1 Definitions, principal dimensions

1.1 Introduction

The subjects treated in this book are the basis of the profession called **Naval Architecture**. The term *Naval Architecture* comes from the titles of books published in the seventeenth century. For a long time, the oldest such book we were aware of was Joseph Furttenbach's *Architectura Navalis* published in Frankfurt in 1629. The bibliographical data of a beautiful reproduction are included in the references listed at the end of this book. Close to 1965 an older Portuguese manuscript was rediscovered in Madrid, in the Library of the Royal Academy of History. The work is due to João Baptista Lavanha and is known as *Livro Primeiro da Architectura Naval*, that is 'First book on Naval Architecture'. The traditional dating of the manuscript is 1614. The following is a quotation from a translation due to Richard Barker:

> Architecture consists in building, which is the permanent construction of any thing. This is done either for defence or for religion, and utility, or for navigation. And from this partition is born the division of Architecture into three parts, which are Military, Civil and Naval Architecture.
>
> And Naval Architecture is that which with certain rules teaches the building of ships, in which one can navigate well and conveniently.

The term may be still older. Thomas Digges (English, 1546–1595) published in 1579 an *Arithmeticall Militarie Treatise,* named *Stratioticos* in which he promised to write a book on 'Architecture Nautical'. He did not do so.

Both the British Royal Institution of Naval Architects – RINA – and the American Society of Naval Architects and Marine Engineers – SNAME – opened their websites for public debates on a modern definition of Naval Architecture. Out of the many proposals appearing there, that provided by A. Blyth, FRINA, looked to us both concise and comprehensive:

> Naval Architecture is that branch of engineering which embraces all aspects of design, research, developments, construction, trials

> and effectiveness of all forms of man-made vehicles which operate either in or below the surface of any body of water.

If Naval Architecture is a branch of Engineering, what is Engineering? In the New Encyclopedia Britannica (1989) we find:

> Engineering is the professional art of applying science to the optimum conversion of the resources of nature to the uses of mankind. Engineering has been defined by the Engineers Council for Professional Development, in the United States, as the creative application of "scientific principles to design or develop structures, machines . . . "

This book deals with the scientific principles of Hydrostatics and Stability. These subjects are treated in other languages in books bearing titles such as *Ship theory* (for example Doyère, 1927) or *Ship statics* (for example Hervieu, 1985). Further scientific principles to be learned by the Naval Architect include Hydrodynamics, Strength, Motions on Waves and more. The 'art of applying' these principles belongs to courses in Ship Design.

1.2 Marine terminology

Like any other field of engineering, Naval Architecture has its own vocabulary composed of technical terms. While a word may have several meanings in common language, when used as a technical term, in a given field of technology, it has one meaning only. This enables unambigous communication within the profession, hence the importance of clear definitions.

The technical vocabulary of people with long maritime tradition has peculiarities of origins and usage. As a first important example in English let us consider the word **ship**; it is of Germanic origin. Indeed, to this day the equivalent Danish word is *skib*, the Dutch, *schep*, the German, *Schiff* (pronounce 'shif'), the Norwegian *skip* (pronounce 'ship'), and the Swedish, *skepp*. For mariners and Naval Architects a ship has a soul; when speaking about a ship they use the pronoun 'she'.

Another interesting term is **starboard**; it means the right-hand side of a ship when looking forward. This term has nothing to do with stars. Pictures of Viking vessels (see especially the Bayeux Tapestry) show that they had a steering board (paddle) on their right-hand side. In Norwegian a 'steering board' is called 'styri bord'. In old English the Nordic term became 'steorbord' to be later distorted to the present-day 'starboard'. The correct term should have been 'steeringboard'. German uses the exact translation of this word, 'Steuerbord'.

The left-hand side of a vessel was called *larboard*. Hendrickson (1997) traces this term to 'lureboard', from the Anglo-Saxon word 'laere' that meant empty, because the steersman stood on the other side. The term became 'lade-board' and 'larboard' because the ship could be loaded from this side only. Larboard sounded too much like starboard and could be confounded with this. Therefore, more than 200 years ago the term was changed to **port**. In fact, a ship with a steering board on the right-hand side can approach to port only with her left-hand side.

1.3 The principal dimensions of a ship

In this chapter we introduce the principal dimensions of a ship, as defined in the international standard ISO 7462 (1985). The terminology in this document was adopted by some national standards, for example the German standard DIN 81209-1. We extract from the latter publication the symbols to be used in drawings and equations, and the symbols recommended for use in computer programs. Basically, the notation agrees with that used by **SNAME** and with the *ITTC Dictionary of Ship Hydrodynamics* (RINA, 1978). Much of this notation has been used for a long time in English-speaking countries.

Beyond this chapter, many definitions and symbols appearing in this book are derived from the above-mentioned sources. Different symbols have been in use in continental Europe, in countries with a long maritime tradition. Hervieu (1985), for example, opposes the introduction of Anglo-Saxon notation and justifies his attitude in the Introduction of his book. If we stick in this book to a certain notation, it is not only because the book is published in the UK, but also because English is presently recognized as the world's *lingua franca* and the notation is adopted in more and more national standards. As to spelling, we use the British one. For example, in this book we write 'centre', rather than 'center' as in the American spelling, 'draught' and not 'draft', and 'moulded' instead of 'molded'.

