \frac{I_T}{\nabla}$$

$$B_{ML} = \frac{K_L}{\nabla}$$

4.3 <u>Transverse Stability</u>

KG / D= 0.63 to 0.70 for normal cargo ships

= 0.83 for passenger ships

= 0.90 for trawlers and tugs

$KM_T = KB + BM_T$

$GM_T = KM_T – KG$

Correction for free surface must be applied over this. Then ,

$GM'_T = GM_T – 0.03\ KG$ (assumed).

This GM'_T should satisfy IMO requirements.

4.3 **Longitudinal Stability**

$$GM_L \cong BM_L = \frac{I_L}{\nabla} = \frac{C_{IL}\ L\ B^3}{LBT\ \ C_B} = \frac{C_{IL}\ L^2}{T.C_B}$$

$$MCT\ 1\ cm = \frac{\nabla GM_L}{100\ \ L_{BP}} = \frac{L.B.T.C_B\ C_{IL}\ L^2}{100.T.\ C_B\ L} = \frac{C_{IL}\ L^2 B}{100}$$

4.5 Longitudinal Centre of Buoyancy (1)

The longitudinal centre of buoyancy LCB affects the resistance and trim of the vessel. Initial estimates are needed as input to some resistance estimating algorithms. Like wise, initial checks of vessel trim require a sound LCB estimate. In general, LCB will move aft with ship design speed and Froude number. At low Froude number, the bow can be fairly blunt with cylindrical or elliptical bows utilized on slow vessels. On these vessels it is necessary to fair the stern to achieve effective flow into the propeller, so the run is more tapered (horizontally or vertically in a buttock flow stern) than the bow resulting in an LCB which is forward of amidships. As the vessel becomes faster for its length, the bow must be faired to achieve acceptable wave resistance, resulting in a movement of the LCB aft through amidships. At even higher speeds the bow must be faired even more resulting in an LCB aft of amidships.

Harvald

$$LCB = 9.70 - 45.0\ Fn\ \pm 0.8$$

Schneekluth and Bestram

$$LCB = 8.80 - 38.9\ Fn$$

$$LCB = -13.5 + 19.4\ C_P$$

Here LCB is estimated as percentage of length, positive forward of amidships.

5.0 Lightship Weight Estimation

(a) Lightship weight $= 1128\left[\dfrac{dwt}{1000}\right]^{0.64}$ (4)

(b) Lightship = Steel Weight + Outfil weight + Machinery Weight + Margin.

5.1 Steel Weight

The estimated steel weight is normally the Net steel. To this Scrap steel weight (10 to 18 %) is added to get gross steel weight.

Ship type	Cargo	Cargo cum Passenger	Passenger	Cross Channe Pass. ferry
$\left(100/\Delta\right) \times Steel\ weight$	20	28	30	35

For tankers, $\dfrac{100}{\Delta} \times Steel\ weight = 18$

5.1.1 Steel weight Estimation – Watson and Gilfillan

From ref. (3),

Hull Numeral E = $L\,(B+T) + 0.85\ (D-T)L + 0.85\sum l_1\ h_1 + 0.75\sum l_2\ h_2$ in metric units where

$l_1\ and\ h_1$: length and height of full width erections

$l_2\ and\ h_2$: length and height of houses.

$$W_s = W_{s7}\ \left[1 + 0.5\left(C_{B1} - 0.70\right)\ \right]$$

where W_s : Steel weight of actual ship with block C_{B1} at 0.8D

W_{s7} : Steel weight of a ship with block 0.70

$$C_{B1} = C_B + \left(1 - C_B\right)\left(\frac{0.8D - T}{3T}\right)$$

Where C_B : Actual block at T.

$$W_{s7} = K.\ E^{1.36}$$

Ship type	Value of K	For E
Tanker	0.029 – 0.035	1,500 < E < 40, 000
Chemical Tanker	0.036 – 0.037	1,900 < E < 2, 500
Bulker	0.029 – 0.032	3,000 < E < 15, 000
Open type bulk and Container ship	0.033 – 0.040	6,000 < E < 13, 000
Cargo	0.029 – 0.037	2,000 < E < 7, 000
Refrig	0.032 – 0.035	E 5,000
Coasters	0.027 – 0.032	1,000 < E < 2, 000
Offshore Supply	0.041 – 0.051	800 < E < 1, 300
Tugs	0.044	350, E < 450
Trawler	0.041 – 0.042	250, E < 1, 300
Research Vessel	0.045 – 0.046	1, 350 < E < 1, 500
Ferries	0.024 – 0.037	2,000 < E < 5, 000
Passenger	0.037 – 0.038	5, 000 < E < 15, 000

5.1.2 From Basic Ship

Steeel weight from basic ship can be estimated assuming any of the following relations :

(i) $W_s \propto L \times$weight per foot amidships

(ii) $W_s \propto L.B.D.$

(iii) $W_s \propto L.(B+D)$

To this steel weight, all major alterations are added / substracted.

Schneekluth Method for Steel Weight of Dry Cargo Ship

∇_u = volume below topmost container deck (m^3)

∇_D = hull volume upto main deck (m^3)

∇_s = Volume increase through sheer (m^3)

∇_b = Volume increase through camber (m^3)

s_v, s_u = height of s hear at FP and AP

L_s = length over which sheer extends ($L_s \le L_{pp}$)

n = number of decks

∇_L = Volume of hatchways

$\ell_L ; b_L$ *and* h_L are length, breadth and height of hatchway

$$\nabla_u = \underbrace{L \cdot B \cdot D \cdot C_{BD}}_{\nabla_D} + \underbrace{L_s \cdot B \cdot (s_u + s_\vartheta) \cdot C_2}_{\nabla_s} + \underbrace{L \cdot B \cdot b \cdot C_3}_{\nabla_b} + \underbrace{\sum l_L \cdot b_L \cdot h_L}_{\nabla_L}$$

$$C_{BD} = C_B + C_4 \frac{D-T}{T}(1-C_B)$$

Where C_4 = 0.25 for ship forms with little flame flare

= 0.4 for ship forms with marked flame flare

$$C_2 = \frac{(C_{BD})^{2/3}}{b} \quad ; \qquad C_3 = 0.7\, C_{BD}$$

$$W_{st}\ (\pm) = \nabla_u\, C_1\ \left[1+0.033\left(\tfrac{L}{D}-12\right)\right]\ \left[1+0.06\left(n-\tfrac{D}{4}\right)\right]$$

$$\left[1+0.05\left(1.85-\tfrac{B}{D}\right)\right]\ \left[1+0.2\left(\tfrac{T}{D}-0.85\right)\right]$$

$$\left[0.92+(1-C_{BD})^2\right]\ \left[1+0.75\, C_{BD}(C_M-0.98)\right]$$

Restriction imposed on the formula :

$$\frac{L}{D} < 9, \text{ and}$$

C_1 the volumetric weight factor and dependent on ship type and measured in t/m^3

