Part 1
Ship Design

Chapter 1

Preliminary estimates for new ships: Main Dimensions

It has been said that the problem for a Naval Architect is to design a ship that will carry a certain deadweight at a reasonable rate of stowage in a seaworthy vessel at a predetermined speed on a given radius of action as cheaply as possible all in conjunction with a General Arrangement suited to the ship's trade.

The Naval Architect must therefore keep in mind all of the following:

- Main Dimensions
- Hull form
- Displacement
- Freeboard
- Depth
- Capacities
- Trim and stability
- Economic considerations
- Longitudinal and transverse strength
- Structural scantlings
- Resistance and powering
- Machinery
- Endurance
- Wood and Outfit
- Lightweight and deadweight
- Material costs

In determining the Main Dimensions for a new ship, guidance can be taken from a similar ship for which basic details are known. This is known as a 'basic vessel' and must be similar in type, size, speed and power to the new vessel. It is constantly referred to as the new design is being developed.

When a shipowner makes an initial enquiry, he usually gives the shipbuilder four items of information:

- Type of vessel
- Deadweight of the new ship
- Required service speed
- Route on which the new vessel will operate

The intended route for a new vessel is very important for the designer to know. For example there may be a maximum length to consider. If the new vessel is to operate through the Panama Canal her maximum length must be 289.56 m. For the St. Lawrence Seaway the restriction for length is 225.5 m.

Beam restriction for the Panama Canal is 32.26 m and 23.8 m for the St. Lawrence Seaway. Draft restriction for the Panama is 12.04 m up to the tropical fresh water mark. For the St. Lawrence Seaway the draft must be no more than 8.0 m. For the Suez Canal, there are limitations of ship breadth linked with Ship Draft.

Finally there is the Air Draft to consider. This is the vertical distance from the waterline to the highest point on the ship. It indicates the ability of a ship to pass under a bridge spanning a seaway that forms part of the intended route. For the Panama Canal, this is to be no greater than 57.91 m. For the St. Lawrence Seaway the maximum Air Draft is to be 35.5 m.

The first estimate that the Naval Architect makes is to estimate the lightweight of the new ship. Starting with some definitions:

1. *Lightweight*: This is the weight of the ship itself when completely *empty*, with boilers topped up to working level. It is made up of steel weight, wood and outfit weight and machinery weight.
2. *Deadweight*: This is the weight that a ship *carries*. It can be made up of oil fuel, fresh water, stores, lubricating oil, water ballast, crew and effects, cargo and passengers.
3. *Displacement*: This is the weight of the volume of water that the ship displaces. Displacement is lightweight (lwt) + deadweight (dwt). The lightweight will not change much during the life of a ship and so is reasonably constant. The deadweight however will vary, depending on how much the ship is loaded.

Deadweight coefficient C_D: This coefficient links the deadweight with the displacement:

$$C_D = \frac{\text{deadweight}}{\text{displacement}} = \frac{\text{dwt}}{W}$$

C_D will depend on the ship type being considered. Table 1.1 shows typical values for Merchant ships when fully loaded up to their Summer Loaded Waterline (SLWL) (Draft Mld). The abbreviation Mld is short for moulded.

Table 1.1 Typical dwt coefficients for several Merchant ships

Ship type	*C_D@SLWL*	*Ship type*	*C_D@SLWL*
Oil Tanker	0.800–0.860	Container ship	0.600
Ore Carrier	0.820	Passenger Liners	0.35–0.40
General Cargo ship	0.700	RO-RO vessel	0.300
LNG or LPG ships	0.620	Cross-channel	0.200

As a good first approximation, for General Cargo ships and Oil Tankers, it can be stated that at the SLWL, the C_B approximately equals the C_D where:

$$C_B = \frac{\text{volume of displacement}}{L \times B \times H}$$

where:

L = Length between perpendiculars (LBP),
B = Breadth Mld,
H = Draft Mld.

Worked example 1.1

For a new design, a shipowner has specified a dwt of 9000 tonnes. Information from a database of previously built similar ships suggests C_D to be 0.715.

Estimate the fully loaded displacement (W) and the lwt for this new ship.

$$C_D = \text{dwt}/W \quad \text{So} \quad W = \text{dwt}/C_D$$

$$W = 9000/0.715 = \quad 12\,587 \text{ tonnes}$$

$$-\text{dwt (as specified)} = \quad -9000 \text{ tonnes}$$

$$\text{lwt} = \quad 3587 \text{ tonnes}$$

The dwt coefficient is not used for Passenger vessels. This is because deadweight is not so important a criterion. Furthermore, Passenger vessels are usually specialist 'one-off ships' so selection of a basic ship is much more difficult. For Passenger vessels, floor area in square metres is used as a means for making comparisons.