To enable the reader to consult technical literature using other symbols, we shall mention the most important of them. For ship dimensions we do this in Tables 1.1 and 1.2, where we shall give also translations into French and German of the most important terms, following mainly ISO 7462 and DIN 81209-1. In addition, Italian terms will be inserted and they conform to Italian technical literature, for example Costaguta (1981). The translations will be marked by 'Fr' for French, 'G' for German and 'I' for Italian. Almost all ship hulls are symmetric with respect with a longitudinal plane (plane xz in Figure 1.6. In other words, ships present a 'port-to-starboard' symmetry. The definitions take this fact into account. Those definitions are explained in Figures 1.1 to 1.4.

The outer surface of a steel or aluminium ship is usually not smooth because not all plates have the same thickness. Therefore, it is convenient to define the hull surface of such a ship on the inner surface of the plating. This is the **Moulded surface** of the hull. Dimensions measured to this surface are qualified as **Moulded**. By contrast, dimensions measured to the outer surface of the hull or of an appendage are qualified as **extreme**. The moulded surface is used in the first stages of ship design, before designing the plating, and also in test-basin studies.

Table 1.1 Principal ship dimensions and related terminology

English term	Symbol	Computer notation	Translations
After (aft) perpendicular	AP		Fr perpendiculaire *arrière* G hinteres Lot, I perpendicolare addietro
Baseline	BL		Fr ligne de base, G Basis, I linea base
Bow			Fr proue, l'avant, G Bug, I prora, prua
Breadth	B	B	Fr largeur, G Breite, I larghezza
Camber			Fr bouge, G Balkenbucht, I bolzone
Centreline plane		CL	Fr plan longitudinal de symétrie, G Mittschiffsebene I Piano di simmetria, piano diametrale
Depth	D	DEP	Fr creux, G Seitenhöhe, I altezza
Depth, moulded			Fr creux sur quille, G Seitenhöhe I altezza di costruzione (puntale)
Design waterline	DWL	DWL	Fr flottaison normale, G Konstruktionswasserlinie (KWL) I linea d'acqua del piano di costruzione
Draught	T	T	Fr tirant d'eau, G Tiefgang, I immersione
Draught, aft	T_{A}	TA	Fr tirant d'eau arrière, G Hinterer Tiefgang I immersiona a poppa
Draught, amidships	T_{M}		Fr. tirant d'eau milieu, G mittleres Tiefgang I immersione media
Draught, extreme			Fr profondeur de carène hors tout, G größter Tiefgang I pescaggio
Draught, forward	T_{F}	TF	Fr tirant d'eau avant, G Vorderer Tiefgang, I immersione a prora
Draught, moulded			Fr profondeur de carène hors membres,
Forward perpendicular	FP		Fr perpendiculaire avant, G vorderes Lot I perpendicolare avanti

Table 1.1 *Cont.*

English term	Symbol	Computer notation	Translations
Freeboard	f	FREP	Fr franc-bord, G Freibord, I franco bordo
Heel angle	ϕ_s	HEELANG	Fr bande, gîte, Krängungswinkel I angolo d'inclinazione trasversale

Table 1.2 Principal ship dimensions and related terminology, continuation

English term	Symbol	Computer notation	Translations
Length between perpendiculars	L_{PP}	LPP	Fr. longueur entre perpendiculaires G. Länge zwischen den Loten I lunghezza tra le perpendicolari
Length of waterline	L_{WL}	LWL	Fr. longueur à la flottaison G Wasserlinielänge, I lunghezza al galleggiamento
Length overall	L_{OA}		Fr longueur hors tout, G Länge über allen I lunghezza fuori tutto
Length overall submerged	L_{OS}		Fr longueur hors tout immergé G Länge über allen unter Wasser I lunghezza massima opera viva
Lines plan			Fr plan des formes, G Linienriß I piano di costruzione, piano delle linee
Load waterline	DWL	DWL	Fr ligne de flottaison en charge, G Konstruktionswasserlinie I linea d'acqua a pieno carico
Midships			Fr couple milieu, G Hauptspant, I sezione maestra
Moulded			Fr hors membres, G auf Spanten, I fuori ossatura
Port		P	Fr bâbord, G Backbord, I sinistra
Sheer			Fr tonture, G Decksprung, I insellatura
Starboard		S	Fr tribord, G Steuerbord, I dritta
Station			Fr. couple, G Spante, I ordinata
Stern, poop			Fr arrière, poupe, G Hinterschiff, I poppa
Trim			Fr assiette, G Trimm, I differenza d'immersione
Waterline	WL	WL	Fr ligne d'eau, G Wasserlinie, I linea d'acqua

