한국해양공학회 2004년도 춘계학술대회 논문집 PP.73~78

PARAMETRIC MAIN DIMENSION FIXING OF MEDIUM SIZED BULK CARRIERS

Prof. LEE KWIJOO, KIM KYOUNG HWA, KARL ISAACS
Department of Naval Architecture and Ocean Engineering
Chosun University, Korea

KEYWORDS: *Empirical formula, main dimensions, preliminary design*

ABSTRACT: *For the preliminary stages of ship design it is necessary to develop a basic design, which specifies the main particulars of the vessel, based on the requirements given by the owner. An efficient design enables the shipyard to make a rough estimate of the construction costs and to put forward a favourable quote during the call for tenders. The parametric determination of the main particulars of the vessel involves the application of empirical formulae. These formulae have been created after detailed tests and research by maritime research institutions and researchers had been carried out. Here, the design of a medium sized Bulk Carrier (26000t dwt) with a service speed of 17 knots for carrying rice and rock phosphate has been illustrated. Medium sized Bulk Carriers (25,000t dwt - 50,000t dwt) are in steady demand among small shipping companies. They have a size advantage, in that port size restrictions do not affect their design tremendously. Nevertheless, structurally, they are one of the most difficult to build. During design, the rules of the maritime regulatory bodies were strictly adhered to.*

1. Introduction

The Bulk Carrier is designed as a deadweight carrier. Based on the owners requirements of deadweight and speed, a database of similar previously built ships is created. The Froude numbers of the ships should be within an appreciable range. From this, the average values of the main dimensional ratios are tabulated.

Table 1 Main Dimension Ratios

Averages	
L/B	7.157
B/T	2.279
T/D	0.725
L/D	11.781
B/D	1.65
Froude Number (Fn)	0.2149
Power (kW)	8404.8

2.a Estimation of Main Dimensions

2.1 First Estimates of Displacement

An initial estimate for the displacement can be made based on the required total deadweight and the deadweight coefficient, C_D

C_D = Deadweight/Displacement

For Bulk Carriers the value of C_D falls in between 0.8 and 0.85. So C_D is taken as 0.8, then the preliminary displacement can be estimated as,

Displacement, Δ = 26000/0.8 = 32500 t

2.2 Preliminary Selection of Main and Auxiliary Engines

An empirical relation exists for calculating power delivered (P_D) and is given as,

$$P_D = (\Delta^{0.567} \times V^{3.6})/1000 \quad (1)$$

$$= 9724.2 \text{ kW}$$

$$P_B = 1.02 \times P_D = 9918.7 \text{ kW}$$

From the Wärtsila 2001 engine manual the engine selected is:

Name :SULZER RTA60C
Cylinders :6
Rpm :114
Power (at MCR) : 14160kW

As an approximation, the power of the auxiliary engine is taken as 15% of the main engine power.

15% of main engine power = 0.15×9918.7
= 148738 kW

2.3 Initial Parametric Estimation of Main Dimensions

The concept is to find the average of the ratios of parent ship main particulars of each ship such as L/B, L/D, B/D etc. and then using empirical relations, the range of length is fixed. From the graph plotted between length between perpendiculars and dead weight, we get the length of the vessel corresponding to the required dead weight to be carried.

2.3.1 Length between perpendiculars (L_{BP})

The empirical formulae used for the estimation of the length, is given below.

Schneekluth's formula [1]

$L_{BP} = (\Delta)^{0.3}(V_S)^{0.3} C$ (2)

Where

Δ = displacement in tons = 32,500 t

V_S = service speed in knots = 17 knots

C = 3.2 , if $0.48 < C_B < 0.85$

L_{BP} = 169m

Dankwardt's formula [2]

$L_{BP} = [5.1 \pm 0.2 + (Vt-15)0.07] (\Delta)^{1/3}$ (3)

Where

Vt = trial speed in knots

= $V_S \times 1.05$ = 17.85 knots.

L_{BP} = 175.5m to 150m

Range of length selected for main dimension fixing is, 150m to 175m

2.3.2 Breadth, Depth and Draft

The breadth, depth and the draft is calculated from the average L/D, L/B and B/T ratios of the parent vessel.

