Useful design and performance formulae

Preliminary estimates for dimensions

$C_D = \text{dwt}/W$ where $W = \text{lwt} + \text{dwt}$

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

$$L = \left[\frac{\text{dwt} \times (L/B)^2 \times (B/H)}{p \times C_B \times C_D}\right]^{1/3}$$

where:

$B = (L/10) + (5.0\text{–}7.5)$, for General Cargo ships
$B = (L/10) + (7.5\text{–}10.0)$, for Container ships
$L/B = 5.00 - 5.75$, for modern Supertankers
$C_B = 1.2 - (0.39 \times V/L^{0.5})$
$L = 5.32 \times \text{dwt}^{0.351}$ approximately for General Cargo ships

Estimates for steel weight

$W_d = W_b \times (W_d/W_b) \times (L_d/L_b)$

$$\text{Average sheer} = \frac{\text{Sheer Aft} + \text{Sheer Forward}}{6}$$

$$W_{ST} = 26.6 \times 10^{-3} \times L^{1.65} \frac{(B + D + H/2)\,(0.5C_B + 0.4)}{0.8}$$

Estimates for wood and outfit weight

$$\alpha = \text{W\&O weight for basic ship} \times \frac{100}{L_B \times B_B}$$

$$\text{W\&O weight} = \frac{1}{2}(\text{W\&O})_B + \frac{1}{2}(\text{W\&O})_B \times \frac{L_D \times B_D}{L_B \times B_B} \qquad \text{Cargo ships}$$

$$\text{W\&O weight} = \frac{2}{3}(\text{W\&O})_B + \frac{1}{3}(\text{W\&O})_B \times \frac{L_D \times B_D}{L_B \times B_B} \qquad \text{Oil Tankers}$$

Estimates for machinery weight

$$A_C = \frac{W^{2/3} \times V^3}{P} \qquad \text{if } V < 20\text{ kt}$$

$$A_C = \frac{W^{2/3} \times V^4}{P} \qquad \text{if V equals or} > 20\text{ kt}$$

$$M_W = 0.075\, P_B + 300 \qquad M_W = 0.045\, P_S + 500 \qquad M_W = 10.2\, P_S^{0.5}$$

Estimates for capacities

Grain Capacity = Mld Capacity × 98% approximately

Bale Capacity = Grain Capacity × 90% approximately

Insulated Capacity = Mld Capacity × 75% approximately

$$G_D = G_B \times \frac{L_D \times B_D \times 'D_D' \times C_B@SLWL_D}{L_B \times B_B \times 'D_B' \times C_B@SLWL_B}$$

$$'D' = \text{Depth Mld} + \frac{\text{Camber}}{2} + \frac{\text{Sheer Aft} + \text{Sheer Forward}}{6}$$
$$- \text{Tank Top height} - \text{Tank Top ceiling}$$

$$V_t = L_t \times B \times D_t \times C_B \times 1.16 \qquad \text{for Tankers}$$

$$V_t = L_h \times B \times D_h \times C_B \times 1.19 \qquad \text{for Bulk Carriers}$$

C_B@85% Depth Mld = C_B@SLWL × 101.5% approximately

Approximate hydrostatics

$$\text{Any } C_B = C_B@SLWL \times \left(\frac{\text{Any waterline}}{\text{SLWL}}\right)^x$$

$$x = 4.5 \times e^{-5 \times C_B@SLWL} \qquad \text{where } e = 2.718$$

$$K = \frac{1 - C_B}{3}$$

$$C_W = (2/3 \times C_B) + 1/3 \qquad \text{at SLWL}$$

$$W = L \times B \times H \times C_B \times p$$

$$KB = 0.535 \times H \qquad 2/3 \times H \qquad H/2 \qquad \text{for various ship types}$$

$$KB = \frac{H}{1 + C_B/C_W} \qquad GM_L = BM_L \text{ approximately}$$

$$BM_T = I_T/V \qquad BM_L = I_L/V$$

$$BM_T = \frac{\eta_T \times B^2}{H \times C_B} \qquad BM_L = \frac{\eta_L \times L^2}{H \times C_B}$$

$$\eta_T = 0.084 \times C_W^2 \quad \text{or} \quad \eta_T = 1/12 \times C_W^2 \text{ approximately}$$