Estimations of the length for a new design

1. Ship *length* is controlled normally by the space available at the quayside.
2. Ship *breadth* is controlled by stability or canal width.
3. Ship *depth* is controlled by a combination of draft and freeboard.
4. Ship *draft* is controlled by the depth of water at the Ports where the ship will be visiting. Exceptions to this are the ULCCs and the Supertankers. They off-load their cargo at single point moorings located at the approaches to Ports.

Method 1: Cube root format

From information on ships already built and in service, the Naval Architect can decide upon the relationships of L/B and B/H for the new ship.

Knowing these values he can have a good first attempt at the Main Dimensions for the new vessel. He can use the following formula:

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

where:

L = LBP in metres for the new ship,
B = Breadth Mld in metres,
p = salt water density of 1.025 tonnes/m^3,
C_B and C_D are as previously denoted.

Worked example 1.2

From a database, information for a selected basic ship is as follows:

$$C_D = 0.715, \quad C_B = 0.723, \quad L/B = 7.2, \quad B/H = 2.17$$

For the new design the required dwt is 6700 tonnes. Estimate the L, B, H, lwt and W for the new ship.

$$C_D = \text{dwt}/W \quad \text{So} \quad W = \text{dwt}/C_D$$

$$W = 6700/0.715 = 9371 \text{ tonnes}$$

$$-\text{dwt (as given)} = -6700 \text{ tonnes}$$

$$\text{lwt} = \underline{2671} \text{ tonnes}$$

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

$$= \left(\frac{6700 \times 7.2 \times 7.2 \times 2.17}{1.025 \times 0.723 \times 0.715}\right)^{1/3}$$

$$= \underline{112.46 \text{ m}}$$

$$L/B = 7.2 \quad \text{So} \quad B = L/7.2 = 112.46/7.2 = 15.62\,\text{m}$$

$$B/H = 2.17 \quad \text{So} \quad H = B/2.17 = 15.62/2.17 = 7.20\,\text{m} = \text{SLWL}$$

Check!!

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

$$W = 112.46 \times 15.62 \times 7.2 \times 0.723 \times 1.025$$

W = 9373 tonnes (very close to previous answer of 9371 tonnes)

These values can be slightly refined and modified to give:

$L = 112.5\,\text{m}$, $B = 15.60\,\text{m}$, $H = 7.20\,\text{m}$, $C_D = 0.716$, $C_B = 0.723$,
fully loaded displacement (W) = 9364 tonnes, lwt = 2672 tonnes.

In the last decade, LBPs have decreased in value whilst Breadth Mld values have increased. The reasons for this are threefold.

Because of oil spillage following groundings, new Oil Tankers have double skins fitted. These are formed by fitting side tanks P&S, where it is hoped they will reduce loss of oil after side impact damage. In essence, a form of damage limitation.

Alongside this has been the development of Container ships with the demand for more deck containers. Some of these vessels are large enough to have 24 containers stowed across their Upper Deck.

In order to reduce vibration and strength problems together with decreases in first cost, Oil Tanker designers have tended to reduce the LBP. To achieve a similar dwt, they have increased the Breadth Mld. L/B values have gradually reduced from 6.25 to 5.50 to 5.00.

One such vessel is the 'Esso Japan' with 350 m LBP and a Breadth Mld of 70 m, and a massive dwt of 406 000 tonnes. Truly an Ultra Large Crude Carrier (ULCC). Another example is the 'Stena Viking' delivered in April 2001. She has a dwt of 266 000 tonnes, an LBP of 320 m and a Breadth Mld of 70 m. This makes her L/B a value as low as 4.57.

Method 2: The geosim procedure

This is a method used when a new order is geometrically similar to a basic ship. The method is as follows.

Worked example 1.3

A 100 000 tonnes dwt Very Large Crude Carrier (VLCC) is 250 m LBP, 43 m Breadth Mld and 13.75 m Draft Mld. Her C_B is 0.810 and her C_D is 0.815.

A new similar design is being considered, but with a dwt of 110 000 tonnes. Estimate the new principal dimensions, W and the corresponding lwt.

