UNIT 4

~~2.4.2 Effect on the Ship's Structure~~

In consistency with the effort to minimize the frictional resistance for relatively slow ships with the distribution of displacement over a relatively short length, large beam, and draft (hence also of side depth), it is concluded that low slenderness coefficients combined with high block coefficients, lead to relatively simple and economical structures. The increased distribution of displacement in the transverse direction may be limited in extreme situations by transverse strength problems that require special transversal strengthening.

~~2.4.3 Approximate Values~~

Approximate values of the slenderness coefficient for common ship types are given in Tables 2.6 and 2.7 (and in Appendix A).

In the preliminary design phase and especially for deadweight carriers (see Sect. 1.4.2), it is appropriate to preliminarily estimate the length through the slenderness coefficient of similar ships. The resulting length can be examined by well-established empirical or semiempirical formulas (see Sect. 2.3).

2.5 Selection of Other Main Dimensions

After the preliminary estimation of the ship's length (see Sect. 2.3) and of the block coefficient C_B (see more details in Sect. 2.10), as well as of the displacement (see Sect. 2.1) (in the case of deadweight carriers), we commonly proceed with the selection of the beam B and draft T, which are directly related to each other, namely through

$$B \cdot T = \nabla / (L \cdot C_B). \tag{2.49}$$

The basic factor that influences the selection of B and T is at first possible topological limits of the route, that is restrictions on the beam in terms of the passage of canals and channels, for example for Panamax ships (passing through the Panama Canal, $B_{max} = 32.31$ m/106 ft). Also, there may be limitations for the ship's operational draft due to the ship's approach to river estuaries, transiting through canals or channels, calling at certain ports of limited depth (for example for Panamax ships, $T_{max} = 12.09$ m or 39 ft, 6 in) .

The *minimum* values for the beam are determined by the requirements for adequate stability, while for the draft the main requirement arises from the need of fitting a propeller of as large as possible diameter (for achieving higher efficiency). This applies particularly to ships of increased towing power (like tugboats and fishing vessels).

Table 2.6 Hull form coefficients and ratios of main dimensions for merchant ships (synthesis of original data by Strohbusch, 1971, updated by Papanikolaou by use of IHS Fairplay World Shipping Encyclopedia, v. 12.01, 2011). Given upper and lower boundaries correspond to the standard deviation from the regression relationship of sample ships, as shown in Appendix A.

Ship type	Hull form coefficients				Ratios of main dimensions		
	C_P	C_M	C_B	C_{WP}	L/B	B/T	$L_{PP}/\nabla^{1/3}$
Fast seagoing cargo ships	0.57–0.65	0.97–0.98	0.56–0.64	0.68–0.74	5.7–7.8	2.2–2.6	5.6–5.9
Slow seagoing cargo ships	0.66–0.74	0.97–0.995	0.65–0.73	0.80–0.86	4.8–8.5	2.1–2.3	5.2–5.4
Coastal cargo ships	0.69–0.73	-0.985	0.58–0.72	0.78–0.83	4.5–5.5	2.5–2.7	4.2–4.8
Small short sea passenger ships	0.61–0.63	0.82–0.85	0.51–0.53	0.65–0.70	5.8–6.5	3.3–3.9	6.3–6.6
Ferries	0.53–0.62	0.91–0.98	0.50–0.60	0.69–0.81	5.9–6.2[a] 5.2–5.4[b]	3.7–4.0	6.2–6.9[a] 5.7–5.9[b]
Fishing vessels	0.61–0.63	0.87–0.90	0.53–0.56	0.76–0.79	5.1–6.1	2.3–2.6	5.0–5.4
Tugboats	0.61–0.68	0.75–0.85	0.50–0.58	0.79–0.84	3.8–4.5	2.4–2.6	4.0–4.6
Bulk carriers	0.79–0.84	0.990–0.997	0.72–0.86	0.88–0.92	5.0–7.1[a]	2.1–3.2	4.7–5.6
Tankers $F_n=0.15$	0.835–0.855	0.992–0.996	0.82–0.88	0.88–0.94	5.1–6.8	2.4–3.2	4.5–5.6
Tankers $F_n=0.16$–0.18	0.79–0.83	0.992–0.996	0.78–0.86	0.88–0.92	5.0–6.5	2.2–2.9	4.5–5.2
Fast seagoing reefers	(0.55)[c] 0.59–0.62	0.96–0.985	(0.53)[c] 0.57–0.59	0.68–0.72	6.7–7.2	2.8–3.0	6.1–6.5

[a] For $L > 100$ m
[b] For $L = 80$–95 m
[c] Rarely: C_P, $C_B < 0.57$

Regarding the influence of *B/T* ratio on resistance, the frictional resistance, which is directly related to the wetted surface of the hull, is minimized for a *B/T* value around 2.5 and approximately the same applies to the residuary resistance, if there are no other restrictions or requirements on the absolute *B* and *T* values.

Thus the *B/T* ratio is usually selected close to 2.5 and possible exceedances are usually due to restrictions relating to limitations of the draft (always occurring for large tankers and bulk carriers) or due to particular, enhanced requirements on stability (for example for ROPAX ships). Note that significantly smaller values than 2.5 are rare.