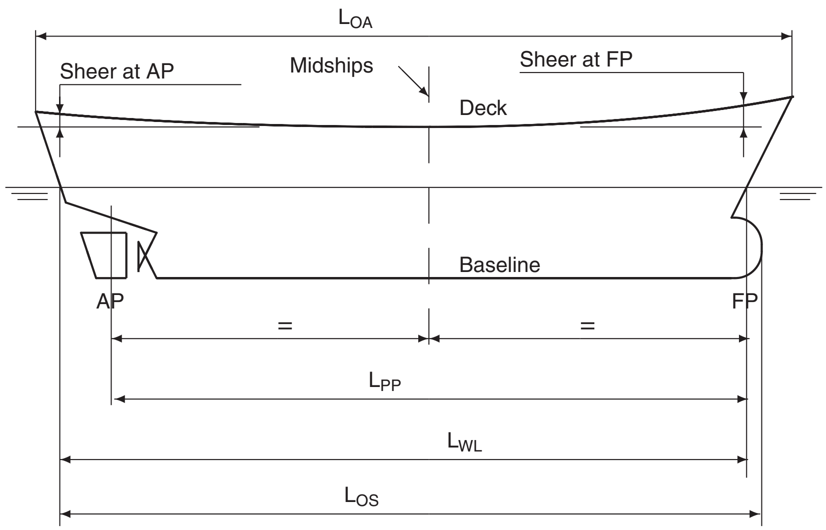

Figure 1.1 Length dimensions

Figure 1.2 How to measure the length between perpendiculars

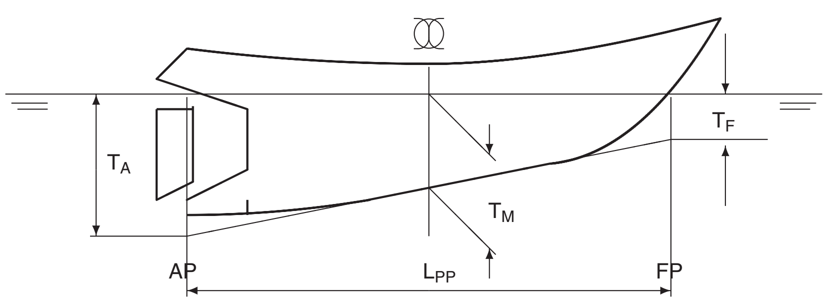

Figure 1.3 The case of a keel not parallel to the load line

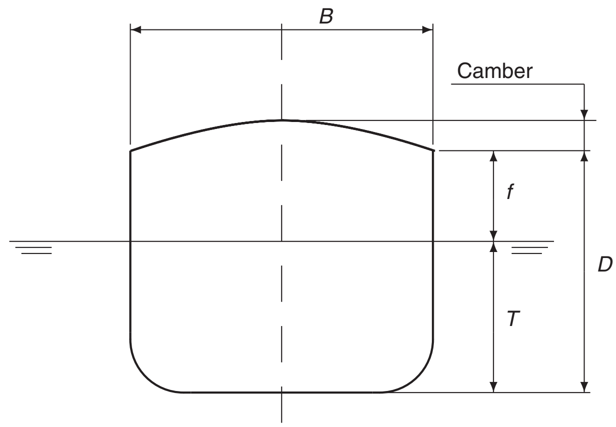

Figure 1.4 Breadth, depth, draught and camber

The **baseline**, shortly BL, is a line lying in the longitudinal plane of symmetry and parallel to the designed summer load waterline (see next paragraph for a definition). It appears as a horizontal in the lateral and transverse views of the hull surface. The baseline is used as the longitudinal axis, that is the x-axis of the system of coordinates in which hull points are defined. Therefore, it is recommended to place this line so that it passes through the lowest point of the hull surface. Then, all z-coordinates will be positive.

Before defining the dimensions of a ship we must choose a reference waterline. ISO 7462 recommends that this **load waterline** be the **designed summer load line**, that is the waterline up to which the ship can be loaded, in sea water, during summer when waves are lower than in winter. The qualifier 'designed' means that this line was established in some design stage. In later design stages, or during operation, the load line may change. It would be very inconvenient to update this reference and change dimensions and coordinates; therefore, the 'designed' datum line is kept even if no more exact. A notation older than ISO 7462 is DWL, an acronym for 'Design Waterline'.

The **after perpendicular**, or **aft perpendicular**, noted AP, is a line drawn perpendicularly to the load line through the after side of the rudder post or through the axis of the rudder stock. The latter case is shown in Figures 1.1 and 1.3. For naval vessels, and today for some merchant vessels ships, it is usual to place the AP at the intersection of the aftermost part of the moulded surface and the load line, as shown in Figure 1.2. The **forward perpendicular**, FP, is drawn perpendicularly to the load line through the intersection of the fore side of the stem with the load waterline. Mind the slight lack of consistency: while all moulded dimensions are measured to the moulded surface, the FP is drawn on the outer side of the stem. The distance between the after and the forward perpendicular, measured parallel to the load line, is called **length between perpendiculars** and its notation is L_{pp}. An older notation was LBP. We call **length overall**, L_{OA}, the length between the ship extremities. The **length overall submerged**, L_{OS}, is the maximum length of the submerged hull measured parallel to the designed load line.

We call **station** a point on the baseline, and the transverse section of the hull surface passing through that point. The station placed at half L_{pp} is called **midships**. It is usual to note the midship section by means of the symbol shown in Figure 1.5 (a). In German literature we usually find the simplified form shown in Figure 1.5 (b).

The **moulded depth**, D, is the height above baseline of the intersection of the underside of the deck plate with the ship side (see Figure 1.4). When there are several decks, it is necessary to specify to which one refers the depth.

The **moulded draught**, T, is the vertical distance between the top of the keel to the designed summer load line, usually measured in the midships plane (see Figure 1.4). Even when the keel is parallel to the load waterline, there may be appendages protruding below the keel, for example the sonar dome of a warship. Then, it is necessary to define an **extreme draught** that is the distance between the lowest point of the hull or of an appendage and the designed load line.

Certain ships are designed with a keel that is not parallel to the load line. Some tugs and fishing vessels display this feature. To define the draughts associated with such a situation let us refer to Figure 1.3. We draw an auxiliary line that extends the keel afterwards and forwards. The distance between the intersection of this auxiliary line with the aft perpendicular and the load line is called **aft draught** and is noted with T_{A}. Similarly, the distance between the load line and the intersection of the auxiliary line with the forward perpendicular is called **forward draught** and is noted with T_{F}. Then, the draught measured in the midship section is known as **midships draught** and its symbol is T_{M}. The difference between depth and draft is called **freeboard**; in DIN 81209-1 it is noted by f.