For geosims $(L_2/L_1)^3 = W_2/W_1$

Thus $L_2/L_1 = (W_2/W_1)^{1/3} = (111\,000/100\,000)^{1/3}$

$$L_2/L_1 = 1.0323 = \text{say } K$$

$$\text{New LBP} = \text{old LBP} \times K = 250 \times 1.0323 = 258.08\,\text{m}$$

$$\text{New Breadth Mld} = \text{old Breadth Mld} \times K = 43 \times 1.0323 = 44.389\,\text{m}$$

$$\text{New draft} = \text{old draft} \times K = 13.74 \times 1.0323 = 14.194\,\text{m.}$$

Check!!

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

$$W = 258.08 \times 44.389 \times 14.194 \times 0.810 \times 1.025$$

$$W = 135\,003 \text{ tonnes}$$

$$C_D = \text{dwt}/W = 110\,000/135\,003 = 0.8148 \quad \text{say 0.815, same as the basic ship.}$$

$$\text{lwt} = W - \text{dwt} = 135\,003 - 110\,000 = 25\,003 \text{ tonnes}$$

Dimensions could be refined to L = 258 m, B = 44.4 m, H = 14.2 m.

The main drawback with this method is that it only serves as a first approximation, because it is unlikely in practice that:

$$L_2/L_1 = B_2/B_1 = H_2/H_1 = K$$

Finally note that for both vessels $C_B = 0.810$ and $C_D = 0.815$.

Method 3: Graphical intersection procedure

From a study of a large number of Merchant ships, it has been shown that in modern ship design practice, the parameters L and B can be linked as follows:

$B = (L/10) + (5 \text{ to } 7.5)$ m	General Cargo ships
$B = (L/10) + (7.5 \text{ to } 10)$ m	Container vessels
$B = (L/5) - 12.5$ m	Supertankers (C.B. Barrass 1975)
$L/B = 6.00–6.25$	Supertankers (1975–1990)
$L/B = 5.00–5.75$	Supertankers (1990–2004)

C_B can also be linked with service speed (V) and the LBP (L) in that:

$$C_B = 1 - m\,(V/L^{0.5}) \qquad \text{Evolution of Alexander's formula.}$$

The slope 'm' varies with each ship type, as shown in Figure 1.1. However, only parts of the shown straight sloping lines are of use to the Naval Architect. This is because each ship type will have, in practice, a typical design service speed.

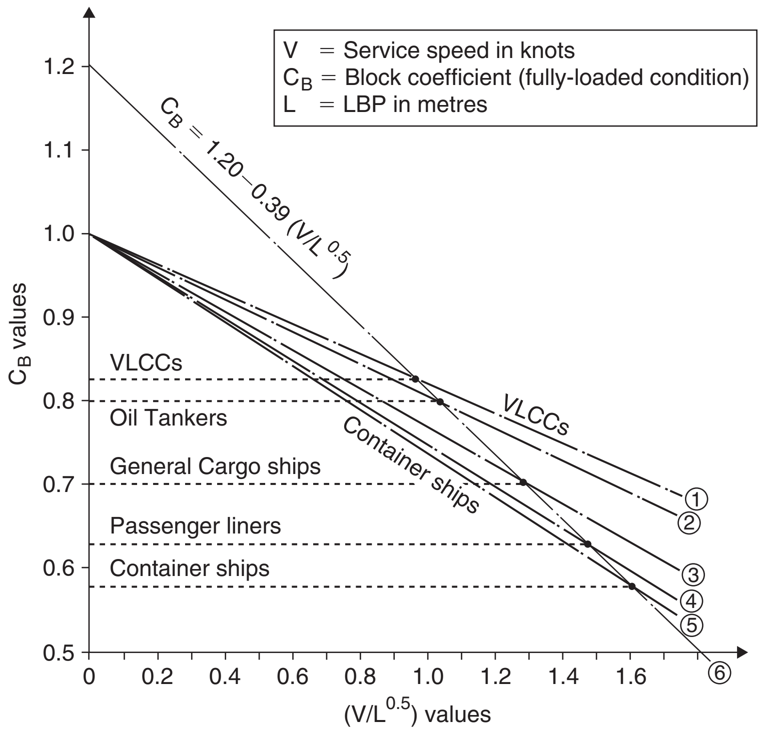
For example, an Oil Tanker will have a service speed of say 15–15.75 kt, but generally not more than 16 kt. A General Cargo ship will have a service speed in the order of 14–16 kt but normally not greater than 16 kt. A Container ship will be typically 20–25 kt service speed, but not less than 16 kt. Further examples are shown in Table 1.2.