The beam can be determined based on the *L/B* ratio of similar ships (see Table 2.6) and following this the draft *T* can be approximated through the chosen

Table 2.7 Hull form coefficients and ratios of main dimensions for merchant ships (synthesis of original data by Strohbusch, 1971, updated by use of IHS Fairplay World Shipping Encyclopedia, v. 12.01, 2011). Given upper and lower boundaries correspond to the standard deviation from the regres-sion line of sample ships, as shown in Appendix A

Ship type	Ratio of main dimensions		
	L_{PP}/D	F_{FP}-$\%L_{PP}$	L_P-$\%L_{PP}$
Fast seagoing cargo ships	9.9–13.5	5.1–6.3	20–25
Slow seagoing cargo ships		5.8–7.0	30–35
Coastal cargo ships	10.0–12.0	up to 7.0	40–50
Small short sea passenger ships	10.4–11.6	6.6–7.9	20–25
Ferries	8.6–10.3	7.0–10.0	25–35
Fishing vessels	8.2–9.0	8.0–8.5	15–25
Tugboats	7.7–10.0	8.2–10.2	20–30
Bulk carriers	10.5–12.8	4.4–4.9	50–60
Tankers $F_n=0.15$	12.0–14.0	3.6–4.5	50–60
Tankers $F_n=0.16$–0.18	10.5–12.8	4.4–4.9	50–60
Fast seagoing reefers	−11.0	5.6–6.6	10–15

B/T ratio. The influence of *L/B* on the ship's resistance is not straightforward, like that of the slenderness coefficient $L/\nabla^{1/3}$, though one would generally expect that a lower *L/B* ratio affects negatively ship's wave resistance. However, for a given draft *T*, length *L* and displacement, an *increase* of beam *B*, or *reduction* of the ratio *L/B*, means *reduction* of the block coefficient $C_B$and consequently *possible reduction* of the total resistance (see example, see Sect. 2.6.2).

The above considerations apply mainly to "normal" general dry cargo ships or liquid cargo ships without special requirements in terms of the transported cargo type or stability. However, for cargo ships transporting standardized/unitized cargos of fixed size (*linear dimension ships*) , for example containerships, Ro-Ro, etc., the beam generally changes stepwise, depending on the number of transversely stowed standardized (unitized) cargo, for example for *containerships of about Panamax size*:

$$B \cong 3n + 2.2\text{m} \tag{2.50}$$

where *n* is the number of transversely stackable standardized containers under deck (TEU containers; standard cross-section in feet: $8' \times 8'$ and up to $8.0' \times 8.5'$).

The beam's influence on stability, especially on the initial stability (metacentric height $\overline{GM}$) is drastic, given that a small increase of beam leads to significant increase of $\overline{BM}$ (see Sect. 2.6).

Regarding the selection of draft, the factors that have significant influence are briefly listed as follows:

- Large draft contributes to the selection of propellers of higher efficiency due to the possible fitting of a large diameter propeller (low thrust/load coefficient) and low number of propeller revolutions (rpm); it allows, also the fitting of larger rudders for improved maneuverability.

- Large draft requires strengthening of the ship's structural elements in the bottom area and lower hull shell.
- The resulting *freeboard* of the ship, defined as the difference between the selected draft and the upper side of the bulkhead deck (side depth D), must be in any case *greater* than the resultant *minimum* freeboard value derived from application of the International Load Line Convention regulations.

As to stability, the influence of an *increase* of draft is complicated and is certainly associated with possible changes of other dimensions, that is, of the ship's length and in particular the ship's beam:

- If other ship sizes (such as L, B, and water plane area) are assumed fixed, but the displacement increases (*due to the draft increase*), then the metacentric radius $\overline{BM}$ will decrease. The same will happen even more drastically, if for a given displacement and length, the beam of the ship decreases in parallel to the increase of the draft (in order to keep the block coefficient unchanged).
- If the side depth remains fixed and the freeboard is at acceptable level, the maximum value and the range of the righting arm *will decrease* due to premature immersion of the deck edge into water. For certain hulls, where the immersion of the deck follows the emergence of the bottom, just the opposite may happen.
- An increase of the distance of the center of buoyancy from the base leads to increased $\overline{KB}$; thus, a possible reduction of $\overline{BM}$ may be partially balanced by the increase of $\overline{KB}$ resulting in an increase or decrease of $\overline{KM}$ depending on the hull form.

A large draft may be excluded due to topological limiting requirements of routes.

A useful formula for the selection of B and T through the ratio (L/B) is concluded from an algebraic processing of the definition of C_B:

$$\nabla = L \cdot B \cdot T \cdot C_B = L^3 \cdot C_B / [(L/B)^2 \cdot B/T] \Rightarrow B/T = \frac{L^3 C_B}{(L/B)^2 \nabla} \tag{2.51}$$

which in combination with the equation

$$B \cdot T = \frac{\nabla}{L \cdot C_B} \tag{2.52}$$

leads to the values for B and T (two equations for two unknowns).

The effect of changing B and T by δB and δT, respectively on the stability can simply be examined on the basis of the resulting changes of the metacentric radius $\overline{BM}$ (see Sect. 2.6) :

$$\frac{\delta \overline{\mathrm{BM}}}{\overline{\mathrm{BM}}} = 3\frac{\delta B}{B} - \frac{\delta T}{T} \tag{2.53}$$

For fixed ∇ and T, the approximation formula may be simplified:

$$\frac{\delta\overline{\mathrm{BM}}}{\overline{\mathrm{BM}}} = 3\frac{\delta B}{B} \tag{2.54}$$

and assuming $\overline{KG}$ unchanged ($\delta\overline{KG} = 0$) the following important formula is derived:

$$\delta(\overline{GM}) = \delta(\overline{BM}) = \overline{BM}\cdot 3\frac{\delta B}{B} \tag{2.55}$$

Therefore, an *increase of beam* by 10 % leads approximately to an *increase of* $\overline{GM}$ by 30 %.