The **moulded volume of displacement** is the volume enclosed between the submerged, moulded hull and the horizontal waterplane defined by a given draught. This volume is noted by ∇, a symbol known in English-language literature as *del*, and in European literature as *nabla*. In English we must use two words, ‘submerged hull’, to identify the part of the hull below the waterline. Romance languages use for the same notion only one word derived from the Latin ‘carina’. Thus, in French it is ‘carène’, while in Catalan, Italian, Portuguese, Romanian, and Spanish it is called ‘carena’.

In many ships the deck has a transverse curvature that facilitates the drainage of water. The vertical distance between the lowest and the highest points of the

Figure 1.5 (a) Midships symbol in English literature, (b) Midships symbol in German literature

deck, in a given transverse section, is called **camber** (see Figure 1.4). According to ISO 7460 the camber is measured in mm, while all other ship dimensions are given in m. A common practice is to fix the camber amidships as 1/50 of the breadth in that section and to fair the deck towards its extremities (for the term 'fair' see Section 1.4.3). In most ships, the intersection of the deck surface and the plane of symmetry is a curved line with the concavity upwards. Usually, that line is tangent to a horizontal passing at a height equal to the ship depth, D, in the midship section, and runs upwards towards the ship extremities. It is higher at the bow. This longitudinal curvature is called **sheer** and is illustrated in Figure 1.1. The deck sheer helps in preventing the entrance of waves and is taken into account when establishing the load line in accordance with international conventions.

1.4 The definition of the hull surface

1.4.1 Coordinate systems

The DIN 81209-1 standard recommends the system of coordinates shown in Figure 1.6. The x-axis runs along the ship and is positive forwards, the y-axis is transversal and positive to port, and the z-axis is vertical and positive upwards. The origin of coordinates lies at the intersection of the centreline plane with the transversal plane that contains the aft perpendicular. The international standards ISO 7460 and 7463 recommend the same positive senses as DIN 81209-1 but do not specify a definite origin. Other systems of coordinates are possible. For example, a system defined as above, but having its origin in the midship section, has some advantages in the display of certain hydrostatic data. Computer programmes written in the USA use a system of coordinates with the origin of coordinates in the plane of the forward perpendicular, FP, the x-axis positive

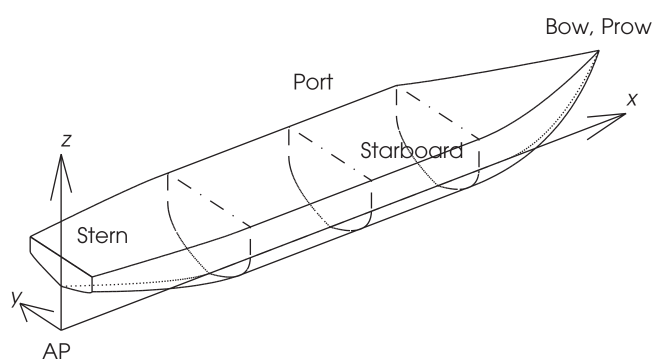

Figure 1.6 System of coordinates recommended by DIN 81209-1

afterwards, the y-axis positive to starboard, and the z-axis positive upwards. For dynamic applications, taking the origin in the centre of gravity simplifies the equations. However, it should be clear that to each loading condition corresponds one centre of gravity, while a point like the intersection of the aft perpendicular with the base line is independent of the ship loading. The system of coordinates used for the hull surface can be also employed for the location of weights. By its very nature, the system in which the hull is defined is fixed in the ship and moves with her. To define the various **floating conditions**, that is the positions that the vessel can assume, we use another system, fixed in space, that is defined in ISO 7463 as $x_0,\ y_0,\ z_0$. Let this system initially coincide with the system $x,\ y,\ z$. A vertical translation of the system $x,\ y,\ z$ with respect to the space-fixed system $x_0,\ y_0,\ z_0$ produces a draught change.

If the ship-fixed z-axis is vertical, we say that the ship floats in an upright condition. A rotation of the ship-fixed system around an axis parallel to the x-axis is called **heel** (Figure 1.7) if it is temporary, and **list** if it is permanent. The heel can be produced by lateral wind, by the centrifugal force developed in turning, or by the temporary, transverse displacement of weights. The list can result from incorrect loading or from flooding. If the transverse inclination is the result of ship motions, it is time-varying and we call it **roll**.

When the ship-fixed x-axis is parallel to the space-fixed x_0-axis, we say that the ship floats on **even keel**. A static inclination of the ship-fixed system around an axis parallel to the ship-fixed y-axis is called **trim**. If the inclination is dynamic, that is a function of time resulting from ship motions, it is called **pitch**. A graphic explanation of the term trim is given in Figure 1.7. The trim is measured as the difference between the forward and the aft draught. Then, trim is positive if the ship is **trimmed by the head**. As defined here the trim is measured in metres.