Table 1.2 Typical $V/L^{0.5}$ values for several Merchant ships

Ship type	*Typical fully loaded C_B value*	*Typical service speed (kt)*	*LBP circa (m)*	*$V/L^{0.5}$ values*
VLCCs	0.825	15.50	259.61	0.962
Oil Tankers	0.800	15.50	228.23	1.026
General Cargo ships	0.700	14.75	132.38	1.282
Passenger Liners	0.625	22.00	222.77	1.474
Container ships	0.575	22.00	188.36	1.063

Figure 1.1 shows C_B plotted against $V/L^{0.5}$. It shows Alexander's straight line relationships for several ship types, with the global formula suggested by the author in 1992. This global formula can replace the five lines of previously plotted data. The equation for the global formula is:

$$C_B = 1.20 - 0.39\,(V/L^{0.5}) \qquad \text{C.B. Barrass (1992)}$$



CBB and via Alexander's research:

① $C_B = 1 - 0.182\,(V/L^{0.5})$ For VLCCs, 50 000 to 200 000 tonnes dwt

② $C_B = 1 - 0.195\,(V/L^{0.5})$ For Oil Tankers, 25 000 to 50 000 tonnes dwt

③ $C_B = 1 - 0.234\,(V/L^{0.5})$ For General Cargo ships

④ $C_B = 1 - 0.254\,(V/L^{0.5})$ For Passenger liners

⑤ $C_B = 1 - 0.265\,(V/L^{0.5})$ For Container ship

CBB (1992):

⑥ $C_B = 1.20 - 0.39\,(V/L^{0.5})$ Global formula for all ships

Fig. 1.1 Graphs of $C_B \propto V/L^{0.5}$ for several ship types.

Worked example 1.4

A ship has an LBP of 124 m with a service speed of 14.25 kt.

(a) Estimate C_B at her fully loaded draft.

(b) If a new design of similar length but with a speed of 18 kt, what would be her C_B value?

(a) $C_B = 1.20 - 0.39\,(V/L^{0.5})$

$C_B = 1.20 - 0.39\,(14.25/124^{0.5})$

$C_B = 0.700$

(b) $C_B = 1.20 - 0.39\,(18.00/124^{0.5})$

$C_B = 0.570$

The first ship is likely to be a General Cargo ship. It is quite likely that the second ship is a RO-RO vessel.

Generally, it can be assumed that the higher the designed service speed, the smaller will be the corresponding C_B value. As we increase the design service speed, the hull contours will change from being full-form (Oil Tankers) to medium-form (General Cargo ships) to fine-form (Container vessels).

Worked example 1.5

The Main Dimensions for a new vessel are being considered. She is to be 14 000 tonnes dwt with a service speed of 15 kt, to operate on a maximum summer draft of 8.5 m.

Estimate LBP, Breath Mld, C_B and W if from basic ship information, the C_D is to be 0.700 and B is to be (L/10) + 6.85 m.

$$W = dwt/C_D = 14\,000/0.700 \quad \text{So} \quad W = 20\,000 \text{ tonnes}$$

$$W = L \times B \times H \times C_B \times p \quad \text{So} \quad C_B = W/(L \times B \times H \times p)$$

$$C_B = 20\,000/\{L \times (L/10 + 6.85) \times 8.5 \times 1.025\}$$

$$= 2295.6/\{L \times (L/10 + 6.85)\} \qquad (1)$$

$$= 1.20 - 0.39\,(V/L^{0.5}) \quad \text{as per global formula}$$

$$= 1.20 - 0.39\,(15/L^{0.5})$$

$$= 1.20 - 5.85/L^{0.5} \qquad (2)$$

Now equation (1) = equation (2)

Solve graphically by substituting in values for L.

Let L = say 142 m, 148 m and 154 m, then C_B values relation to LBP values are given in Table 1.3.