$C_1 = 0.103\left[1+17(L-110)^2\ 10^{-6}\right]\ t/m^3$ for $80\,m \le L \le 180\,m$ for normal ships

C_1 = 0.113 to 0.121 t/m^3 for $80\,m \le L \le 150\,m$ of passenger ships

C_1 = 0.102 to 0.116 t/m^3 for $100\,m \le L \le 150\,m$ of refrigerated ships

5.1.3 Schneekluth's Method for Steel Weight of container Ships

$$W_{st} = \nabla_u \quad 0.093\left[1+0.002(L-120)^2\right]10^{-3}$$

$$\left[1+0.057\left(\frac{L}{D}-12\right)\right]\left[\frac{30}{(D+14)}\right]^{1/2}$$

$$\left[1+0.01\left(\frac{B}{D}-2.1\right)^2\right]\left[1+0.02\left(\frac{T}{D}-0.85\right)\right]\left[0.92+(1-C_{BD})^2\right]$$

Depending on the steel construction the tolerance width of the result will be somewhat greater than that of normal cargo ships. The factor 0.093 may vary between

0.09 and 0 the under deck volume contains the volume of a short forecastle for the volume of hatchways

The ratio $\frac{L}{D}$ should not be less than 10

Farther Corrections :

(a) where normal steel is used the following should be added :

$$\delta W_{st}(\%) = 3.5\left(\sqrt{L} - 10\right)\left[1 + 0.1\left(\frac{L}{D} - 12\right)\right]$$

This correction is valid for ships between 100 m and 180 m length

(b) No correction for wing tank is needed

(c) The formulae can be applied to container ships with trapizoidal midship sections. These are around 5% lighter

(d) Further corrections can be added for ice-strengthening, different double bottom height, higher latchways, higher speeds.

Container Cell Guides

Container cell guides are normally included in the steel weight. Weight of container cell guides.

Ship type	Length (ft)	Fixed	*Detachable*
Vessel	20	0.7 t / TEU	1 t / TEU
Vessel	40	0.45 t / TEU	0.7 t / TEU
Integrated	20	0.75 t / TEU	-
Integrated	40	0.48 t / TEU	-

Where containers are stowed in three stacks, the lashings weigh :

for 20 ft containers 0.024 t / TEU
40 ft containers 0.031 t / TEU
mixed stowage 0.043 t / TEU

5.1.4 <u>Steel Weight Estimations</u> : other formulations

<u>For containce Ships</u> :

$$W_{st} = 0.007\ L_{pp}^{1.759}.\ B^{0.712}.\ D^{0.374}$$ [K. R. Chapman]

$W_{st} \rightarrow$ steel weight in tonns

$L_{pp}, B, D \rightarrow$ are in metres.

$$W_{st} = 340\left(LBD/100{,}000\right)^{0.9}\left(0.675+\frac{C_B}{2}\right) * \left[0.00585\left(\frac{L}{D}-8.3\right)^{1.8}+0.939\right]$$

[D. Miller]

$W_{st} \rightarrow$ tonnes

$L, B, D \rightarrow$ metres

<u>For Dry Cargo vessels</u>

$$W_{st} = 0.0832\ x\ e^{-5.73x10^{-7}}$$

where $x = \dfrac{L_{pp}^{2}\ B}{12}\ \sqrt[3]{C_B}$ [wehkamp / kerlen]

$$W_{st} = C_B^{2/3}\ \frac{LB}{6}\ D^{0.72}\left[0.002\left(\frac{L}{D}\right)^2+1\right]$$

[Ccmyette's formula as represented by watson & Gilfillan]

$W_{st} \rightarrow$ tonnes

$L, B, D \rightarrow$ metres

<u>For tankers</u> :

$$W_{st} = \Delta\left[\alpha_L + \alpha_T\left(1.009-0.004\frac{L}{B}\right) * 0.06 * \left(28.7-\frac{L}{D}\right)\right]$$

DNV – 1972

where

$$\alpha_L = \frac{\left(0.054+0.004\dfrac{L}{B}\right) * 0.97}{0.189 * \left(\dfrac{100\ L}{D}\right)^{0.78}}$$

$$\alpha_T = 0.029 + 0.00235 * \left(\frac{\Delta}{100000}\right) \quad \text{for } \Delta < 600000 \text{ t}$$

$$\alpha_T = 0.0252 * \left(\frac{\Delta}{100000}\right)^{0.3} \quad \text{for } \Delta > 600000 \text{ t}$$

Range of Validity :

$$10 \le \frac{L}{D} \le 14$$

$$5 \le \frac{L}{B} \le 7$$

$$150 \ m \le L \le 480\, m$$

<u>For Bulk Carriers</u>

$$W_{st} = 0.1697\, L^{1.56} \left(\frac{B}{D} + \frac{T}{2}\right) * \frac{(0.5\, C_B + 0.4)}{0.8} \qquad \text{[J. M. Hurrey]}$$

$$W_{st} = 4.274\, Z^{0.62}\, L \left(1.215 - 0.035\frac{L}{B}\right)\left(0.73 + 0.025\frac{L}{B}\right)\left(1 + \frac{L-200}{1800}\right)$$

$$* \left(2.42 - 0.07\frac{L}{D}\right)\left(1.146 - 0.0163\frac{L}{D}\right) \qquad \text{[DNV 1972]}$$

here Z is the section modulus of midship section area

The limits of validity for DNV formulae for bulkers are same as tankers except that is, valid for a length upto 380 m

5.2 <u>Machinery Weight</u>

5.2.1 <u>Murirosmith</u>

W_m = BHP/10 + 200 tons diesel

= SHP/17 + 280 tons turbine

= SHP/ 30 + 200 tons turbine (cross channel)

This includes all weights of auxiliaries within definition of m/c weight as part of light weight. Corrections may be made as follows:

For m/c aft deduct 5%

For twin-screw ships add 10% and

For ships with large electrical load add 5 to 12%

5.2.2 **Watson and Gilfillan**

W_m (diesel) $= \sum_i 12[MCRi / RPMi]^{0.84} + Auxiliary\, wt.$

W_m (diesel-electric) $= 0.72\ (M\ CR)^{0.78}$ W_m (gas turbine) $= 0.001$ (MCR)

Auxiliary weight = 0.69 $(MCR)^{0.7}$ for bulk and general cargo vessel

= 0.72 $(MCR)^{0.7}$ for tankers

= 0.83 $(MCR)^{0.7}$ for passenger ships and ferries

= 0.19 for frigates and Convetters

MCR is in kw and RPM of the engine

5.3 **Wood and Outfit Wight (W_o)**

5.3.1 Watson and Gilfilla

W and G (RINA 1977): (figure taken from [1])