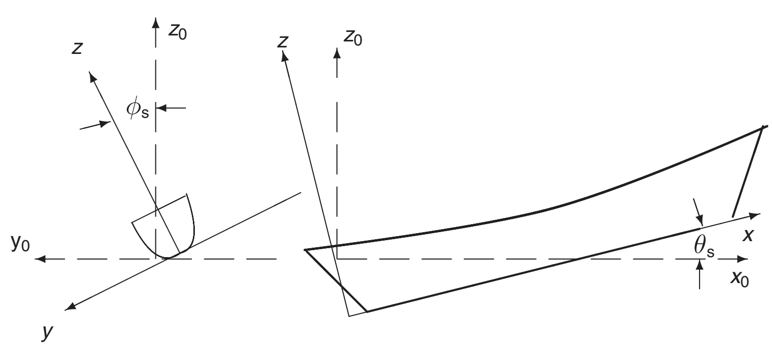

Figure 1.7 Heel and trim

1.4.2 Graphic description

In most cases the hull surface has double curvature and cannot be defined by simple analytical equations. To cope with the problem, Naval Architects have drawn lines obtained by cutting the hull surface with sets of parallel planes. Readers may find an analogy with the definition of the earth surface in topography by *contour lines*. Each contour line connects points of constant height above sea level. Similarly, we represent the hull surface by means of lines of constant x, constant y, and constant z. Thus, cutting the hull surface by planes parallel to the yOz plane we obtain the **transverse** sections noted in Figure 1.8 as $\mathrm{St}0$ to $\mathrm{St}10$, that is **Station 0**, **Station 1**, ... **Station 10**. Cutting the same hull by horizontal planes (planes parallel to the base plane xOy), we obtain the **waterlines** marked in Figure 1.9 as $\mathrm{WL}0$ to $\mathrm{WL}5$. Finally, by cutting the same hull with longitudinal planes parallel to the xOz plane, we draw the buttocks shown in Figure 1.10. The most important buttock is the line $y = 0$ known as **centreline**; for almost all ship hulls it is a plane of symmetry.

Stations, waterlines and buttocks are drawn together in the **lines drawing**. Figure 1.11 shows one of the possible arrangements, probably the most common one. As stations and waterlines are symmetric for almost all ships, it is sufficient to draw only a half of each one. Let us take a look to the right of our drawing; we see the set of stations represented together in the **body plan**. The left half of the body plan contains stations 0 to 4, that is the stations of the **afterbody**, while the right half is composed of stations 5 to 10, that is the **forebody**. The set of buttocks, known as **sheer plan**, is placed at the left of the body plan. Beneath is the set of waterlines. Looking with more attention to the lines drawing we find out that each line appears as curved in one projection, and as straight lines in

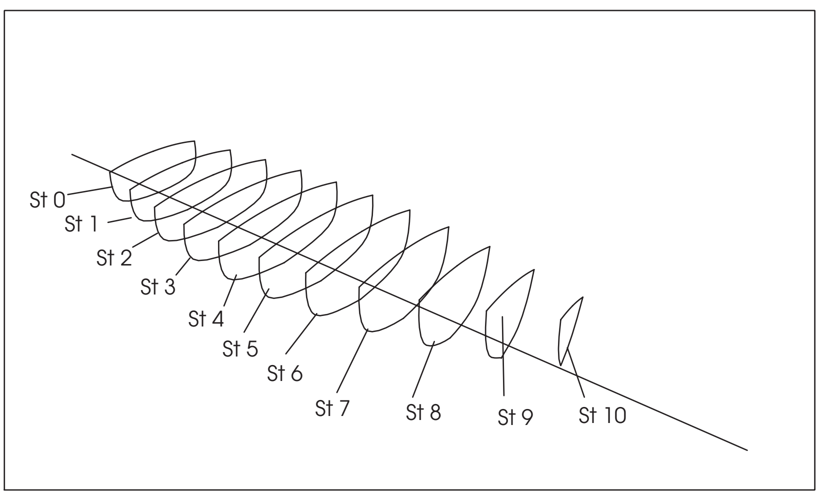

Figure 1.8 Stations

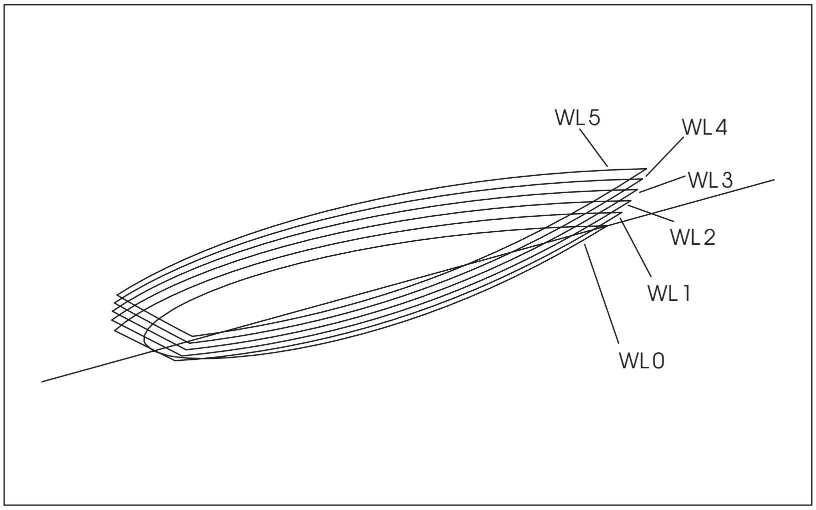

Figure 1.9 Waterlines

the other two. For example, stations appear as curved lines in the body plan, as straight lines in the sheer and in the waterlines plans.

The station segments having the highest curvature are those in the **bilge** region, that is between the bottom and the ship side. Often no buttock or waterlines cuts them. To check what happens there it is usual to draw one or more additional lines by cutting the hull surface with one or more planes parallel to the baseline