Table 1.3 C_B values relating to LBP values

Length L (m)	*C_B*	
	Equation (1)	*Equation (2)*
142	0.768	0.709
148	0.716	0.719
154	0.667	0.729

Figure 1.2 shows the two sets of C_B values plotted against the LBPs. When the two graphs intersect it can be seen that C_B was 0.718 and L was 147.8 m.

$$L = 147.8\text{ m}$$

$$\text{Breadth Mld} = (L/10) + 6.85 = 14.78 + 6.85 = 21.63\text{ m}$$

$$H = 8.5\text{ m, as prescribed in question.}$$

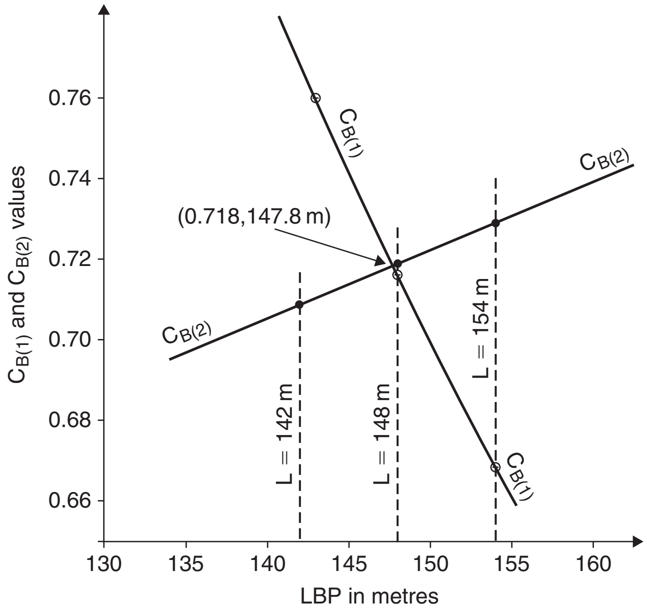


Fig. 1.2 C_B values against LBP values for Worked example 1.4.

$$W = L \times B \times H \times C_B \times p$$
$$= 147.8 \times 21.63 \times 8.5 \times 0.718 \times 1.025$$
$$= 19\,999 \text{ tonnes}$$ say 20 000 tonnes, as previously calculated.

After modifying and slightly refining:

$$L = 148 \text{ m}, \quad B = 21.60 \text{ m}, \quad H = 8.5 \text{ m}, \quad C_B = 0.718, \quad C_D = 0.700,$$
$$W = 20\,000 \text{ tonnes}, \quad \text{lwt} = W - \text{dwt} = 20\,000 - 14\,000 = 6000 \text{ tonnes}.$$

Selection of LBP values for graphs

Collection of data from various sources suggest the approximate values given in Table 1.4. These values were plotted and are shown in Figure 1.3.

Table 1.4 General Cargo ships: approximate LBP against dwt

Approx LBP (m)	*Deadweight (tonnes)*
97.6	4000
112.8	6000
125.0	8000
134.2	10 000
143.5	12 000
151.0	14 000

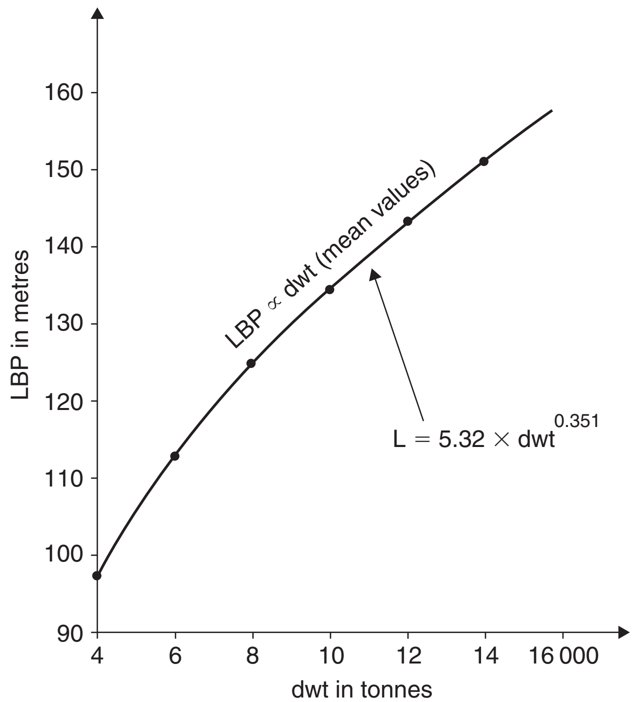


Fig. 1.3 LBP ∝ dwt for General Cargo ships.