Finally, for the selection of the side depth D the key point is to achieve the required hold volume of the ship and to satisfy the Load Line regulations, namely, to reach the required minimum freeboard. Other influential factors are as follows:

- An increase of the side depth D involves an increase of the ship's gravity center $\overline{KG}$ and consequently a reduction of $\overline{GM}$ (negative influence on the *initial* stability). However, as to the *large angle stability*, we have an increase of the *range of the righting lever* due to the delayed immersion of the side deck and of the superstructures in water.
- An increase of D involves an increase in the modulus of the midship section. Therefore, for fixed L, due to the reduction of the occurring bending stresses on the ship's extremes (deck and bottom), there is a possibility to reduce the thickness of the plating and hence of the weight of the steel structure (see Sect. 2.7).

The L/D ratio can be selected from similar ships or in accordance with typical values of Table 2.7.

2.6 Selection of Beam

As has been pointed out earlier, the proper procedure of selecting the ship's main dimensions and of other fundamental ship values is to proceed, after the determination of the length, with the selection of the block coefficient C_B and thereafter of the beam, together with the draft. The selection of the C_B coefficient will be elaborated later in Sect. 2.10.

Assuming that the length L and the block coefficient C_B are known (predetermined), as we may assume this also for the ship's displacement Δ in first approximation (and for the corresponding displaced volume ∇), then the following relationship holds for the product $B{\cdot}T$:

$$B{\cdot}T = \frac{\nabla}{L{\cdot}C_B}$$

that is the selection of beam B can be accomplished on the basis of the product $B \cdot T$. Thereby changes of the beam require inversely proportional changes in the draft and indirectly of the side depth D (due to the minimum freeboard requirements).

Alternatively, the beam selection can be done through the L/B ratio, either by using data of similar ships (see Table 2.7), as explained previously, or by using some relationships, which are presented below and are deduced from the analysis of data of ships built in the 1990s. These relationships provide the L/B ratio as a function of length L (m) (Friis et al. 2002).

For cargo ships with $50 \leq L \leq 200$ m:

$$L / B = 4 + 0.015 \cdot (L + 17) \tag{2.56}$$

For reefer ships with $60 \leq L \leq 180$ m:

$$L / B = 4 + 0.014 \cdot (L + 11) \tag{2.57}$$

For containerships with $100 \leq L \leq 200$ m:

$$L / B = 4 + 0.009 \cdot (L + 42) \tag{2.58}$$

For containerships with $L > 200$ m:

$$6.5 \leq L \leq 7.1$$

For bulk cargo carriers with $L \geq 120$ m:

$$L / B = 6$$

For tankers:

$$L / B = 5.5$$

For LPG and LNG ships with $L \geq 100$ m:

$$L / B = 5.7 + 0.002 \cdot (L - 100) \tag{2.59}$$

For Ro–Ro cargo ships with $L \geq 80$ m:

$$L / B = 5.5 + 0.0036 \cdot (L - 41) \tag{2.60}$$

For ROPAX ships with $L \geq 80$ m:

$$L / B = 5.5 + 0.0033 \cdot (L - 141) \tag{2.61}$$

Similar set of data and relationships for various types of ships are also listed in Appendix A.

ing the turning ability within a small diameter circle, in contrast to the course stability, which becomes generally worse.

2.7 Selection of the Side Depth

The side depth D of the ship's main deck is crucial for two fundamental ship properties:

- The available holds' volume
- The achieved freeboard

It is obvious that the selection of the side depth is inherently linked to the permissible draft. Indirectly it is related to the ship's length, in consideration of the ship's longitudinal strength, and beam, in terms of the stability of the ship.

It is considered that the side depth is the "*cheapest*" and *less problematic* main dimension of a ship. In particular, increase of side depth by 10 % causes an increase of the steel weight by 8 % for $L/D = 10$ or by 4 % for $L/D = 14$ (Schneekluth 1985), that is, the achievable volume increases more rapidly than the resultant increase of the ship's structural weight; consequently it is appropriate to prefer an increase of the ship's side depth rather than changes of other main dimensions, in case the ship's hold volume is inadequate.

2.7.1 Effect of Safety Regulations on Side Depth

The selection of side depth is significantly influenced by the following regulations regarding safety and operation:

1. The International Load Line Convention (ICLL 1988) that determines the freeboard deck and the permissible freeboard, namely the allowable difference between side depth and draft.
2. Regulations regarding the watertight subdivision of ships (International Convention for the Safety Of Life at Sea—SOLAS), which determine the subdivision (or bulkhead) deck of the ship. This regulation mainly affects the selection of the side depth of passenger ships, but also of some types of cargo ships, such as tankers longer than 150 m (ship of type A according to the Load Line Convention) and other dry cargo ships (type B ships) with reductions of the required freeboard (B-60 and B-100 bulk carriers). Certainly, when deciding on the watertight subdivision of a ship based on the floodable lengths curve, a relatively high position of the bulkhead deck and fewer bulkheads should be preferred, rather than vice versa.
3. Regulations of tonnage measurement (National and International Regulations—tonnage mark) affect the position of the main deck less than in former times, due to the more rational method of determining the ship's enclosed–exploitable spaces regardless of the existence of "tonnage openings" (see older types of cargo ships with a "shelter" deck, Antoniou and Perras 1984).