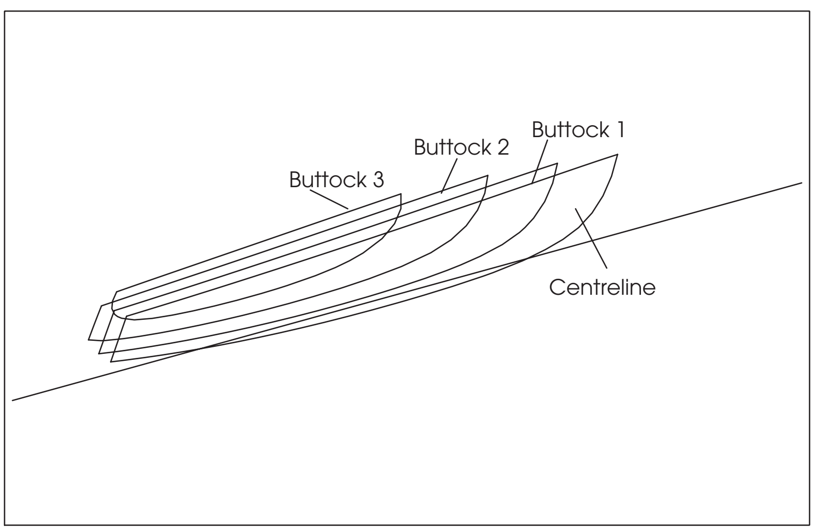

Figure 1.10 Buttocks

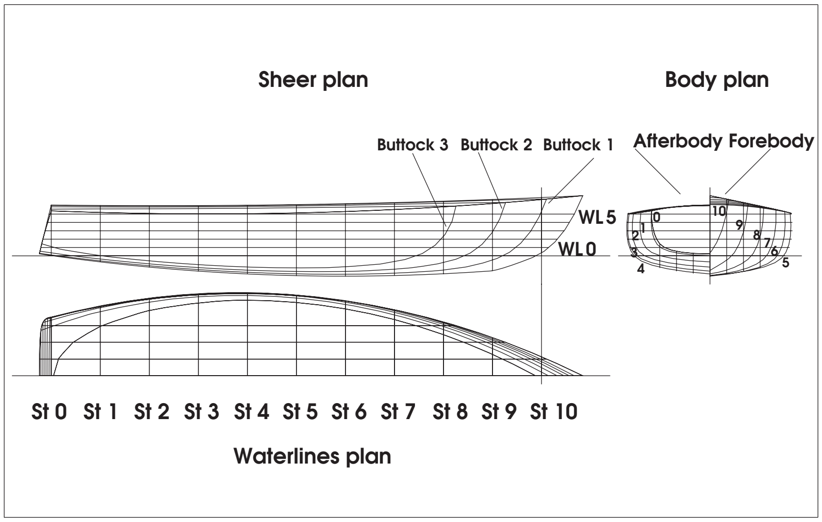

Figure 1.11 The lines drawing

but making an angle with the horizontal. A good practice is to incline the plane so that it will be approximately normal to the station lines in the region of highest curvature. The intersection of such a plane with the hull surface is appropriately called **diagonal**.

Figure 1.11 was produced by modifying under MultiSurf a model provided with that software. The resulting surface model was exported as a DXF file to TurboCad where it was completed with text and exported as an EPS (Encapsulated PostScript) file. Figures 1.8 to 1.10 were obtained from the same model as MultiSurf **contour** curves and similarly post-processed under TurboCad.

1.4.3 Fairing

The curves appearing in the lines drawing must fulfill two kinds of conditions: they must be coordinated and they must be 'smooth', except where functionality requires for abrupt changes. Lines that fulfill these conditions are said to be **fair**. We are going to be more specific. In the preceding section we have used three projections to define the ship hull. From descriptive geometry we may know that two projections are sufficient to define a point in three-dimensional space. It follows that the three projections in the lines drawing must be coordinated, otherwise one of them may be false. Let us explain this idea by means of Figure 1.12. In the body plan, at the intersection of Station 8 with Waterline 4, we measure that **half-breadth** $y(\mathrm{WL4},\ \mathrm{St8})$. We must find exactly the same dimension between the centreline and the intersection of Waterline 4 and Station 8 in the waterlines plan. The same intersection appears as a point, marked by a circle, in the sheer

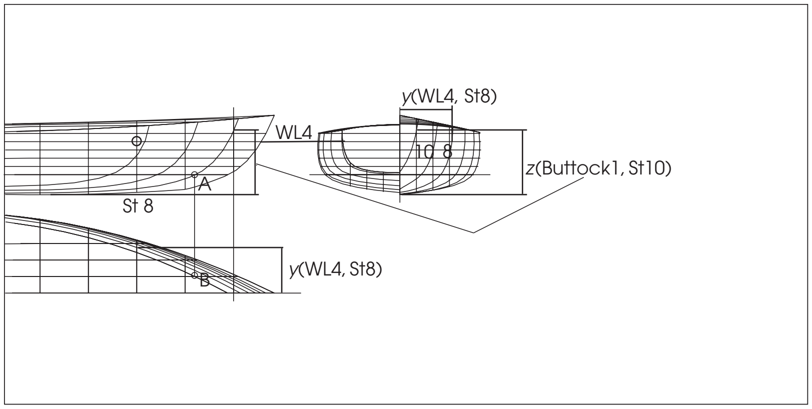

Figure 1.12 Fairing

plan. Next, we measure in the body plan the distance z(Buttock1, St10) between the base plane and the intersection of Station 10 with the longitudinal plane that defines Buttock 1. We must find exactly the same distance in the sheer plan. As a third example, the intersection of Buttock 1 and Waterline 1 in the sheer plan and in the waterlines plan must lie on the same vertical, as shown by the segment AB.

The concept of smooth lines is not easy to explain in words, although lines that are not smooth can be easily recognized in the drawing. The manual of the surface modelling program *MultiSurf* rightly relates fairing to the concepts of beauty and simplicity and adds:

> A curve should not be more complex than it needs to be to serve its function. It should be free of unnecessary inflection points (reversals of curvature), rapid turns (local high curvature), flat spots (local low curvature), or abrupt changes of curvature . . .