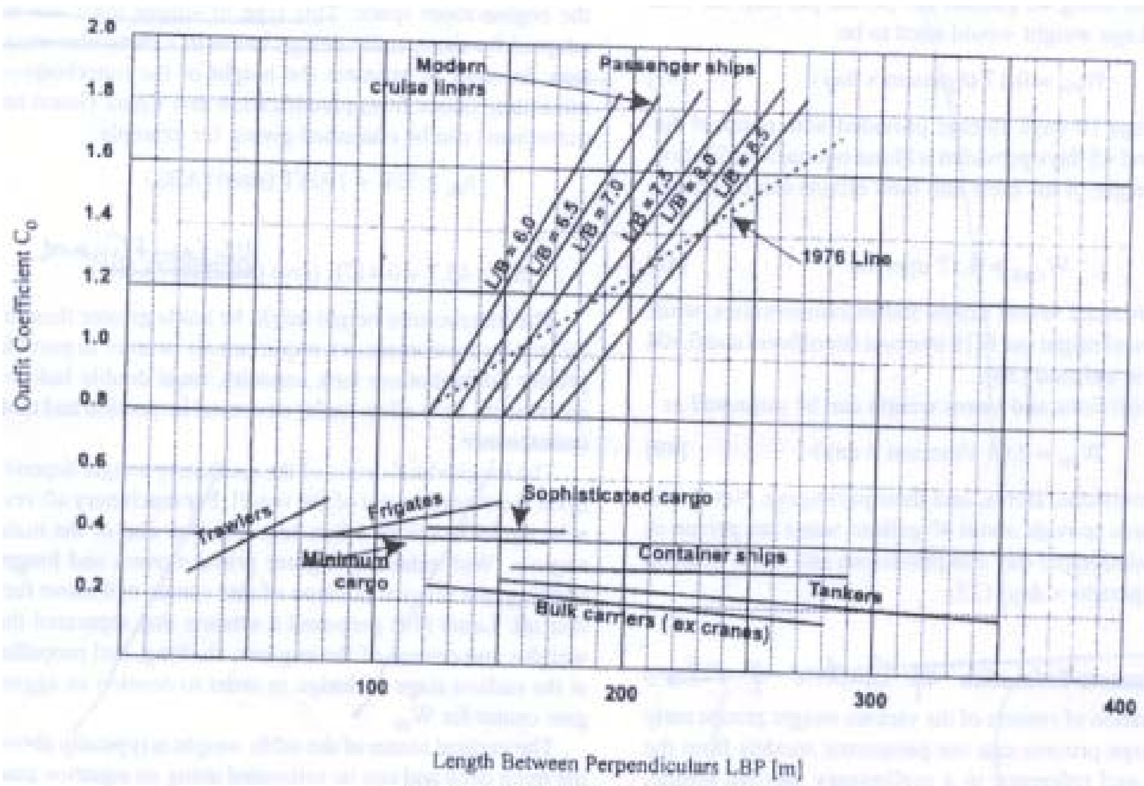


Figure 11.17 Outfit Weight Coefficient C_0 (18)

5.3.2. Basic Ship

W_o can be estimated from basic ship using any of the proportionalities given below:

5.3.3. Schneekluth

<u>Out Fit Weight Estimation</u>

Cargo ships at every type

N_o = K. L. B., $W_o \rightarrow tonnes$, L, B $\rightarrow$ meters

Where the value of K is as follows

	Type	K
(a)	Cargo ships	0.40-0.45 t/m^2
(b)	Container ships	0.34-0.38 t/m^2
(c)	Bulk carriers without cranes	
	With length around 140 m	0.22-0.25 t/m^2
	With length around 250 m	0.17-0.18 t/m^2
(d)	Crude oil tankers:	

With lengths around 150 m	0.25 t/m^2
With lengths around 300 m	0.17 t/m^2

Passenger ships – Cabin ships

$W_0 = K\sum\nabla$ where $\sum\nabla$ total volume 1n m^3

$K = 0.036\, t/m^3 - 0.039\, t/m^3$

Passenger ships with large car transporting sections and passenger ships carrying deck passengers

$W_0 = K\sum\nabla$, where K = 0.04 t/m^2 – 0.05 t/m^2

$$W_o \;\alpha\; L \times B \quad \text{or} \quad W_{02} = \frac{W_0\, L}{2} + \frac{L_2}{L_1} \times \frac{B_2}{B_1}$$

Where suffix 2 is for new ship and 1 is for basic ship.

From this, all major alterations are added or substracted.

5.4 Margin on Light Weight Estimation

Ship type	Margin on Wt	Margin on VCG
Cargo ships	1.5 to 2.5%	0.5 to ¾ %
Passenger ships	2 to 3.5%	¾ to 1 %
Naval Ships	3.5 to 7%	

5.5 Displacement Allowance due to Appendages $(\Delta_{\alpha PP})$

(i) Extra displacement due to shell plating = molded displacement x (1.005 do 1.008) where 1.005 is for ULCCS and 1.008 for small craft.

(ii) where C = 0.7 for fine and 1.4 for full bossings
d: Propeller diameter.

(iii) Rudder Displacement = 0.13 x (area)$^{9/2}$ tonnes

(iv) Propeller Displacement = 0.01 x d^3 tonnes

$$\Delta_{ext} = \Delta_{ext} + \Delta_{app.}$$

5.6 Dead weight Estimation

At initial stage deadweight is supplied. However,

$$Dwt = W_{Cargo} + W_{HFO} + W_{DO} + W_{LO} + W_{FW} + W_{C\&E} + W_{PR}$$

Where W_{Cargo} : Cargo weight (required to be carried) which can be calculated from cargo hold capacity

$$W_{HFO} = \text{SFC x MCR x } \frac{range}{speed} \times margin$$

Where

SFC : specific fuel consumption which can be taken as 190gm/kw hr for DE and 215gm/kw hr for 6T (This includes 10% excess for ship board approx)
Range: distance to be covered between two bunkeriy port margin : 5 to 10%

W_{DO} : Weight of marine diesel oil for DG Sets which is calculated similar to above based on actual power at sea and port(s)

W_{LO} : weight of lubrication oil
W_{LO} = 20 t for medium speed DE
=15 t for slow speed DE

W_{FW} : weight of fresh water
W_{FW} = 0.17 t/(person x day)

$W_{C\&E}$: weight of crew of fresh water
$W_{C\&E}$: 0.17t / person
W_{PR} : weight of provisions and stores
W_{PR} = 0.01t / (person x day)

5.7 Therefore weight equation to be satisfied is

Δ_{ext} = Light ship weight + Dead weight

where

light ship weight = steel weight + wood and out fit weight + machinery weight + margin.