4. Regulations of classification societies specify an upper limit for the *L/D* ratio, which usually ranges between 14 and 16. If the upper limit of *L/D* = 14–16 (depending on the classification society) is not observed, then a dedicated examination of longitudinal strength and approval by the classification society is required. Particularly for certain small coastal ships or barge and bulk carriers operating in sheltered areas (e.g., Great Lakes ships), *L/D* ratios up to 20 have been approved in the past by some classification societies (e.g., ABS).

2.7.2 Effect of Side Depth on Hold Volume and Arrangement

As stated before, an increase of the side depth involves an increase of the available hold volume or of the *capacity factor* (Räumte), which expresses the ratio of the available grain hold volume to the ship's deadweight. Thereby, while an increase of the ship's length involves in general the synchronous increase of the ship's displacement, the increase of the ship's side depth results in an expansion of the available volume vertically and has no significant direct influence on the ship's displacement, besides causing a small increase of the ship's steel weight, if all the other dimensions remain constant. The height of the ship's main hull is very important for cargo ships, which, depending on the type of carried cargo, may be horizontally subdivided by intermediate decks at different levels.

Typically we refer to Ro/Ro cargo ships, ferries, reefer ships, as well as to conventional general cargo ships, which, for easy stowage and unloading reasons, dispose intermediate decks through which the ship is subdivided in the vertical direction. Obviously, the number and the exploitable height of the intermediate decks are determined by the cargo type and stowage method. Thus, while for general cargo ships there is some flexibility as to the available height of decks, this is not the case for Ro/Ro ships, car/train ferries, and reefer ships, where the height is determined by the cargo's standard dimensions and stowage/loading–unloading method.

Finally, for bulky cargo units, with standard dimensions, there are specific requirements as to the height of the side depth. Typically, the side depth of ships carrying standard containers is determined by the number of vertically stackable containers (height of 8′ to 8.5′ per unit). Here, the height of the coamings of the hatchways as well as the height of double bottom are taken into account. With the same criterion in mind, modern multipurpose/semi-container ships dispose similar side deck heights, so as to enable them to transport an integer number of containers in the area of the openings of their hatchways.

2.7.3 Effect of Side Depth on the Ship's Stability

The influence of the side depth on the ship's stability is complex and should be examined separately for the initial stability and stability at large angles.

2.8 Selection of the Draft

As mentioned earlier, during the selection of the beam, following the estimation of the displacement, length and block coefficient, the product $B \cdot T$ is considered known. Thus, the selection of the beam (see Sect. 2.6) involves indirectly the selection of draft, namely through the selection of typical values of the B/T ratio (see Table 2.6, Sect. 2.3), assuming that the product $B \cdot T$ is not known from other sources. Also, following the selection of side depth, the maximum permissible draft is determined by the required freeboard, which is calculated based on the length L, the side depth D, C_B and various other ship particulars. The main factors affecting the selection of draft are analyzed in the following.

2.8.1 Effect of Draft on Resistance and Propulsion

The draft of the ship appreciably affects the components of the total resistance, that is the frictional and wave resistance, of both slow and fast ships.

As indicated in Sect. 2.6.2 regarding the reduction of frictional resistance, which dominates the total resistance for relatively slow ships of small Froude number, it is required to achieve a minimum wetted surface area, which can be shown to be associated with values $B/T = 2.0–2.5$, depending on the C_B and the form of sections at the ship's both ends.

In addition, in order to minimize the wave resistance, we aim at shifting displacement away from the water plane downwards, which results in slender hulls.

It has been verified by experiments that a ratio B/T around 2.5 serves best not only frictional resistance but also wave resistance aspects.

From the propulsion point of view, one as large as possible draft is always sought aiming at the fitting of a large diameter propeller, with good efficiency in view of the resulting moderate loading on the propeller blades and the low turning of the propeller (low RPM). This general rule applies to all types of ships and especially to towing ships (tug boats and fishing vessels). It should be, however, taken into account that for not fully loaded or bow trim conditions, a large diameter propeller tends to emerge more frequently than a smaller one. Finally, on certain types of ships it is not possible to install a large diameter propeller because of the required high RPM of propeller and engine (small boats), or in case of multipropeller ships. Generally, for twin-propeller ships the ratio B/T is higher than the corresponding one for single-propeller ships (>2.6 vs. 2.1–2.5).

2.8.2 Effect of Draft on Stability

The influence of draft on the stability is not as obvious as that of the beam and side depth. From the relationship:

$$\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG},$$

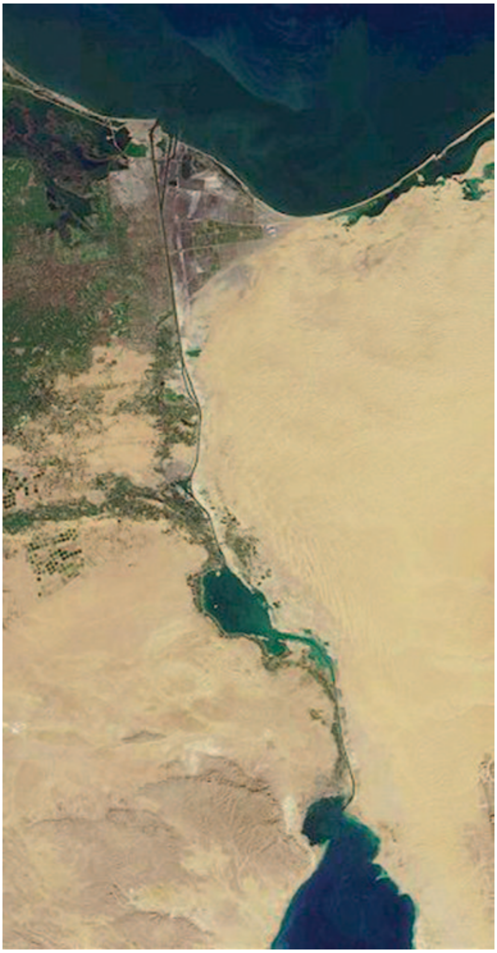

Fig. 2.39 Satellite photograph of the Suez Canal

2.9 Selection of Hull Form Coefficients

With the determination of the ship's block coefficient C_B, which generally expresses the fullness of the wetted part of the ship's volume compared to the volume of a rectangular parallelepiped of the same main dimensions L, B and T, the other hull form coefficients, such as the midship section coefficient C_M, the prismatic coefficient C_P, and finally the water plane coefficient C_{WP}, have been essentially also determined.

The coefficients affecting the selection of C_B also influence the selection of C_P, since both coefficients do not differ significantly, for common values of the midship section coefficient C_M varying between 0.94 and 0.99 for cargo and passenger ships (see Table 2.6); we may recall the well-known relationship

$$C_P = C_B / C_M$$

However, in a sense, the selection of C_P,

$$C_P = \nabla / (L \cdot A_M) \tag{2.79}$$

where A_M is the midship section area, should precede that of C_B, because C_P expresses more properly the fullness of the hull of the ship under study compared to that of a prismatic hull, of basis area A_M and height L. Particularly, small C_P means a concentration of displacement amidships and slender ends, whereas a large C_P corresponds to a relatively small midship section area, an even distribution of the displacement longitudinally and an extended parallel body amidships.

The midship section coefficient *C*M

$$C_M = A_M / (B \cdot T) \tag{2.80}$$

expresses the fullness of the midship section area in relation to the area of the circumscribed rectangle of the same B and T. Besides certain relatively small vessels with special requirements on stability and propulsion, namely need for sufficient draft for the installation of a propeller of as large as possible diameter, all other ships have very high C_M values (see Table 2.6). Small vessels that are exceptions from the above rule are fishing boats, tugboats, pilot boats, etc., with relatively small C_M (up to 0.70). For those vessels the difference between C_B and C_P is significant and attention should be paid during the preliminary design stage, when interpreting corresponding values.

Following empirical data of vessels *without* bottom deadrise, as it is common for large cargo ships, the following formulas, which correlate C_M with C_B, are recommended for use (Table 2.14):

For ships with a small L/B and bottom deadrise (such as fishing boats, tugs) the use of data from similar ships is recommended.

Finally as to the selection of the waterplane area coefficient C_{WP}, which influences the stability and wave-making resistance of the ship, both the fullness of the hull, namely C_B (or C_P) coefficient, and the form/character of the sections, also the bow type, should be taken into account. Generally the C_{WP} coefficient varies according to the variation of C_B (C_P).

The following formulas are concluded from empirical data:

a. **U-type sections**

$$C_{WP} = 0.778 C_B + 0.248 \tag{2.81}$$

$$C_{WP} = 0.95 C_P + 0.17(1 - C_P)^{1/3} \text{(Schneekluth)} \tag{2.82}$$

Table 2.14 Empirical data of vessels without bottom deadrise

V. Lammeren	$C_M = 0.9 + 0.1\ C_B$
H. Kerlen	$C_M = 1.006 - 0.0056\ C_B^{-3.56}$
HSVA Tank (Hamburg)	$C_M = 1/(1 + (1 - C_B)^{3.5})$

b. **Normal sections**

$$C_{WP} = (1 + 2C_B)/3 \tag{2.83}$$

c. **V-type sections**

$$C_{WP} = 0.743C_B + 0.297 \tag{2.84}$$

$$C_{WP} = (1 + 2C_B/\sqrt{C_M})/3 \text{ (Schneekluth)} \tag{2.85}$$

The above formulas are valid for cruiser stern ships, or ships with transom stern of limited extent. Newer constructions, with intense transom lines at waterline, have usually higher C_{WP} values, as can be seen from comparisons with similar ships. Typical values of the C_{WP} coefficient are presented in Table 2.6, Sect. 2.3.

2.10 Selection of Block Coefficient C_B and Prismatic Coefficient C_P

The *block coefficient* C_B (see Papanikolaou 2009a, Vol. 2 for all definitions) represents the ratio of the ship's displaced volume to the volume of the circumscribed rectangular parallelepiped with dimensions L (usually L_{PP}), B, and T. It can easily be shown that the C_B is the product of the *prismatic coefficient* C_P and *midship section* coefficient C_M (Fig. 2.40), i.e.,

$$C_B = C_P \cdot C_M, \text{where } C_B = \frac{\nabla}{LBT} \text{ and } C_P = \frac{\nabla}{A_M L}$$

Thus, if the midship section coefficient C_M does not change significantly, as typically happens to large and mainly bulky vessels, the C_P and C_B coefficients can be considered to be equivalent in terms of their meaning with respect to the slenderness of the hull form, exhibiting comparable values.

The prismatic coefficient C_P represents the ratio of the displaced volume to the volume of a prism with the basic area A_M (midship section area) and the height (=length) L (see also the following sketch; Fig. 2.41).