With other words, a 'curve should be pleasing to the eye' as one famous Naval Architect was fond of saying. For a formal definition of the concept of **curvature** see Chapter 13, Computer methods.

The fairing process cannot be satisfactorily completed in the lines drawing. Let us suppose that the lines are drawn at the scale 1:200. A good, young eye can identify errors of 0.1 mm. At the ship scale this becomes an error of 20 mm that cannot be accepted. Therefore, for many years it was usual to redraw the lines at the scale 1:1 in the **moulding loft** and the fairing process was completed there.

Some time after 1950, both in East Germany (the former DDR) and in Sweden, an optical method was introduced. The lines were drawn in the design office at the scale 1:20, under a magnifying glass. The drawing was photographed on glass plates and brought to a projector situated above the workshop. From there

Table 1.3 Table of offsets

	St	0	1	2	3	4	5	6	7	8	9	10
	x	0.000	0.893	1.786	2.678	3.571	4.464	5.357	6.249	7.142	8.035	8.928
WL	z	Half breadths										
0	0.360		0.900	1.189	1.325	1.377	1.335	1.219	1.024	0.749	0.389	
1	0.512	0.894	1.167	1.341	1.440	1.463	1.417	1.300	1.109	0.842	0.496	0.067
2	0.665	1.014	1.240	1.397	1.482	1.501	1.455	1.340	1.156	0.898	0.564	0.149
3	0.817	1.055	1.270	1.414	1.495	1.514	1.470	1.361	1.184	0.936	0.614	0.214
4	0.969	1.070	1.273	1.412	1.491	1.511	1.471	1.369	1.201	0.962	0.648	0.257
5	1.122	1.069	1.260	1.395	1.474	1.496	1.461	1.363	1.201	0.972	0.671	0.295

the drawing was projected on plates so that it appeared at the 1:1 scale to enable cutting by optically-guided, automatic burners.

The development of hardware and software in the second half of the twentieth century allowed the introduction of computer-fairing methods. Historical highlights can be found in Kuo (1971) and other references cited in Chapter 13. When the hull surface is defined by algebraic curves, as explained in Chapter 13, the lines are smooth by construction. Recent computer programmes include tools that help in completing the fairing process and checking it, mainly the calculation of curvatures and **rendering**. A rendered view is one in which the hull surface appears in perspective, shaded and lighted so that surface smoothness can be summarily checked. For more details see Chapter 13.

1.4.4 Table of offsets

In shipyard practice it has been usual to derive from the lines plan a digital description of the hull known as **table of offsets**. Today, programs used to design hull surface produce automatically this document. An example is shown in Table 1.3. The numbers correspond to Figure 1.11. The table of offsets contains half-breadths measured at the stations and on the waterlines appearing in the lines plan. The result is a table with two entries in which the offsets (half-breadths) are grouped into columns, each column corresponding to a station, and in rows, each row corresponding to a waterline. Table 1.3 was produced in MultiSurf.

1.5 Coefficients of form

In ship design it is often necessary to classify the hulls and to find relationships between forms and their properties, especially the hydrodynamic properties. The **coefficients of form** are the most important means of achieving this. By their definition, the coefficients of form are non-dimensional numbers.

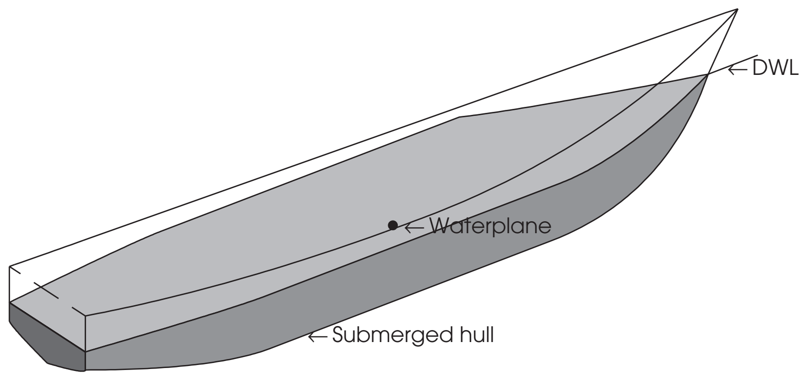

Figure 1.13 The submerged hull

The **block coefficient** is the ratio of the moulded displacement volume, ∇, to the volume of the parallelepiped (rectangular block) with the dimensions L, B and T:

$$C_{\mathrm{B}} = \frac{\nabla}{LBT} \tag{1.1}$$

In Figure 1.14 we see that C_{B} indicates how much of the enclosing parallelepiped is filled by the hull.

The **midship coefficient**, C_{M}, is defined as the ratio of the midship-section area, A_{M}, to the product of the breadth and the draught, BT,

$$C_{\mathrm{M}} = \frac{A_{\mathrm{M}}}{BT} \tag{1.2}$$

Figure 1.15 enables a graphical interpretation of C_{M}.