$$\eta_L = 0.075 \times C_W^2 \quad \text{or} \quad \eta_T = 3/40 \times C_W^2 \text{ approximately}$$

$$KM_T = KG + GM_T \qquad KM_T = KB + BM_T$$

$$WPA = L \times B \times C_W \qquad TPC_{SW} = WPA/97.56$$

$$MCTC_{SW} = 7.8 \times (TPC_{SW}^2)/B \quad \text{for Oil Tankers}$$

$$MCTC_{SW} = 7.31 \times (TPC_{SW}^2)/B \quad \text{for General Cargo ships}$$

$$WPA = K \times H^n \qquad H_2/H_1 = (W_2/W_1)^{C_B/C_W}$$

At each draft $\quad BM_L/BM_T = 0.893 \times (L/B)^2$

Ship resistance

$R_t = R_f + R_r \quad$ where $R_f = f \times A \times V^n$

$$f_s = \frac{0.441}{L_S^{0.0088}} \qquad f_m = \frac{0.6234}{L_m^{0.1176}}$$

$$WSA_{Taylor} = 2.56 \times (W \times L)^{0.5} \qquad \frac{V_S}{L_S^{0.5}} = \frac{V_m}{L_m^{0.5}}$$

$$Fn = \frac{V}{(g \times L)^{0.5}}$$

$$\frac{R_r(\text{ship})}{R_r(\text{model})} = \left(\frac{L_S}{L_m}\right)^3 \qquad R_r \propto L^3$$

$R_r \propto$ Volume of displacement $\quad$ Areas $\propto L^2$

Velocity $\propto$ (Volume of displacement)$^{1/6}$

$Rf_m \propto L_m^{2.7949}$ for ship models

$Rf_s \propto L_S^{2.9037}$ for full size ships

Types of ship speed

$V_T = P \times N \times 60 / 1852 = P \times N / 30.866$

Apparent slip ratio $= \dfrac{V_T - V_S}{V_T}$ Real slip ratio $= \dfrac{V_T - V_a}{V_T}$

$W_t = \dfrac{V_S - V_a}{V_S}$ $W_t = \dfrac{C_B}{2} - 0.05$ approximately

Pitch ratio $= \dfrac{\text{Propeller pitch}}{\text{Propeller diameter}}$

Types of power

$P_T = \text{Thrust} \times V_a$ $P_D = 2 \times \pi \times N \times T$ $P_{NE} = R_T \times V_S$

$P_E = P_{NE}$ + (weather and appendage allowances)

P_E/P_T = Hull efficiency P_T/P_D = Propeller efficiency

P_D/P_B or P_D/P_S = Propeller shaft efficiency

P_B/P_I or P_S/P_I = Engine's mechanical efficiency

$P_I = X/Y$

where:

$X = P_{NE}$ + (weather and appendage allowances)
Y = (Hull efficiency) (Propeller efficiency) (Propeller shaft efficiency) (Engine efficiency)

Power coefficients

$QPC = P_E/P_D$ $PC = P_E/P_B$ or P_E/P_S

$QPC = 0.85 - \dfrac{N \times L^{0.5}}{10\,000}$ approximately

$A_C = \dfrac{W^{2/3} \times V^3}{P}$ if $V < 20$ kt

$A_C = \dfrac{W^{2/3} \times V^4}{P}$ if V equals or >20 kt

$A_C = 26(L^{0.5} + 150/V)$ approximately

Propeller and rudder design

Thickness fraction = t/D a = Pitch/Diameter

$$BAR = \frac{\text{Total blade area}}{\pi \times d^2/4} \qquad B_p = \frac{0.0367 \times N \times P^{0.5}}{V_a^{2.5}}$$

$$\delta = 3.28 \times N \times d / V_a$$

$$\text{Thrust in N/cm}^2 = \frac{\text{Thrust in Newtons}}{\text{Total blade area}}$$

