Chapter 2

Formulation of the Model for optimization

This chapter presents an explanation on the formulation of the weight, and the economics or the cost modules. The formulation of the problem does not involve draft in any of the equations in the weight module. This is done in order to ensure that the weight has no dependence on the draft and hence on the displacement. This is essential to avoid noise during optimization.

2.1 Summary of the Weight Module

The lightship weight and its center of gravity have been calculated using the empirical relations given by [6], [7] and [5]. In this summary the numbers alongside the heading of each section indicate the source of the formulas of that section. All weights are in metric tons and all centers of gravity are in meters.

Weights have been broadly classified into three categories:
1.) Lightship
2.) Cargo
3.) Fuel and miscellaneous
Lightship and fuel and miscellaneous weights are explained here. The cargo weight is simply the product of the number of twenty-foot equivalent units (TEUs) and the weight per unit. The derivation of the number of TEUs is explained in chapter 3.

The lightship weight is broken down into:
1.) Hull steel weight
2.) Outfit and hull engineering weight
3.) Machinery weight.

2.1.1 Lightship Weight

Hull Steel Weight [6]

Hull structure includes the main hull structure, superstructure, deck houses and all internal divisional bulkheads over one eighth inch thick. It also includes masts, king posts and foundations.

$$Ws = Cs \times \left[\frac{CN}{1000}\right]^{0.9} \times CL1 \times CL2 \times CL3 \qquad (2.1)$$

where

Cs = 8550; conversion factor in terms of metric tons per 100,000 cubic meters.

CN = Cubic number = $\frac{Loa \times B \times D}{100}$

Loa = Length, overall
B = Beam, maximum
D = Depth, at side
CL1 = 0.675 + (0.5) Cb
Cb = Block coefficient = $\dfrac{\text{Disp}}{\text{Lwl} \times \text{B} \times \text{T}}$
Disp = Displacement, volume
Lwl = Length, waterline
T = Draft, design
CL2 = $1 + 0.36 \left(\dfrac{\text{Ls}}{\text{Lbp}} \right)$
Ls = Length of superstructure within fore and aft perpendiculars.
Lbp = Length between perpendiculars

We approximate the ratio Ls /Lbp as 0.10 *

CL3 = $0.00585 \times \left(\dfrac{\text{Loa}}{\text{D}} - 8.3 \right)^{1.8} + 0.939$

The coefficients of (2.1) were recalculated using regression [8] to fit the range of data in Table 3.1. The new expression for hull steel weight is as follows:

$$\text{Ws} = 5905.98 \times \left(\frac{\text{CN}}{1000} \right)^{1.003} \times (1 + 0.49532 \times \text{Cb}) \times \left[1 + 0.000928 \times \left(\frac{\text{Loa}}{\text{D}} - 8.3 \right)^{1.691} \right] \quad (2.2)$$

A comparison of the hull steel weight given by (2.1) and (2.2) follows in Table 2.1.

Vertical Center of Gravity for Hull Steel [7]

$$\text{KGs (\% D)} = \left[48 + 0.15 (0.85 - \text{Cb}) \left(\frac{\text{Loa}}{\text{D}} \right)^2 \right] \times \frac{\text{Ds}}{\text{D}} \quad (2.3)$$

where
Ds = Depth increased to take account of the shear and hatchway volume.
We approximate the ratio: Ds / D as 1.008.
Note that this is expressed as a percentage of D.

Outfit and Hull Engineering Weight [6]

Outfit constitutes hull insulation, joiner bulkheads, hawse pipes, deck fittings, cargo booms, hatch covers, anchors, rudder and stock and galley equipment.

$$\text{Wo} = \text{Co} \left(\frac{\text{CN}}{1000} \right)^{0.825} \quad (2.4)$$

where
Co = coefficient with a fixed value of 2412.

The coefficients of (2.4) were recalculated using regression [8] to fit the range of data in Table 3.1. The new expression for outfit weight is as follows:
* Approximation used in [6] is 0.20

$$Wo = 1727.20\times\left(\frac{CN}{1000}\right)^{0.724} \qquad (2.5)$$

Hull Engineering constitutes non-propulsion mechanical equipment such as deck machinery, steering engine, generators, ventilation systems, refrigeration systems, hull piping systems and pumps, and electrical systems.

$$Whe = Che \times\left(\frac{CN}{1000}\right)^{0.825} \qquad (2.6)$$

where
Che = coefficient with a fixed value of 1196.

The coefficients of (2.6) were recalculated using regression [8] to fit the range of data in Table 3.1. The new expression for hull engineering weight is as follows:

$$Whe = 856.44\times\left(\frac{CN}{1000}\right)^{0.724} \qquad (2.7)$$

Therefore Total Outfitting Weight:

Wto = Wo + Whe (2.8)

A comparison of the total outfitting weight obtained as a sum of (2.4) and (2.6) and as a sum of (2.5) and (2.7) follows in Table 2.1. A comparison of the outfit weight and hull engineering weight is not provided for non-availability of the actual values of the same.

Vertical Center of Gravity for Total Outfit Weight [5]

KGto = $(1.005 - 0.000689\times Loa)D$ (2.9)

Propulsion Machinery Weight [6]

$$\mathbf{Wm} = Cm \times\left(\frac{BHP}{1000}\right)^{0.72} \times Cf \qquad (2.10)$$

where

Cm = Machinery weight coefficient = 215.

BHP = Break horsepower

Cf = Coefficient to convert long tons to metric tons = 0.9843

The coefficients of (2.10) were recalculated using regression [8] to fit the range of data in Table 3.1. The new expression for propulsion machinery weight is as follows:

$$\text{Wm} = 93.448 \times \left(\frac{\text{BHP}}{1000}\right)^{0.775} \tag{2.11}$$

A comparison of the propulsion machinery weight given by (2.10) and (2.11) follows in Table 2.1.

<u>Vertical Center of Gravity for Machinery</u> [6]

$$\textbf{KGm} = 0.47 \times \text{D} \tag{2.12}$$

Therefore Total Lightship Weight**:**

$$\textbf{WL} = (\text{Ws} + \text{Wto} + \text{Wm}) \times 1.03 \tag{2.13}$$

where

1.03 denotes a 3 percent margin.

$$\textbf{KGL} = \left[\frac{(\text{Ws} \times \text{KGs}) + (\text{Wto} \times \text{KGto}) + (\text{Wm} \times \text{Kgm})}{(\text{WL}/\ 1.03)}\right] + 0.3 \tag{2.14}$$

From (2.14) it can be seen that we provide a margin of 0.3 meters to the center of gravity of the total lightship weight.

2.1.3 Validation of the Weight Module

Once we have formulated a model, it is essential to validate it against benchmarks to check the accuracy of the model. Table 2.1 displays the weight data on seven ships and provides a comparison of the weights obtained by using the expressions in section 2.1.1 with the actual values for all components of the lightship weight. It also provides a comparison of the original and the new expressions for the lightship weight components.

From Table 2.1, it can be seen that the model for lightship weight is 0.4 to 15.2 percent accurate. Further, the new expressions for the components of the lightship weight are more accurate (0.4 – 15.2 percent) than the original expressions (11.6 – 42.1 percent).