6.0 Estimation of Centre of Mass (1)

The VCG of the basic hull can be estimated using an equation as follows:

$$VCG_{hull} = 0.01D\,[\,46.6 + 0.135\,(\,0.81 - C_B\,)\,(\,L/D\,)^2\,] + 0.008D\,(\,L/B - 6.5\,),\ L \le 120\text{ m}$$

$$= 0.01D\,[\,46.6 + 0.135\,(0.81 - C_B\,)\,(\,L/D\,)^2\,],\ 120\text{ m} < L$$

This may be modified for superstructure & deck housing

The longitudinal position of the basic hull weight will typically be slightly aft of the LCB position. Waston gives the suggestion:

$$LCG_{hull} = -\ 0.15 + LCB$$

Where both LCG and LCB are in percent ship length positive forward of amidships. The vertical center of the machinery weight will depend upon the inner bottom height h_{bd} and the height of the engine room from heel, D. With these known, the VCG of the machinery weight can be estimated as:

$$VCG_M = h_{db} + 0.35\ (\ D' - h_{db}\ )$$

Which places the machinery VCG at 35% of the height within the engine room space. In order to estimate the height of the inner bottom, minimum values from classification and Cost Guard requirements can be consulted giving for example:

$$h_{db} \geq 32B + 190\ \sqrt{T}\ \ \text{(mm) (ABS)}$$

or

$$h_{db} \geq 45.7 + 0.417\ L\ \text{(cm) Us Coast Guard}$$

The inner bottom height might be made greater than indicated by these minimum requirements in order to provide greater double bottom tank capacity, meet double hull requirements, or to allow easier structural inspection and tank maintenance.

The vertical center of the outfit weight is typically above the main deck and can be estimated using an equation as follows:

$$
\begin{aligned}
VCG_o &= D + 1.25, && L \leq 125\ \text{m} \\
&= D + 1.25 + 0.01(L-125), && 125 < L \leq 250\ \text{m} \\
&= D + 2.50,
\end{aligned}
$$

The longitudinal center of the outfit weight depends upon the location of the machinery and the deckhouse since significant portions of the outfit are in those locations. The remainder of the outfit weight is distributed along the entire hull.

$$LCG_o = (\ 25\%\ W_o \text{ at } LCG_M,\ 37.5\% \text{ at LCG dh, and } 37.5\% \text{ at amid ships})$$

The specific fractions can be adapted based upon data for similar ships. This approach captures the influence of the machinery and deckhouse locations on the associated outfit weight at the earliest stages of the design.

The centers of the deadweight items can be estimated based upon the preliminary inboard profile arrangement and the intent of the designer.

7.0 Estimation of Capacity

Grain Capacity = Moulded Col. + extra vol. due to hatch (m^3) coamings,edcape hatched etc – vol. of structurals.

Tank capacity = Max. no. of containers below deck (TEU) and above dk.

Structurals for holds : $1\frac{1}{2}$ to 2% of mid vol.

Structurals for F. O. tanks : $2\frac{1}{4}$ *to* $2\frac{1}{4}$% *of* mid. Vol.(without heating coils):

$2\frac{1}{2}$ *to* $2\frac{9}{4}$% *of* mid vol. (with heating coils):1% for cargo oil tanks

Structurals for BW/FW tanks: $2\frac{1}{4}$ *to* $2\frac{1}{2}$ for d.b. tanks non-cemented;

$2\frac{1}{2}$ *to* $2\frac{3}{4}$% for d.b. tanks cemented;

1 to 1.5 % for deep tanks for FO/BW/PW.

Bale capacity 0.90 x Grain Capacity.

Grain capacity can be estimated by using any one of 3 methods given below as per ref. MSD by Munro-Smith:

1. Grain capacity for underdeck space for cargo ships including machinery space, tunnel, bunkers etc.:

Capacity = $C_1 + C_2 + C_3$

Where

C_1 : Grain capacitay of space between keel and line parallel to L_{WL} drawn at the lowest point of deck at side.

$C_1 = L_{BP}$ x B_{ml} x D_{mld} x C

C : capacity coefficient as given below

C_B at	0.85D	0.73	0.74	0.75	0.76	0.77	0.78
C		0.742	0.751	0.760	0.769	0.778	0.787

C_B at 0.85D can be calculated for the design ship from the relationship

$$\frac{dc_u}{dT} = \frac{1}{10.T}$$

The C.G. of C_1 can be taken as 0.515 x D above tank top.

C_2 : Volume between WL at lowest point of sheer and sheer line at side.

C_2 : 0.236 X S X B X $L_{BP}/2$ with centroid at 0.259S above WL at lowest point of sheer

Where S = sheer forward + sheer aft.

C_3 = 0.548 x camber at midship x B x $L_{BP}/ 2$ with centriod at 0.2365 + 0.381 x camber at above WL at lowest point of sheer. Both forward and aft calculations are done separately and added. C_2 and C_3 are calculated on the assumption that deck line, camber line and sheer line are parabolic.

II. Capacity Depth D_C

$$D_C = D_{mld} + ½ \text{ camber} + 1/6 (S_A + S_F) – (\text{depth of d.b.} + \text{tank top ceiling})$$

Grain capacity below upper deck and above tank top including non cargo spaces is given as:

$LBD_C.C_B/100(ft^3)$	2000	3000	4000	5000	6000	7000	8000
Grain Cap. (ft^3)	2000	3000	4000	5050	6100	7150	8200

III. From basic ship:

C_1: Under dk sapacity of basic ship
= Grain cap. of cargo spaces + under dk non-cargo spaces – hatchways.

C_2: Under deck capacity of new ship.

$$C_2 = \frac{C_1}{L_1 B_1 D_1 C_{BL}} \times L_2\, B_2\, D_{c2} - C_{B2}$$

Where C_B is taken at 0.85 D

If D_H : Depth of hold amidships and C_9 : cintoroid of this capacity above tank top then, for

C_B = 0.76 at 0.85 D,

$1/6(S_F + S_A)/D_H$	0.06	0.08	0.10	0.12
C_9/D_H	0.556	0.565	0.573	0.583

For an increase of decrease of C_B by 0.02,
C_9/D_H is decreased or increased by 0.002.

From the capacity thus obtained, non cargo spaces are deducted and extra spaces as hatchways etc. are added go get the total grain capacity.