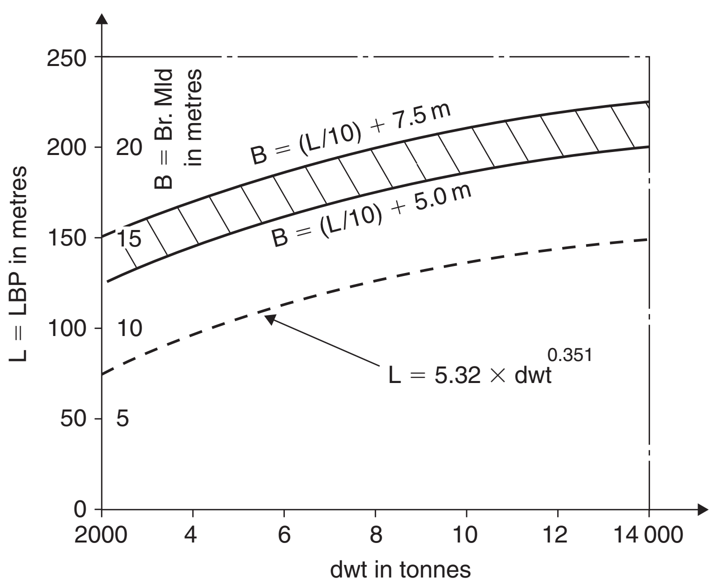


Fig. 1.4 (L and B) ∝ dwt for General Cargo ships.

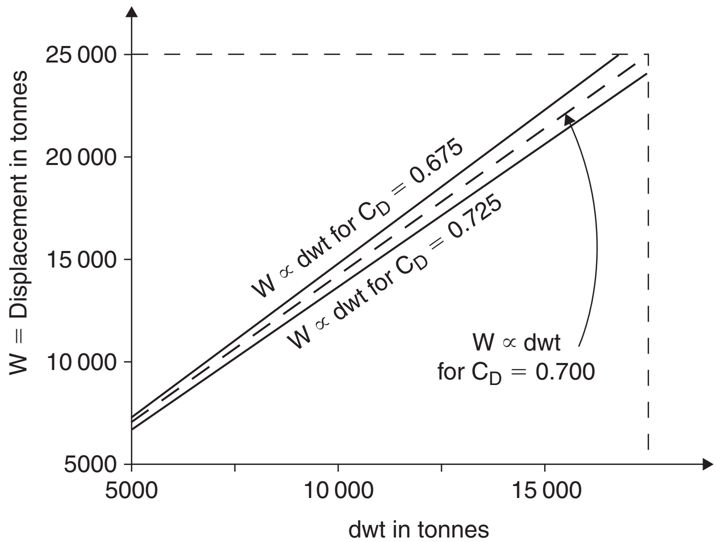


Fig. 1.5 W ∝ dwt for General Cargo ships for a range of C_D values.

As can be seen in Figure 1.3, a mean line through the plotted points gave the equation:

$$L = 5.32 \times \text{dwt}^{0.351}\ \text{m}$$

Figures 1.4 and 1.5 show more relationships to assist the designer in fixing the Main Dimensions for a new General Cargo vessel.

When selecting LBP for equations (1) and (2), for most Merchant ships at SLWL, we will soon know if practical values have been inserted.

If $C_B > 1.000$ this is impossible!!
If $C_B < 0.500$ this is improbable!!

Worked example 1.6

Estimates for a 500 000 tonnes are being considered. Service speed is to be 16 kt operating on a maximum draft of 25.5 m with a C_D of 0.861.

Calculate the LBP, Breadth Mld, C_B, W and lwt if it is assumed that:

$$B = 0.24L - 28\,\text{m} \quad \text{and} \quad C_B = 1.066 - V/(4 \times L^{0.5})$$

$$C_D = \text{dwt}/W \quad \text{So} \quad W = \text{dwt}/C_D$$

Thus $W = 500\,000/0.861 = 580\,720$ tonnes

$$\text{lwt} = W - \text{dwt} = 580\,720 - 500\,000 = 80\,720\ \text{tonnes}$$

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

$$C_B = W/(L \times B \times H \times p)$$

So $C_B = 580\,720/\{L \times (0.24L - 28) \times 25.5 \times 1.025\}$

$$C_B = 22\,218/\{L(0.24L - 28)\} \quad (1)$$

$$C_B = 1.066 - V/(4 \times L^{0.5})$$

$$C_B = 1.066 - 4/L^{0.5} \quad (2)$$

Now equation (1) = equation (2)

Substitute values for L of 380, 390 and 400 m. Draw graphs (as before) of L against C_B values. At the point of intersection,

$$L = 391\,\text{m} \quad \text{and} \quad C_B = 0.863$$

$$B = 0.24L - 28 = (0.24 \times 391) - 28 = 65.84\,\text{m}$$

$$H = 25.5\,\text{m, as prescribed}$$

$$W = 391 \times 65.84 \times 25.5 \times 0.863 \times 1.025 = 580\,686 \text{ tonnes,}$$

which is very close to the previous estimate of 580 720 tonnes.