2.3.3 Block Coefficient (C_B) [2]

$C_B = 0.975 - 0.9 \times F_n + 0.2$ (4)

2.3.4 Displacement

Displacement $(\Delta) = LBT \times C_B \times \rho \times (1+s)$ [2] (5)

Where ρ = density of sea water

s = side shell correction factor, taken as 0.0006

2.3.5 Steel Mass [3]

$\Delta_{SE} = \Delta_{SE}^{7} \{1 + 0.5 (C_B^{8} - 0.7)\}$ (6)

Where

C_B^{8} = Block coefficient at draught 0.8 × D

$C_B^{8} = C_B + \{(1-C_B)(0.8\,D - T)/3\,T\}$

$\Delta_{SE}^{7} = K\,E^{1.36}$

$E = L(B + T) + 0.85\,L(D - T) + 250$

K = 0.029 to 0.032 for Bulk carriers for which $3000 \le E \le 15000$. Taking average value, K = 0.0305

2.3.6 Outfit Mass

$\Delta_{OU} = M_{OU} \times LB$ (tonnes) (7)

$M_{OU} = M_{OU1} + M_{OU2} \times L$

For Bulk carriers,

M_{OU1} = 0.325

M_{OU2} = -0.0006

2.3.7 Engine Plant Mass

$\Delta_{EP} = 0.102 \times P_B$ (t) (8)

Where,

$P_B = 1.02 \times P_D$

$P_D = (\Delta^{0.567} \times V_T^{3.6}) / 1000$ (kW)

(Volkes formula)

To the above steel, outfit and engine plant mass, an allowance of 1.5%, 5% and 2.5% is added respectively. The Lightship is obtained by adding the steel, outfit and the engine plant mass. From this we can obtain the deadweight as:

Deadweight = Displacement – Lightship weight

Based on the above formulae, a range of particulars is calculated and a particular set is chosen, one, which satisfies the deadweight requirements.

Table 2 Calculated Main Particulars

LBP	150	160	170	175
B(m)	20.957	22.3544	23.7516	24.45013
D(m)	12.732	13.581	14.4298	14.85424
T(m)	9.1955	9.80853	10.4216	10.72808
F_n	0.228	0.22073	0.21414	0.211055
C_B	0.7898	0.79635	0.80228	0.80505
Δ	23416	28653.2	34624.4	37900.82
Δ_{SE}	3697.2	4385.13	5151.29	5564.86
Δ_{OU}	775.68	860.019	945.443	988.3965
Δ_{EP}	1026.5	1150.9	1281.3	1348.701
Δ_{LS}	5499.4	6396.05	7378.03	7901.957
Dwt	17917	22257.1	27246.4	29998.87

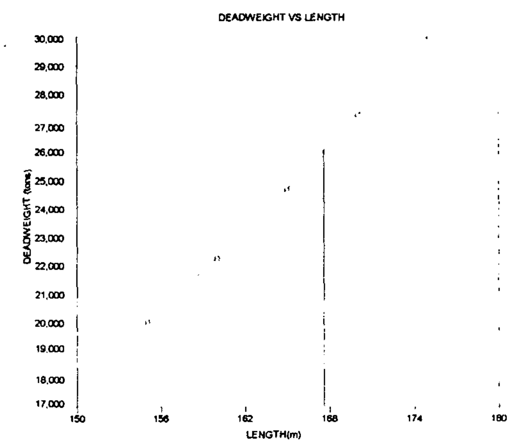

Fig 1 Deadweight Vs. Length

The length which satisfies the required deadweight, is 167.6m and the particulars are as given below:

Particulars for a length of 167.6m

L	= 167.6m
B	= 23.41 m
D	= 14.22 m
T	= 10.27 m
C_B	= 0.8
Δ	= 33121.7 t
Δ_{SE}	= 4960.1t
Δ_{OU}	= 924.9t
Δ_{EP}	= 1249.7t
Δ_{LS}	= 7134.42t
Dwt	= 25987.3t

Since the deadweight is a little less than required, and also the draft had to be restricted to 9.4m (draft restriction at destination port), further iteration is carried out.

Particulars for length of 174m

L	= 174m
B	= 25.5 m
D	= 15.5 m
T	= 9.4 m
C_B	= 0.805
Δ	= 34620.63 t
Δ_{SE}	= 5823.16t
Δ_{OU}	= 1027.74t
Δ_{EP}	= 1276.87t
Δ_{LS}	= 8127.78t
Dwt	= 26285.85t

All the above particulars are within parent ship ranges. Following these calculations the lines are designed.