8.0 Power Estimation

For quick estimation of power:

(a) $$\frac{SHP}{V_0^3} = 0.5813[DWT/1000]^{0.5}$$

(b) Admirality coefficient is same for similar ships (in size, form, F_n).

$$A_C = \frac{\Delta^{2/3} V^9}{BHP}$$

Where $A_C = Admirality Coefficent$

$\Delta = Displacement\ in\ tons$

$V = Speed\ in\ Knots$

(c) In RINA, vol 102, Moor and Small Have proposed

$$SHP = \frac{H \Delta^{1/3} V^3 \left(40 \frac{L}{200} + 400 (K-1)^2 - 12 C_B \right)}{1500 - N \gamma L}$$

Where $N : RPM$

$H : Hull\ correction\ factor = 0.9\ for\ welded\ construction$
$K : To\ be obtained\ from\ Alexander's\ formula$
$L : in\ ft, V\ in\ knots, \Delta\ in\ tons.$

(d) From basic ship: If basic ship EHP is known. EHP for a new ship with similar hull form and Fr. No.- can be found out as follows:

(i) Breadth and Draught correction can be applied using Mumford indices (moor and small, RINA, vol. 102)

$$^{\Theta}new = ^{\Theta}basic\left(\frac{B_n}{B_b}\right)^{X-2/3}\left(\frac{T_n}{T_b}\right)^{Y-2/3}$$

Where x = 0.9 and y is given as a function of $V/\gamma L$ as

$\frac{V}{\gamma L}$	0.50	0.55	0.60	0.65	0.70	0.75	0.80
γ	0.54	0.55	0.57	0.58	0.60	0.62	0.64

Where

$$\Theta = \frac{EHP}{\Delta^{2/3}\, V^{3\times 427.1}}\ and where\, \Delta : tons, V : knots$$

(ii) Length correction as suggested by wand G (RINA 1977)

$$@L_1 - @L_2 = 4(L_2 - L_1)\, x10^{-4}$$

This correction is approximate where $L : ft.$

(e) Estimation of EHP from series Data wetted surface Area S in m^2 is given as

$$S = \frac{\sqrt{2\pi}}{\eta}\sqrt{\Delta.L},\ \nabla = m^3, L = m$$

$\eta =$ Wetted surface efficiency (see diagram of Telfer, Nec, Vol. 79, 1962-63).

The non-dimensional resistance coefficients are given as

$$C_R = \frac{R_R}{1/2\,\rho S V^2} =$$ This can be estimated from services data with corrections.

$$C_F = \frac{R_F}{1/2\,\rho S V^2}$$

From ITTC, $$C_F = \frac{0.075}{(\log_{10} R_n - 2)^2}$$

Where R_n :Re$ynold's\ No. = \frac{VL}{\nu}$

$v = Kinematic\ coefficient\ of\ Viscocity\ and$

$= 1.188 \times 10^{-6}\ m^2/\sec\ for\ sea\ water\ and\ for\ F.W., 1.139 \times 10^{-6}\ m^2/\sec\ for\ fresh\ water$

$C_A = Roughness\ Allowance$

$= 0.0004\ in\ general$

$or\ C_A = (0.8 - 0.004\, L_{wl}) \times 10^{-3}$

where $L_{wl}\ is\ in\ m$

$$C_T = C_F + C_R + C_A = \frac{R_T}{1/2\,\rho\, S V^2}$$

Where R_T *is the bare hull resistance.*

To get total resistance, Appendage resistance must be added to this:

Twin Screw Bossings	8 to 10%
A bracket	5%
Twin Rudder	3%
Bow Thruster	2 to 5%
Ice Knife	0.5%

If resistance is in Newtons and V is in m/sec,

$$EPH_{service} = EHP_{Lrial} \times (1.1\, to\, 1.25)\, KW.$$

(f) *EHP from statistical Data* : See Holtrop and Mannen, ISP 1981/1984 (given at the end of these notes)

(g) Estimation of SHP or shaft horse power

$$SHP = \frac{EHP_{service}}{QPC}$$

$$QPC = \eta_0\, \eta_H\, \eta_R = K - \frac{N \gamma L}{10000}$$

Where $N = RPM$

$L = L_{BP}\ in\ m$

$K = 0.84$ For fixed pitch propellers

$= 0.82$ For controllable pitch propellers can be estimated more accurately later

(h) BHP_s

$$BHP_s = SHP + Transmission\, losses$$

Transmission loss can be taken as follows:

Aft Engine	1%
Engine Semi aft	2%
Gear losses	3 to 4%

(i) Selection of Engine Power:

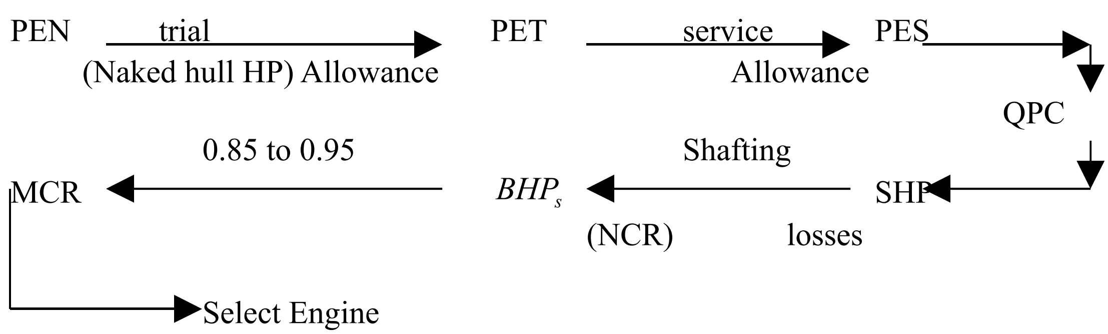
The maximum continuous rating (MCR) of a diesel engine is the power the engine can develop for long periods. By continuous running of engine at MCR may cause excessive wear and tear. So Engine manufactures recommend the continuous service rating (CSR) to be slightly less than MCR. Thus CSR of NCR (Normal Continuous Rating)

$$= MCR \times (0.85\, to\, 0.95)$$

Thus engine selected must have MCR as

$$MCR = BHP_s / 0.85 / 0.95.$$

Thus



9.0 <u>Seakeeping Requirement</u>

9.1 <u>Bow Freeboard</u> F_{bow}

$\frac{V}{\gamma L}$	0.60	0.70	0.80	0.90
$\frac{F_{bow}}{L}$	0.045	0.048	0.056	0.075

(b) Probability of Deckwetness P for various F_{bow}/L values have been given in Dynamics of Marine Vehicles, by R.Bhattacharya:

$L(ft)$		200	400	600	800
$L(m)$		61	122	183	244
	F_{bow}/L for				
P =	0.1%	0.080	0.058	0.046	0.037
	1%	0.056	0.046	0.036	0.026
	10%	0.032	0.026	0.020	0.015

Estimate F_{bow} check for deckwetness probability and see if it is acceptable. F_{bow} Should also be checked from load line requirement.