C_P describes the degree of concentration of the ship's displacement with respect to the midship section; however, the lengthwise distribution of the displacement cannot be concluded uniquely based on the value of C_P only. Nevertheless, small C_P generally indicates a ship with a relatively large area A_M and concentrated displacement around the midship section (thus slender ends), whereas large C_P means evenly distributed displacement along the ship length and long parallel body around the middle of the ship with short and bulky ends.

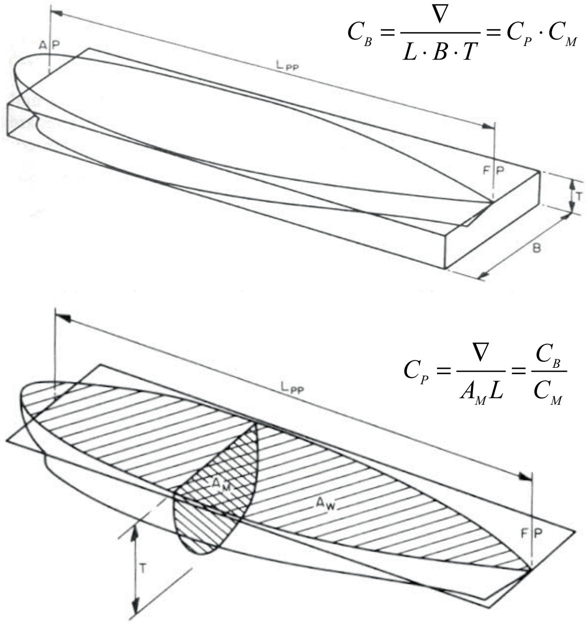

Fig. 2.40 Hull form coefficients C_B and C_P

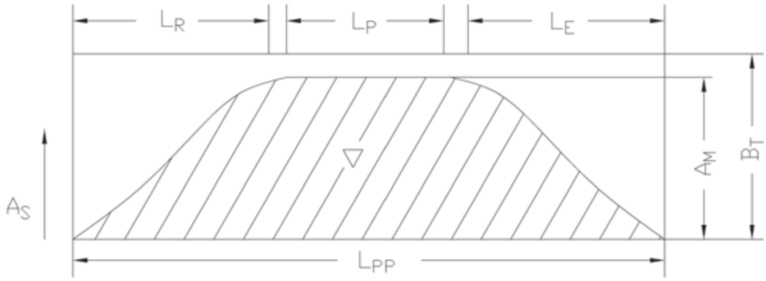

Fig. 2.41 Definition of sectional area curve

Particular attention is required when evaluating the true meaning of the information that the values of the coefficients C_B and C_P contain, especially when dealing with small vessels such as fishing boats, tugs, and speedboats. Here, the significant effect of the relatively small C_M must be assessed in parallel (see Fig. 2.42).

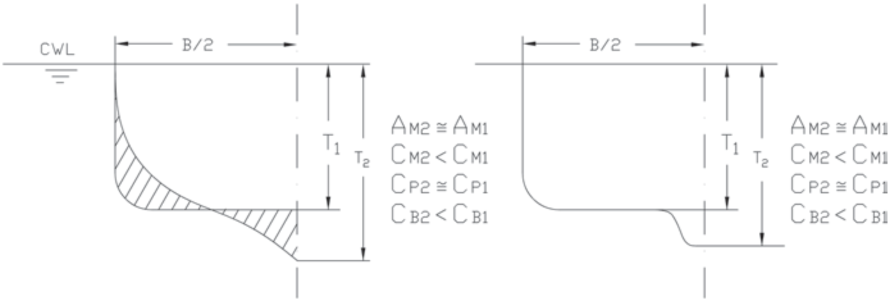

Fig. 2.42 Representativeness of block- and prismatic coefficients with respect to ship's hull form

Thus, in the above cases, while for the two hulls with $T_1 < T_2$ the prismatic coefficient remains, in both cases, almost unchanged (and the displacement also does not change), the block coefficients C_B differ significantly ($C_{B1} > C_{B2}$).

In conclusion, the prismatic coefficient describes more effectively the form of the hull and any review of the ship's hull geometry must take into account, in addition to $C_{B,}$ also the values of the coefficients C_P and C_M.

The slenderness ratio $L/\nabla^{1/3}$ complements the quantitative description of the wetted hull of the ship. The following examples demonstrate the importance of the coefficient C_P and ratio $L/\nabla^{1/3}$ in the assessment of the hull geometry of various types of ships:

a. Ocean liner—fast passenger ship: $L_{PP}/\nabla^{1/3} = 7.2$, $C_P = 0.57$
b. Fishing vessel—tugboat: $L_{PP}/\nabla^{1/3} = 5.2$, $C_P = 0.62$
c. River boat—cargo ship: $L_{PP}/\nabla^{1/3} = 6.8$, $C_P = 0.85$

From the above examples it is concluded that, only high values of slenderness ratios, accompanied by small C_P, lead to slender hulls.

2.10.1 *Effect of C_P and C_B on the Ship's Resistance*

The influence of C_P and C_B coefficients on the ship's resistance is significant. However, the factors affecting the selection of C_P (and C_B) differ depending on the corresponding operational Froude number.

For relatively slow ships (low Froude number), we try to minimize the wetted surface, as the objective is herein to keep the frictional resistance as low as possible, as in the total resistance breakdown this resistance component prevails significantly over the wave-making resistance. Thus, relatively high coefficients C_P (and C_B) and large midship sectional areas are concluded for tankers and bulkcarriers (C_P and C_B up to 0.88, C_M up to 0.99).