2.b Lines and General Arrangement

The lines are designed based on the BSRA series charts[8]. From the BSRA Charts, the desired half breadths are obtained by reading the ratios of ordinates to half breadths. These values are given as a set of graphs – one for each station. At each station, the half breadth is read out for the different BSRA water lines. These half breadths are given for varying values of C_B. So, once we know the C_B of the ship, we can obtain the half breadth values for different BSRA water lines from the BSRA graph, for stations 0 to 10.

The General Arrangement is done in order to do an initial calculation of the volume of holds, and do a capacity check. The G.A. gives a detail picture of vessel, the position of holds and various allocations of rooms. The General Arrangement of the vessel is done based on guide lines laid down by the classification society[6]. The vessel is required to have a minimum of 8 bulkheads according to the rules. The location of various spaces is given in Table 4.

Table 4 Location of spaces

Zone	Length
Aft Peak tank	9m
Engine room	26.4m
Holds #1-6	21.6m
Fore Peak tank	9m

3. Preliminary Stability Check

A preliminary check on stability is done by Prohaska's method

Righting lever $GZ = GM \sin\Theta + BM \times h^* m$ (9)

Θ = Angle of heel

h^* = constant from prohaskas curve

BM = Metacentric Radius

GM = Metacentric height.

$GM = KB + BM - KG$

$KB = [C_W/(C_W + C_B)] \times T$ (10)

$C_W = 0.76 \times C_B + 0.273$

= 0.89

KB = [0.89/(0.89+0.805)]9.4

= 4.94 m

$BM = C_{IT} B^2/12TC_B$ (11)

C_{IT} is a factor based on shape of waterplane.

$C_{IT} = 0.894 \times C_W^2 + 0.096$ (Normand)

= 0.804

$C_{IT} = 0.87 \times C_W^2 + 0.13 \times C_W$ (Dankwardt)

= 0.805

∴BM = 5.765 m

KG = 0.57 x D → for Bulk Carriers

= 0.57 x 15.5 → 8.835m

KG = 8.835 m

∴GM = 1.87m

GM/B should be between 0.08 and 0.12 for Bulk Carriers

GM/B = 1.87/ 25.5 = 0.073

The requirement is not satisfied. So we have to go in for a reduction in depth. The depth is reduced to 15m. The calculations are done once again. GM/B is obtained as,

GM / B = 2.155/ 25.5 = 0.0845

The calculated values are given in Table 3 and the GZ curve can be seen in Fig 2.

Table 3 GZ values

θ	h*	GZ = GM×Sin θ + BM×h*
15	0.009	0.609
30	0.025	1.221
45	0.01	1.581
60	-0.125	1.145
75	-0.28	0.467
90	-0.42	-0.266

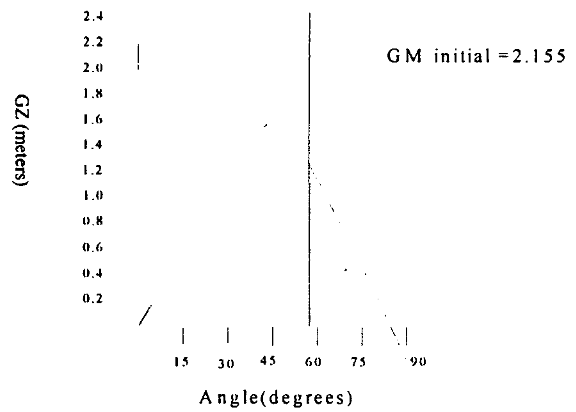

Fig 2 GZ curve

4. Capacity Calculation

4.1 Estimation of Consumables

4.1.1 Mass of heavy fuel (M_{HF})

M_{HF} = $sfc \times P_B \times Range/V$ (12)