9.2

Early estimates of motions natural frequencies effective estimates can often be made for the three natural frequencies in roll, heave, and pitch based only upon the characteristics and parameters of the vessel. Their effectiveness usually depends upon the hull form being close to the norm.

An approximate roll natural period can be derived using a simple one-degree of freedom model yielding:

$$T_{\phi} = 2.007\, k_{11} / \sqrt{GM_t}$$

Where k_{11} is the roll radius of gyration, which can be related to the ship beam using:

$k_{11} = 0.50KB$, With $0.76 \leq \kappa \leq 0.82$ for merchant hulls and $0.69 \leq \kappa \leq 1.00$ generally.

Using $\kappa_{11} \approx 0.40B$. A more complex parametric model for estimating the roll natural period that yields the alternative result for the parameter κ is

$$\kappa = 0.724\sqrt{(C_B(C_B+0.2)-1.1(C_B+0.2)\times(1.0-C_B)(2.2-D/T)+(D/B)^2)}$$

Roll is a lightly damped process so the natural period can be compared directly with the domonant encounter period of the seaway to establish the risk of resonant motions. The encounter period in long- crested oblique seas is given by:

$$T_e = 2\pi/\left(\omega-\left(V\omega^2/g\right)\cos\theta_w\right)$$

Where ω is the wave frequency, V is ship speed, and θ_w is the wave angle relative to the ship heading with $\theta_w = 0^\bullet$ following seas, $\theta_w = 90^\bullet$ beam seas, and $\theta_w = 180^\bullet$

Head seas. For reference, the peak frequency of an ISSC spectrum is located at $4.85T_1^{-1}$ with T_1 the characteristics period of the seaway. An approximate pitch natural period can also be derived using a simple one- degree of freedom model yielding:

$$T_\theta = 2.007\,k_{22}/\sqrt{GM_L}$$

Where now k_{22} is the pitch radius of gyration, which can be related to the ship length by noting that $0.24L \le k_{22} \le 0.26L$.

An alternative parametric model reported by Lamb can be used for comparison:

$$T_\theta = 1.776\,C^{-1}{}_{wp}/\sqrt{(T\,C_B(0.6+0.36/T))}$$

Pitch is a heavily-damped (non resonant) mode, but early design checks typically try to avoid critical excitation by at least 10%

An approximate heave natural period can also be derived using a simple one degree-of-freedom model. A resulting parametric model has been reported by Lamb:

$$T_h = 2.007\sqrt{(T\,C_B(B+3T+1.2)/C_{wp})}$$

Like pitch, heave is a heavily damped (non resonant) mode. Early design checks typically try to avoid having $T_h = T_\phi$, $T_h = T_\theta$, $2T_h = T_\theta$, $T_\phi = T_\theta$, $T_\phi = 2T_\theta$, which could lead to significant mode coupling. For many large ships, however, these conditions often cannot be avoided.

9.3 Overall Seakeeping Ranking used Bales regression analysis to obtain a rank estimator for vertical plane seakeeping performance of combatant monohulls.

This estimator $\hat{R}$ yields a ranking number between 1 (poor seakeeping) and 10 (superior seakeeping) and has the following form:

$$\hat{R}=8.42+45.1C_{wpf}+10.1C_{wpa}-378T/L+1.27C/L-23.5C_{vpf}-15.9C_{vpa}$$

Here the waterplane coefficient and the vertical prismatic coefficient are expressed separately for the forward (f) and the aft (a) portions of the hull. Since the objective for superior seakeeping is high $\hat{R}$, high C_{wp} and low C_{vp},

Corresponding to V-shaped hulls, can be seen to provide improved vertical plane seakeeping. Note also that added waterplane forward is about 4.5 times as effective as aft and lower vertical prismatic forward is about 1.5 times as effective as aft in increasing $\hat{R}$. Thus, V-shaped hull sections forward provide the best way to achieve greater wave damping in heave and pitch and improve vertical plane seakeeping.

10. <u>Basic Ship Method</u>

1. Choose basic ship such that $V/\gamma L$, ship type and are nearly same and detailed information about the basic ship is available.
2. Choose $LBTC_B$ from empirical data and get Δ

   Such that $(dw/\Delta)_{basic}=(dw/\Delta)_{new}$.

   Choose $L.B.T.C_B$ etc as above to get Δ_{new}

   $= LBTC_B\times 1.03 to 1.033.$
3. Satisfy weight equation by extrapolating lightship from basic ship data.
4. For stability assume $(KG/D)_{basic}=(KG/D)_{new}$ with on your deletion
5. Check capacity using basic ship method. Use inference equation wherever necessary

10.1 <u>Difference Equations</u>

These equations are frequently used to alter main dimensions for desired small changes in out put. For example

$$\Delta = L.B.T.C_B\,\rho$$

Or, $\log\Delta = \log L + \log B + \log T + \log C_B + \log\rho$

Assuming ρ to be constant and differentiating,

$$\frac{d\Delta}{\Delta} = \frac{dL}{L} + \frac{dB}{B} + \frac{dT}{T} + \frac{dC_B}{C_B}$$

So if a change of $d\Delta$ is required in displacement, one or some of the parameters $L, B, T, or\ C_B$ can be altered so that above equation is satisfied. Similarly, to improve the values of BM by dBM, one can write

$$BM \,\alpha\, B^2/T$$

or $BM = k \times B^2/T$

or $\log BM = \log k + 2\log B - \log T$

Differentiating and assuming k constant

$$\frac{dBM}{BM} = 2\frac{dB}{B} - \frac{dT}{T}$$

11. Hull Vibration Calculation

11.1 For two node Vertical Vibration, hull frequency is

$$\underset{\text{(cpm)}}{N} = \phi\gamma\left[\frac{I}{\Delta L^3}\right] \qquad \text{[Schlick]}$$

Where I : Midship m . i. in $in^2\ ft^2$

Δ : tons, L : f t

ϕ = 156 , 850 for ships with fine lines

= 143, 500 for large passenger lines

= 127, 900 for cargo ships

$$\underset{(\mathrm{cpm})}{N} = \beta\gamma \left[\frac{BD^3}{\Delta L^3}\right]$$

B: breadth in ft and D : Depth upto strength dk in ft. This is refined to take into account added mass and long s .s. decks as,

$$\underset{(\mathrm{cpm})}{N} = C_1 \left[\frac{B.D_E{}^3}{\left(1.2 + B/3T\right) L^3 \Delta)}\right]^{1/2} + C_2 \qquad \text{[Todd]}$$