For relatively fast ships (high Froude number) it is necessary to reduce the more significant wave resistance as much as possible. The objective herein, is to control/tune the superposition of the various ship generated wave systems, especially those created at the ends (bow and stern) and the shoulders of the ship. The concentration of displacement in the middle of the ship generally leads to a smoothing of the about the centerline (I_T, thus also *BM*) can be positively influenced by small C_P coefficients, which are combined with relatively large draft and beam as well as V-type sections.

Summary—Conclusions

Likewise in the selection of length, the basic factor affecting the determination of the C_B (and C_P) coefficient is the low resistance (and powering) of the ship, for the required speed, and in combination with the pre-estimated length, for the given Froude number. Generally: *high Froude number requires a low C_B (and C_P) coefficient for a hydrodynamically optimal ship.*

Other factors affecting the selection of C_B are: the weight and the cost of steel structure, the exploitation of cargo spaces, and the seakeeping behavior of the ship in waves (the motions and accelerations at various points of the ship, as well as the added resistance due to her motions in waves). In practice, like with the selection of the ship's length, C_B is selected differently from the optimal one with respect to least resistance, namely, usually larger values than those corresponding to hydrodynamically optimal solutions are preferred.

2.10.6 Approximate/Semiempirical Formulas

Common ways of estimating the value of C_B are:

A. Using semiempirical mathematical formulas from statistical data of built ships (considering both hydrodynamic and economic criteria).
B. Using semiempirical mathematical formulas from statistical analysis of ships of "minimum building cost for given deadweight (DWT) and speed."
C. Using diagrams based on mathematical formulas according to A or from statistical data of similar ships.

Notes

A. The employed semiempirical formulas have the following general form (in metric system):

$$C_B = K_1 - K_2 F_n - K_3 F_n^2 \tag{2.86}$$

where the coefficients K_1, K_2, K_3 are listed in Table 2.15 below (they may refer to the ship's *trial* speed V_T or *service* speed $V_S \approx 0.94\ V_T$).

Table 2.16 summarizes similar, well known formulas given in the Anglo-Saxon/British Imperial system (V [kn] and L [ft]), which take the general form:

$$C_B = K_4 - K_5 V/\sqrt{L} \tag{2.87}$$

where V is mainly the trial speed, unless otherwise noted.

Table 2.15 Coefficients of semiempirical formulas for the calculation of C_B (metric system units)

Formula	K_1	K_2	K_3	Comments
Horn	1.06	1.68	0	Single-screw ships, service speed
Ayre	1.08	1.68	0	Single-screw, trial speed
Ayre	1.09	1.68	0	Twin-screw, trial speed
Heckser	1.00	1.44	0	Single-screw, trial speed
V. Lammeren	1.08	1.68	0.224	Single-screw, trial speed

Table 2.16 Coefficients of semiempirical formulas for the estimation of C_B (Anglo-Saxon system of units)

Formula	K_4	K_5	Comments
Alexander and Watson	1.06	0.500	$0.65 \le V/\sqrt{L} \le 0.8$ (cargo ships)
	1.03	0.500	$V/\sqrt{L} > 0.89$ (fast cargo ships)
	1.12	0.500	$V/\sqrt{L} < 0.65$ (slow cargo ships)
Silverleaf and Dawson	1.214	0.394	bulky ships, $C_B \ge 0.75$, length L[m]
Chirila	1.225	0.378	bulky ships, $C_B \ge 0.75$, length L[m]
Troost	1.156	0.625	Service speed $V_S \cong 0.94\ V_T$

B. The below given formulas are derived from optimization studies of ships with respect to minimum building cost for given deadweight and speed (Schneekluth 1985):

$$C_B = \frac{0.14}{F_n} \cdot \frac{L/B + 20}{26} \tag{2.88}$$

$$C_B = \frac{0.23}{F_n^{2/3}} \cdot \frac{L/B + 20}{26} \tag{2.89}$$

The formulas are valid for $0.14 \le F_n \le 0.32$ and are limited to ships with $0.48 \le C_B \le 0.85$.

C. Finally, the following diagrams or comparable graphs of $C_B = f(F_n)$ as a function of the ship type (see Figs. 2.47 and 2.48) can also be used.

2.11 Midship Section Coefficient C_M

The midship section coefficient C_M, which, as mentioned above, connects the most important hull form coefficients C_B and C_P, can be selected quite freely by the designer, taking into account some basic factors such as low resistance, ease for construction, space exploitation, and sufficient stability.For a given midship section area A_M, B, and T, thus also fixed C_M, the possibility of alternative configuration of the midship section is associated with the selection of the bilge radius and the deadrise of the bottom (see Fig. 2.49).

C. Typical sizes of bilge radius and bottom deadrise

2.12 Waterplane Area Coefficient C_{WP}

The C_{WP} coefficient, which expresses the degree of fullness of the waterplane area in relation to the circumscribed rectangle of length L and width B, is significantly influenced by the form of the transverse sections and by the coefficients C_B and C_M (C_P).

Usually, the C_{WP} coefficient is selected in the preliminary design context so that the stability requirements are satisfied, i.e., namely relatively high C_{WP} values are selected, which affect negatively the ship's resistance (wave-making).

It is however more appropriate to consider in the preliminary selection of C_{WP} values around the lower typical limits and develop the shiplines almost independently from a pre-selected C_{WP} value. This leads to hydrodynamically favorable shiplines, without the C_{WP} value being a constraint for achieving adequate stability. Problems of insufficient stability should be rather treated with more drastic means, for example, change of the main dimensions (beam), of weight distribution, of sectional form character, etc.