Sfc = 180 g/kWhr

P_B = $1.02 \times \Delta^{0.567} \times (V_T)^{3.6} / 1000$

= 11056.18kW

$\therefore M_{HF}$ ≈ 400 t

4.1.2 Mass of Diesel fuel(M_{DF})

M_{DF} = 1/3 × 400

$\therefore M_{DF}$ = 133.3 t

4.1.3 Mass of lube oil(M_{LO})

M_{LO} = $0.04(M_{HF} + M_{DF}) = 21.33$ t

4.1.4 Mass of boiler fuel (M_{BF})

M_{BF} = 1 % of (M_{HF} + M_{DF})

M_{BF} = 5.33 t

4.1.5 Mass of fresh water (M_{FW})

M_{FW} = volume × compliment × days of voyage × 10^{-3} t

Days of voyage = range/(speed×24) = 3400/(17×24) = 8.33 ≈ 8.5 days

Mass of fresh water and stores depends on number of persons on board. This in turn depends on GRT of the vessel.

GRT = $CGT \times L \times B \times D \times C_B$ m^3 [3] (13)

CGT = Correction factor for gross tonnage

= 0.0 to 1.15 for bulk carriers, taking average value (0.875)

GRT = 46879.68m^3

Based on GRT, approximate number of persons on board is calculated as 29

M_{FW} = $M_{Drinking\ water} + M_{washing\ water}$

$M_{Drinking\ Water}$ = 10 to 20 litres / person / day

$M_{Washing\ water}$ = 60 litres/ person/ day for crew.

= 120 litres / person / day for officers

M_{FW} = 23.7 tonnes

4.1.6 Mass of provisions(M_{PR})

Depends on the number of crew, number of passengers and the radius of action of the ship

M_{PR} = 6 kg / person / day(crew)

= 8 kg / person /day(officers)

M_{PR} = 1.65 t

M_{ST} (stores) = $M_{HF} + M_{DF} + M_{LO} + M_{FW} + M_{PR} + M_{BF}$

= 400 + 133.33+21.33 +23.7+ 1.65 +5.33

= 585.34 t

4.1.7 Mass of crew and effects (M_{CR})

Mass and effects = 120.Kg / person

For officers = 150 Kg / person

$\therefore M_{CR}$ = 120×20 + 150×9 = 3.75

4.1.8 Mass of cargo

Cargo mass = Dwt – ($M_{ST} + M_{CA} + M_{WB}$)

= 26000 – (585.34 + 3.75)

= 25410.9m^3

4.2 Checks on Hold and Tank Capacity

This is done to check whether the vessel with given dimensions can carry the required amount of cargo. Given below is a sketch of the bulk carrier midship section.

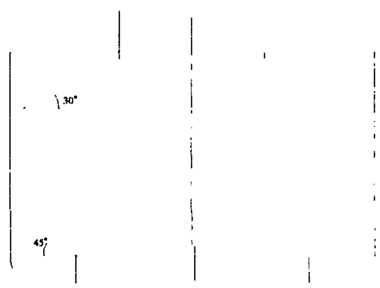

Fig 3 Midship Section of Bulk Carrier

The volume of all the enclosed spaces is calculated using empirical relations. The volume for cargo carriage is found out be,

V = 37614.81m^3

(These calculations are beyond the scope of this paper. Please refer to reference [2])

Stowage factor of rice = $1.359 m^3/ts$

Stowage factor of Phosrock = $0.7 - 0.8 m^3/t$

Volume for carriage of rice = Mass of cargo × stowage factor of rice

= $34533.41\ m^3$

Volume for carriage of rice = Mass of cargo × stowage factor of rock phosphate

= $17787.63\ m^3$

Thus the volume check is satisfactory.

5. Check on Displacement

From the design equation,

$$\text{Displacement } (\Delta) = L \times B \times T \times C_B \times 1.025(1+s)$$

$$= 34620.63t$$

Where s is the shell correction factor it varies between 1.005 and 1.006. 1.006 is chosen.

1.025 is the density of seawater in t/m^3

Also,

Δ = Deadweight +light ship

Light ship = steel mass + engine plant mass + outfit mass

= 5734.76+1280.78+1027.74

= 8039.37t

Dead weight = 26374.25 t

Δ = 8039.37 +26374.25

= 34600 t

Displacement check is satisfactory

6. Powering Calculation

6.1 Resistance Calculation

The resistance is calculated using Guldhammar and Harvald method[7].