Where D_E : effective depth

D_E : $\left[\sum D_1^3 \ L_1 / L\right]^{1/3}$

Where D_1: Depth from keel to dk under consideration

L_1 : Length of s.s. dk

	C_1	C_2
Tankers	52000	28
Cargo Vessels	46750	25
Passenger Vessels		
With s.s	44000	20

$$N = \phi \left[\frac{\mathrm{I}}{\Delta L^3 \left(1 + B/2T\right)\left(1 + r_S\right)}\right]^{1/2} \qquad \text{Burill}$$

Where ϕ = 2,400,000, I : ft^4 , others in British unit

$$r_S : \text{shear correction} = \frac{3.5D\left(3\left(B/D\right)^3 + 9\left(B/D\right)^2 + 6\left(B/D\right) + 1.2\right)}{L^2\left(3B/D + 1\right)}$$

$$N = \frac{K}{L^n}\left[\frac{T\,D_E}{C_B\left(B+3.6T_1\right)}\right]^{1/2} \quad where[Bunyan]$$

K = 48,700 for tankers with long framing

34,000 for cargo ships

38,400 for cargo ships long framed

n= 1.23 for tankers

1.165 for cargo ships

All units are in British unit.

T_1 : Mean draught for condition considered

T : Design Draught

$N_{3V} = 2.\ N_{2V}$

$N_{4V} = 3.N_{2V}$

11.2 Hull Vibration (Kumai)

Kumai's formula for two nodded vertical vibration is (1968)

$$N_{2v} = 3.\ 07 * 10^6 \sqrt{\frac{I_v}{\Delta i\ L^3}}\ cpm$$

Then I_v = Moment of inertia (m^4)

$$\Delta_i = \left(1.2+\frac{1}{3}\frac{B}{T_m}\right)\Delta = displacement$$

including virtual added mass of water (tons)

L = length between perpendicular (m)

B= Breadth amidship (m)

$T_{m =}$= mean draught (m)

The higher noded vibration can be estimated from the following formula by Johannessen and skaar (1980)

$$N_{nv} \approx N_{2v}\left(n-1\right)^{\propto}$$

Then $\propto = 0.845$ general cargo ships

1.0 bulk carriers

1.2 Tankers

N_{2V} is the two noded vertical natural frequency. n should not exceed 5 or 6 in order to remain within range validity for the above equation.

11.3 <u>Horizontal Vibration</u>

For 2 node horizontal vibration, hull frequency is

$$N_{2H} = \beta_H \left[\frac{D.B^3}{\Delta.L^3}\right]^{1/2} cpm \qquad \text{[Brown]}$$

Where $\beta_H = 42000$, other quantities in British units.

$$N_{2H} = 1.5 N_{2v}$$

$$N_{3H} = 2.N_{2H}$$

$$N_{4H} = 3N_{2H}$$

11.4 <u>Torsional Vibration</u>

For Torsional vibration, hull frequency is

$$N_T = 3\times10^5\, C\left[\frac{I_p}{B^2 + D^2\, L.\Delta}\right]^{1/2} cpm \qquad \text{[Horn]}$$

$C = 1.58\, for\ one\ node, N_{1-T}$

$= 3.00\ for\ two\ node, N_{2-T}$

$= 4.07\ for\ three\ node, N_{3-T}$

$I_p = 4\,A^2 / \Sigma \frac{ds}{T}\left(ft^4\right)$ (This formulae is exact for hollow circular cylinder)

$A =$ Area enclosed by section in ft^2

$d_g =$ Element length along enclosing shell and deck (ft)

$t =$ Corresponding thickness in (ft)

$L, B, D: ft, \Delta: tons.$

11.5 Resonance

Propeller Blade Frequency = No. of blades $\times$ shaft frequency.
Engine RPM is to be so chosen that hull vibration frequency and shaft and propeller frequency do not coincide to cause resonance.

References

1. 'ShipDesign and Construction' edited by Thomas Lab SNAME, 2003.

2. 'Engineering Economics in ship Design, I.L Buxton, BSRA.

3. D. G. M. Waston and A.W. Gilfillan, some ship Design Methods' RINA, 1977.

4. P. N. Mishra, IINA, 1977.

5. 'Elements of Naval Architecture' R.Munro- Smith

6. 'Merchant Ship Design', R. Munro-Smith

7. A. Ayre, NECIES, VOl. 64.

8. R. L. Townsin, The Naval Architect (RINA), 1979.

9. 'Applied Naval Architecture', R. Munro-Smith

10. M. C. Eames and T. C. Drummond, 'Concept Exploration- An approach to Small Warship Design', RINA, 1977.

11. Ship Design for Efficiency and Economy- H Schneekluth, 1987, Butterworth.

12. Ship Hull Vibration F.H. Todd (1961)

13. J. Holtrop- A statistical Re- analysis of Resistance and Propulsion Data ISP 1984.

14. American Bureau of ships- Classification Rules

15. Indian Register of ships- Classification Rules

16. Ship Resistance- H. E. Goldhommce & Sr. Aa Harvald Report 1974.

17. ILLC Rules 1966.

Resistance Estimation Statistical Method (HOLTROP) 1984

$$R_{Total} = R_F(1+K_1) + R_{App} + R_W + R_B + R_{TR} + R_A$$

Where:

R_F = Frictional resistance according to ITTC – 1957 formula
K_1 = Form factor of bare hull

R_W = Wave – making resistance
R_B = Additional pressure resistance of bulbous bow near the water surface

R_{TR} = Additional pressure resistance due to transom immersion

R_A = Model –ship correlation resistance

R_{App} = Appendage resistance

The viscous resistance is calculated from:

$$R_v = \frac{1}{2}\rho v^2 C_{F0}(1+K_1)S \qquad \text{……………(i)}$$

Where

C_{F0} = Friction coefficient according to the ITTC – 1957 frictional

$$= \frac{0.075}{(\log_{10} R_n - 2)^2}$$

$1+K_1$ was derived statistically as

$$1+K_1 = 0.93 + 0.4871c(B/L)^{1.0681}.(T/L)^{0.4611}.(L/L_R)^{0.12}\left(\overset{3}{L}/\nabla\right)^{0.3649}.(1-C_P)^{-0.6042}$$

C is a coefficient accounting for the specific shape of the after body and is given by

C = 1+0.011 C_{Stern}

C_{Stern} = -25 for prom with gondola
= -10 for v-shaped sections
= 0 for normal section shape
= +10 for U-shaped section with hones stern

L_R is the length of run – can be estimated as

$$L_R / L = 1 - C_p + 0.06\, C_p\, LCB / (4\, C_p - 1)$$

S is the wetted surface area and can be estimated from the following statistically derived formula:

$$S = L(2T + B)\, C_M^{0.5} \left(0.4530 + 0.4425\, C_B - 0.2862\, C_M - 0.003467\, B + 0.3696\, C_{wp}\right) + 2.38\, A_{Br} / C_B$$

Where

$T =$ Average moulded draught in m
$L =$ Waterline length in m
$B =$ Moulded breadth in m
$LCB = LCB$ ford's $(+)$ or aft $(-)$ of midship as a percentage of L
$A_{Br} =$ Cross sectional area of the bulb in the vertical plane intersecting the stern contour at the water surface.