2.12.1 *Effect on Stability*

The beam and the waterplane area coefficient influence decisively the calculation of the transverse moment of inertia of the ship's waterplane area, namely, for a given displacement, the magnitude of the vertical distance of the transverse metacenter from the buoyancy center $\overline{BM}$. Accordingly, the length and the C_{WP} coefficient affect the value of the longitudinal metacenter $\overline{BM_L}$.

It is obvious that the moment of inertia of the waterplane area increases as the coefficient C_{WP} increases, likewise the values of $\overline{BM}$ and $\overline{BM_L}$. Meanwhile, assuming constant sectional areas, thus, for given displacement and distribution of it, an increase of C_{WP} leads to V sections with high center of buoyancy, namely to increase of $\overline{KB}$. Overall, an improvement of the *form stability* results, namely of $\overline{KM}$, which is mitigated somewhat by the less pronounced increase of $\overline{KG}$, due to the application V type sections.

The influence of C_{WP} on stability can be approximated as follows: The transverse moment of inertia I_T is considered at first to be known from the formula:

$$I_T = C_{IT} \cdot I_{T*}$$

where

I_{T*}: moment of inertia of the circumscribed rectangle of length L and width B, which is equal to $B^3 \cdot L/12$

C_{IT}: coefficient of specificity of form of waterplane area, $C_{IT} \leq 1.0$.

If we set: $I_T = A_{WP} \cdot r_T^2$

extremely sharp waterline at the ends is favored to avoid intense waves in the bow and stern region; however, this may result particularly to more pronounced local waves around amidships. Generally, for a given speed (Froude number) and beam, the optimal C_{WP} values decrease with the increase of Froude number.

As to the influence of C_{WP} on the ship's performance in waves (motion amplitudes and phases, added resistance in waves), it has been observed in experiments and computations that high C_{WP} values, i.e., very full waterplane lines at the bow, have negative influence on seakeeping, especially on the sailing of the ship in head seas due to likely slamming problems etc.

2.12.3 Approximation Formulas

In general, the waterplane fullness coefficient C_{WP} is a function of block coefficient C_B and of the character of the ship's sections. Special types of ships with a large *L/B* ratio are likely to have both U and V sections, whereas a small *L/B* ratio is mainly associated with intense V sections. In addition, ships with relatively small *B/T* ratio are combined with high C_{WP} values to achieve sufficient stability and deck area.

The basic empirical formulas for the approximation of C_{WP} in the preliminary design phase are:

Intense U type sections

$$C_{WP} = 0.95C_P + 0.17(1 - C_P)^{1/3}\,(\text{Schneekluth}) \tag{2.97}$$

or

$$C_{WP} = 0.778C_B + 0.248$$

Normal sections

$$C_{WP} = (1 + 2C_B)/3 \tag{2.98}$$

Intense V type sections

$$C_{WP} = (1 + 2C_B/C_M^{0.5})/3\,(\text{Schneekluth}) \tag{2.99}$$

or

$$C_{WP} = 0.793C_B + 0.297.$$

The formulas are applicable at first only to ships with cruiser stern. Ships with transom stern generally have higher C_{WP} values. For ships with significant overhang of the wetted part of the stern beyond the aft perpendicular, the correction of the C_{WP} with the following coefficient is applied:

$$K = 1 + C_P \cdot (0{,}975 L_{WL} - L_{PP})/L_{PP} \tag{2.100}$$

2.12.4 Conclusions

a. To achieve satisfactory *form* stability, the increase of beam B should be preferred, which affects more drastically the moment of inertia of the ship's waterplane area, rather than the C_{WP}.
b. In the preliminary design phase and when using approximate formulas the selection of high C_{WP} values must be avoided, as these values may be reduced in the course of the ship's design (development of ship lines), resulting in poor stability.
c. In the transom stern case, which is always accompanied by high C_{WP} values, it needs to be considered that a possible stern emergence due to trim, motions in waves, etc., will cause a considerable loss of waterplane area and hence of stability (drastic $\overline{GM}$ reduction). In specific seaway conditions (following and head seas), this may lead some ships to severe roll motions (*Mathieau instabilities and parametric roll phenomena*) .

2.13 Determination of the Main Dimensions Through the Ship Design Equation

The "design equation" (in German *Entwurfsgleichung,* Schneekluth 1985) leads to the determination of the main dimensions of a study ship through the selected ratios of main dimensions and form coefficients of similar ships. In case of lack of data from similar ships, then empirical formulas and data from empirical diagrams, which are supposed to be applicable to the current ship type, can certainly be used.

The "design equation" is derived from the already known "displacement equation" (see Appendix C). As is well known, it holds for the displacement (weight):

$$\Delta = \rho_{SW} \cdot g \cdot \nabla^* \tag{2.101}$$

where

ρ_{SW}: density of sea water
Δ^*: volume of displaced water $= C_B \cdot L \cdot B \cdot T \cdot k_A$
k_A: coefficient of correction of the displaced volume (design—molded volume) for average shell thickness, appendages, etc. (see Sect. 2.15).

Introducing the ratios *L/B* and *B/T*, which, as known, significantly influence both the ship's resistance (*L/B*) and stability (*B/T*), the form of the displacement equation can be rearranged as follows:

$$\Delta = \rho_{SW} \cdot g \cdot (L/B) \cdot B^2 \cdot [B/(B/T)] \cdot C_B \cdot k_A$$

or

$$\Delta = \rho_{SW} \cdot g \cdot C_B \cdot [(L/B)/(B/T)] \cdot B^3 \cdot k_A$$