Total resistance,

$$R_T = C_T \times (1/2)\rho S V^2 \quad (14)$$

$$C_T = C_F + C_R + C_A \quad (15)$$

C_F = coefficient of frictional resistance

C_R = coefficient of residuary resistance

C_A = allowance for surface roughness = 0.0004

$$S = L(C_B \times B + 1.7 \times T) \quad (16)$$

= 174 (0.805×25.5 + 1.7×9.4)

= $6352.305\ m^2$

$$C_F = 0.075/(\log_{10} Rn - 2)^2 \quad (17)$$

Rn = $VL/\nu = 8.75 \times 174/(1.188\times10^{-6})$

= 1.28×10^9

where,

V = 17×0.5144 = 8.75m/s

ν = 1.188×10^{-6}

$\therefore C_F$ = $0.075/(\log_{10} 1.28\times10^9 - 2)^2 = 1.485\times10^{-3}$

C_R is found out from the $L_{WL}/\nabla^{1/3}$ graph

A set of 10^3 C_R Vs Froude number are given for different Cp values, for a given $L_{WL} / \nabla^{1/3}$ value

For the case in question, $L_{WL} / \nabla^{1/3} = 5.39$. But we have curves only for $L_{WL} / \nabla^{1/3} = 5$ and 5.5. So we have to interpolate to get intermediate values.

For $L_{WL} / \nabla^{1/3} = 5$ $10^3 C_R = 1.95$

For $L_{WL} / \nabla^{1/3} = 5.5$ $10^3 C_R = 1.75$

For $L_{WL} / \nabla^{1/3} = 5.39$, by linear interpolation we get,

C_R = 1.8×10^{-3}

C_T = $(1.485+1.8+0.4)\times10^{-3} = 3.685\times10^{-3}$

R_T = $3.685\times10^{-3} \times 0.5\times1.025\times6352.305\times8.75^2$

= 918500 N

6.2 Power Prediction

Calculation of Quasi propulsive coefficient

a) $QPC = \eta_D = K - (N\sqrt{L}/10000)$ [3]

(Emerson) where,

K = 0.84

N = 114 rpm

$\therefore \eta_D$ = $0.84-(114\sqrt{174}/10000) = 0.689$

b) $QPC = 3.6C_B(1-0.9C_B)-(V/(4.8C_B\sqrt{L}))$ [3] (Lamb)

= 0.7984- 0.1715

= 0.627

Powering calculation and selection of Main engine

$$P_E = R_T V \quad (18)$$

= 918500×8.75

= 8036.875 kW

where,

P_E is the effective power.

P_D = P_E / η_D.

η_D is taken as the average of the above two.

η_D = $(0.627+0.689)/2 = 0.658$

P_D = 8036.875/0.658

= 12214.1 kW

P_B = $P_D/(\eta_G\times\eta_N)$

Where,

η_G and η_N are gear and shaft efficiency ≈ 0.97

$\therefore P_B \quad = 12591.85$ kW

Main Engine selected

Name : Sulzer RTA68T

Cylinders : 7

RPM : 94(max), 75(min)

Power at MCR : 20,580kW

Conclusions

Checks were carried out for stability, resistance, volume capacity satisfactorily. So we can fix the main dimensions of the vessel as in Table 5.

Table 5 Finalized Main Dimensions

L_{BP}	174m
B	25.5m
D	15m
T	9.4m
C_B	0.805

This method of preliminary main dimension fixing was extensively used about a decade ago. But it was time consuming since had to be carried out iteratively. With the advent of computerisation in the shipbuilding field now the time factor can be reduced. Applying the principle of Genetic Algorithm to this process, the iteration process can be speeded up. This usually involves optimization techniques and the process of natural biological selection. As it is known, there can be myriads of solutions. The boundary value parameters and the optimization functions narrow down the number of solutions to an optimized one.

References

1) "Ship Design for Efficiency and Economy", H. Schneekluth

2) "Entewerfen von Schiffen", H. Schneekluth

3) "Some Ship Design Methods", Watson and Gilfillan, RINA Trans '76

4) "Economic Design of Bulk Carriers", Gilfillan, paper read at RINA meeting '68

5) "Principles of Naval Architecture", E.V. Lewis

6) "Lloyds Rules and Regulations for classification of ships"

7) "Resistance and Propulsion of Ships", Harvald

8) "British Ship Research Association Series chart"