All coefficient are based on length on waterline.

The resistance of appendages was also analysed and the results presented in the form of an effective form factor, including the effect of appendages.

$$1 + K = 1 + K_1 + [1 + K_2 - (1 + K_1)] \frac{S\, app}{S\, tot}$$

Where

$K_2 =$ Effective form factor of appendages
$S_{app} =$ Total wetted surface of appendages

$S_{tot} =$ Total wetted surface of bare hull and appendages

The effective factor is used in conjunction with a modified form of equation (i)

$$R_v = \tfrac{1}{2} \rho V^2\, C_{Fo}\, S_{tot}\, (1 + K)$$

The effective value of K_2 when more than one appendage is to be accounted for can be determined as follows

$$(1 + k_2)_{effective} = \frac{\sum S_i\, (1 + k_2)_i}{\sum S_i}$$

In which S_i and $(1 + k_2)_i$ are the wetted area and appendage factor for the i th appendage

TABLE: EFFECTIVE FORM FACTOR VALUES K_2 FOR DIFFERENT APPENDAGES

Type of appendage	value of $(1+k_2)$
Rudder of single screw ship	1.3 to 1.5
Spade type rudder of twin screw ship	2.8
Skeg-rudder of twin screw ships	1.5 to 2.0
Shaft Brackets	3.0
Bossings	2.0
Bilge keels	1.4
Stabilizer fins	2.8
Shafts	2.0
Sonar dome	2.7

For wave-making resistance the following equation of Havelock (1913)
Was simplified as follows:

$$\frac{R_w}{W} = c_1\, c_2\, c_3\, e^{m_1 F_n^d} + m_2 \cos\left(\lambda\ F_n^{-2}\right)$$

In this equation C_1, C_2, C_3, λ and m are coefficients which depend on the hull form. λL is the wave making length. The interaction between the transverse waves, accounted for by the cosine term, results in the typical humps and hollows in the resistance curves.

For low-speed range $F_n \le 0.4$ the following coefficients were derived

$$C_1 = 2223105\ C_4^{3.7861}\ \left(T/B\right)^{1.0796}\ \left(90 - i_E\right)^{-1.3757}$$

with:

$$\begin{cases} C_4 = 0.2296\left(B/L\right)^{0.3333} & for\ \ B/L \le 0.11 \\ C_4 = B/L & for\ \ 0.11 \le B/L \le 0.25 \\ C_4 = 0.5 - 0.0625\ L/B & for\ \ B/L \ge 0.25 \end{cases}$$

d = -0.9

$$m_1 = 0.01404\left(L/T\right) - 1.7525\left(\nabla^{1/3}/L\right) - 4.7932\left(B/L\right) - C_5$$

with:

$$\begin{cases} C_5 = 8.0798\ C_p - 13.8673\ C_p^2 + 6.9844\ C_p^3 & for\ C_p \le 0.8 \\ C_5 = 1.7301 - 0.7067\ C_p & for\ C_p \ge 0.8 \end{cases}$$

$$m_2 = C_6\ 0.4\, e^{-0.034\ F_n^{-3.24}}$$

with:

$$\begin{cases} C_6 = -1.69385 & \rightarrow \quad for\ L^3/\nabla \leq 512 \\ C_6 = -1.69385 + \left(L/\nabla^{1/3} - 8.0\right)/2.36 & for 512 \leq L^3/\nabla \leq 1727 \\ C_6 = 0.0 & \rightarrow \quad for\ L^3/\nabla \geq 1727 \end{cases}$$

$$\lambda = 1.446\ C_p - 0.03\left(L/B\right) \qquad for\ L/B \leq 12$$

$$\lambda = 1.446\ C_p - 0.36 \qquad for\ L/B \geq 12$$

where

i_E = half angle of entrance of the load waterline in degrees

$$i_E = 125.67\left(B/L\right) - 162.25\ C_p^2 + 234.32\ C_p^3 + 0.1551\left(LCB + \frac{6.8\left(T_a - T_f\right)}{T}\right)^3$$

where T_a = moulded draught at A.P
T_f = moulded draught at F.P

The value C_2 accounts for the effect of the bulb.

C_2 = 1.0 if no bulb's fitted, otherwise

$$C_2 = e^{-1.89} \quad \frac{A_{BT}\ \nu_B}{BT\left(\nu_B + i\right)}$$

where

ν_B is the effective bulb radius, equivalent to

$$\nu_B = 0.56 \quad A_{BT}^{0.5}$$

i represents the effect of submergence of the bulb as determine by

$$i = T_f - h_B - 0.4464\ \nu_B$$

where

T_f = moulded draught at FP
h_B = height of the centroid of the area A_{BT} above the base line

$$C_3 = 1 - 0.8\ A_T / \left(BTC_M\right)$$

C_3 accounts for the influence of transom stern on the wave resistance

AT is the immersed area of the transom at zero speed.

For high speed range $F_n \geq 0.55$, Coefficients C_1 and m_1 are modified as follows

$$C_1 = 6919.3\ C_M^{-1.3.346}\left(\nabla / L^3\right)^{2.0098}\left(L/B - 2\right)^{1.4069}$$

$$m_1 = -7.2035\left(B/L\right)^{0.3269}\left(T/B\right)^{0.6054}$$

For intermediate speed range $(0.4 \leq F_n \leq 0.55)$ the following interpolation is used

$$\frac{R_W}{W} = \frac{1}{W}\left[R_{W_{Fn04}} + \frac{(10F_n - 0.4)\left\{R_{W_{Fn0.55}} - R_{W_{Fn04}}\right\}}{1.5}\right]$$

The formula derived for the model-ship correlation allowance C_A is

$$\begin{cases} C_A = 0.006\,(L_{WL} + 100)^{-0.16} - 0.00205 & for \quad T_F / L_{WL} \geq 0.04 \\ C_A = 0.006\,(L_{WL} + 100)^{-0.16} - 0.00205 + 0.003\,(L_{WL} / 7.5)^{0.5} \quad C_B^4\, C_2(0.04 - T_F / L_{WL}) & \\ \qquad for \quad T_F / L_{WL} \geq 0.04 & \end{cases}$$

where C_2 is the coefficient adopted to account for the influence of the bulb.

Total resistance

$$R_T = \frac{1}{2}\rho\, v^2\, S_{tot}\,\left[C_F(1+k) + C_A\right] + \frac{R_W}{W}.W$$