Depth Mld (D) for the new design

Again guidance can be given by careful selection of a basic ship or basic ships. The following approximations can be considered:

For Oil Tankers	H/D = 80% approximately
For General Cargo ships	H/D = 75% approximately
For liquified natural gas (LNG) and liquified petroleum gas (LPG) ships	H/D = 50% approximately

After obtaining draft H, simply transpose to obtain value of D. Freeboard (f) is the difference between these two values.

Freeboard (f) on Oil Tankers

It can be seen from the given H/D percentages that the summer freeboard for the General Cargo ships will be approximately 25%. For the Oil Tankers it is more likely to be nearer 20%.

Freeboard on Oil Tankers have *less freeboard* than General Cargo ships of similar length for several reasons, six of them being:

1. Smaller deck openings in the Upper Deck.
2. Greater sub-division by transverse and longitudinal bulkheads.
3. Density of cargo oil is less than grain cargo.
4. Much larger and better pumping arrangements on tankers to control any ingress of bilge water.
5. Permeability for an oil-filled tank is only about 5% compared to permeability of a grain cargo hold of 60–65%. Hence ingress of water in a bilged compartment will be much less.
6. Larger Transverse Metacentric Height (GM_T) values for an Oil Tanker, especially for modern wide shallow draft tanker designs.

Optimisation of the Main Dimensions and C_B

Early in the design stages, the Naval Architect may have to slightly increase the displacement. To achieve this, the question then arises, 'which parameter to increase, LBP, Breadth Mld, depth, draft or C_B?'

Increase of L

This is the most expensive way to increase the displacement. It increases the first cost mainly because of longitudinal strength considerations. However, and this has been proven with 'ship surgery', there will be a reduction in the power required within the engine room. An option to this would be that for a similar input of power, there would be an acceptable increase in speed.

Increase in B

Increases cost, but less proportionately than L. Facilitates an increase in depth by improving the transverse stability, i.e. the GM_T value. Increases power and cost within the machinery spaces.

Increases in Depth Mld and Draft Mld

These are the cheapest dimensions to increase. Strengthens ship to resist hogging and sagging motions. Reduces power required in the Engine Room.

Increase in C_B

This is the cheapest way to simultaneously increase the displacement and the deadweight. Increases the power required in the machinery spaces, especially for ships with high service speeds. Obviously, the fuller the hull-form the greater will be the running costs.

The Naval Architect must design the Main Dimensions for a new ship to correspond with the specified dwt. Mistakes have occurred. In most ship contracts there is a severe financial penalty clause for any deficiency in the final dwt value.

Questions

1 For a 'STAT 55' proposal it is known that: L/B is 6.23, B/H is 2.625, C_B is 0.805, C_D is 0.812, dwt is 55 000 tonnes. Calculate the LBP, Breadth Mld, W and lwt for this proposed design.

2 Define and list the components for: (a) lightweight, (b) deadweight, (c) load displacement, (d) block coefficient C_B, (e) deadweight coefficient C_D.

3 From a database, information for a new ship is as follows: C_D is 0.701, $B = (L/10) + 6.72$, dwt is 13 750 tonnes, service speed is 14.5 kt, Draft Mld is to be a maximum of 8.25 m. Estimate the LBP, Breadth Mld, C_B, and fully loaded displacement.

4 A 110 000 tonnes dwt tanker is 258 m LBP, 43 m Breadth Mld and 14.20 m Draft Mld. A new similar design of 120 000 tonnes is being considered. Using the geosim method, estimate the LBP, Breadth Mld and Draft Mld for the larger ship.

5 Three new standard General Cargo vessels are being considered. They are to have deadweights of 4500, 8500 and 12 500 tonnes respectively. Estimate (as a first approximation), the LBP for each of these ships.

6 A container ship is to have a service speed of 21.5 kt and an LBP of 180 m. Using two methods, estimate her C_B value at her Draft Mld.