$$A_R = K \times LBP \times d \qquad F = \beta \times A_R \times V^2$$

$$F_t = Fn \cos\alpha = F \sin\alpha \cos\alpha$$

$$F_t = \beta \times A_R \times V^2 \times \sin\alpha \cos\alpha$$

Bollard pulls

Total required bollard pull = (60 × W/100 000) + 40

Total required bollard pull = (0.7 × LBP) − 35

ASD: bollard pull = $0.016 \times P_B$ VS: bollard pull = $0.012 \times P_B$

Speed Trials

$$\text{True speed} = \frac{V_1 + 3V_2 + 3V_2 + V_4}{8}$$

$$\text{True speed} = \frac{V_1 + 5V_2 + 10V_3 + 10V_4 + 5V_5 + V_6}{32}$$

$$\text{True speed} = N \times \frac{60}{Nm}$$

Fuel consumption trials

$$\text{Fuel cons/day} = \frac{W^{2/3} \times V^3}{F_C}$$

where:

F_C = 110 000, for Steam Turbine machinery
F_C = 120 000, for Diesel machinery
F_C = 0.20 kg/kW h (0.0048 × P_S tonnes/day), for Steam Turbines machinery
F_C = 0.18 kg/kW h (0.00432 × P_B tonnes/day), for Diesel machinery

Crash-stop manoeuvres

$$S = 0.38\left[\frac{dwt^2 - dwt}{100\,000}\right] + 1.60$$

$$T = 2.67\left[\frac{dwt}{100\,000}\right]^2 - 0.67\left[\frac{dwt}{100\,000}\right] + 10.00$$

$$S_L = 2\left[\frac{dwt}{100\,000}\right] + 10.50$$

Ship squat

$$\delta_{max} = \frac{C_B \times S^{0.81} \times V^{2.08}}{20} \qquad y_2 = y_0 - \delta_{max} \qquad y_0 = H - T$$

$$\delta_{max} = \frac{C_B \times V^2}{100} \text{ Open water} \qquad \delta_{max} = \frac{C_B \times V^2}{50} \text{ Confined channel}$$

$$K = (6 \times S) + 0.4 \qquad S = \frac{b \times T}{B \times H}$$

$$K_t = 40(0.700 - C_B)^2 \qquad K_{o/e} = 1 - 40(0.700 - C_B)^2$$

$$K_{mbs} = 1 - 20(0.700 - C_B)^2$$

Dynamic trim = $K_t \times \delta_{max}$ $\quad\delta_{o/e} = K_{o/e} \times \delta_{max}$ $\quad$ mbs = $K_{mbs} \times \delta_{max}$

% loss in speed = 60 − (25 × H/T)

% loss in revolutions = 18 − (10/3 × H/T)

% loss in speed = (300 × S) − 16.5 %

% loss in revolutions = (24 × S) + 11.6

Reduced speed and loss of revolutions

$F_B = 7.04/C_B^{0.85}$ $\quad F_D = 4.44/C_B^{1.3}$

% loss in speed = 60 − (25 × H/T)

% loss in revolustions = 18 − (10/3 × H/T)

% loss in speed = (300 × S) − 16.5

% loss in revolutions = (24 × S) + 11.6

Interaction

$$S = \frac{(b_1 \times T_1) + (b_2 \times T_2)}{B \times H}$$

% increase in squat = 150 − (10 × V)

Ship vibration

$$N = \frac{1}{T} \quad N_{Schlick} = \emptyset\left[\frac{I_{NA}}{W \times L^3}\right]^{0.5} \quad N_{Todd} = \beta\left[\frac{B \times D}{W \times L^3}\right]^{0.5}$$

$$W_2 = W\left[\frac{B}{3 \times d} + 1.2\right]$$

$$N_{Todd\ and\ Marwood} = \left[2.29 \times 10^6 \times \frac{I_{NA}}{(W_2 \times L^3)^{0.5}}\right] + 28$$

$$N_{Burrill} = 4.34 \times 10^6 \times \left[\frac{1 + B}{2 \times d}\,(1 + r_s)\right]^{-0.5} \times \left[\frac{I_{NA}}{W \times L^3}\right]^{0.5}$$

$$\emptyset_{Schlick} = 3.15 \times 10^6 \times C_B^{0.5} \text{ approximately}$$

$$\beta_{Todd} = 124\,000 \times C_B^{0.6} \text{ approximately}$$

$$\text{2nd harmonics} = \frac{\text{1st harmonics}}{\text{Number of blades on propeller}}$$