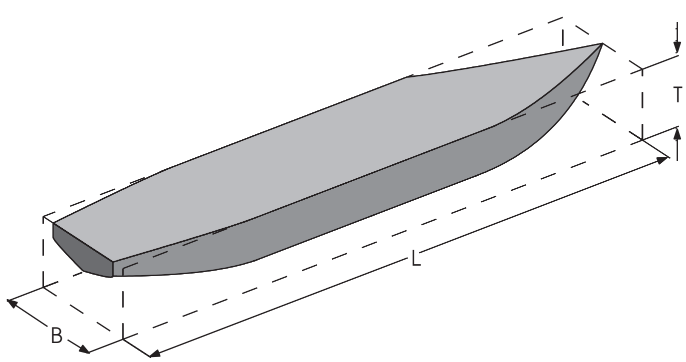

Figure 1.14 The definition of the block coefficient, C_{B}

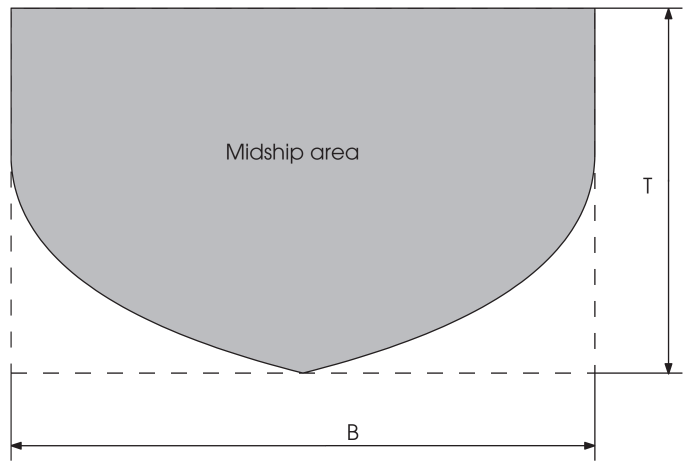

Figure 1.15 The definition of the midship-section coefficient, C_M

The **prismatic coefficient**, C_P, is the ratio of the moulded displacement volume, ∇, to the product of the midship-section area, A_M, and the length, L:

$$C_P = \frac{\nabla}{A_M L} = \frac{C_B LBT}{C_M BTL} = \frac{C_B}{C_M} \tag{1.3}$$

In Figure 1.16 we can see that C_P is an indicator of how much of a cylinder with constant section A_M and length L is filled by the submerged hull. Let us note the **waterplane area** by A_W. Then, we define the **waterplane-area coefficient** by

$$C_{WL} = \frac{A_W}{LB} \tag{1.4}$$

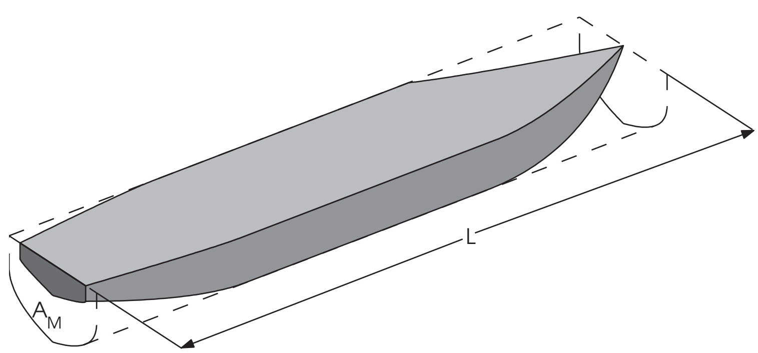

Figure 1.16 The definition of the prismatic coefficient, C_P

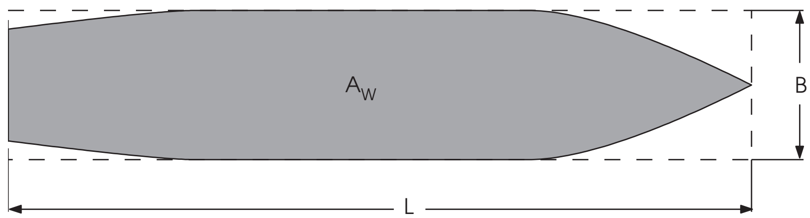

Figure 1.17 The definition of the waterplane coefficient, C_{WL}

A graphic interpretation of the waterplane coefficient can be deduced from Figure 1.17.

The **vertical prismatic coefficient** is calculated as

$$C_{VP} = \frac{\nabla}{A_W T} \tag{1.5}$$

For a geometric interpretation see Figure 1.18.

Other coefficients are defined as ratios of dimensions, for instance L/B, known as **length–breadth ratio**, and B/T known as 'B over T'. The **length coefficient of Froude**, or **length-displacement ratio** is

$$Ⓜ = \frac{L}{\nabla^{1/3}} \tag{1.6}$$

and, similarly, the **volumetric coefficient**, ∇/L^3.

Table 1.4 shows the symbols, the computer notations, the translations of the terms related to the coefficients of form, and the symbols that have been used in continental Europe.

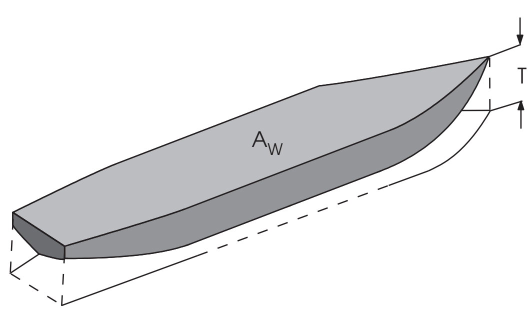

Figure 1.18 The definition of the vertical prismatic coefficient, C_{VP}

Table 1.4 Coefficients of form and related terminology

English term	Symbol	Computer notation	Translations European symbol
Block coefficient	C_{B}	CB	Fr coefficient de block, δ, G Blockcoeffizient I coefficiente di finezza (bloc)
Coefficient of form			Fr coefficient de remplissage G Völligkeitsgrad, I coefficiente di carena
Displacement	Δ		Fr déplacement, G Verdrängung, I dislocamento
Displacement mass	Δ	DISPM	Fr déplacement, masse, G Verdrängungsmasse
Displacement volume	∇	DISPV	Fr Volume de la carène G Verdrängungs Volumen, I volume di carena
Midship coefficient	C_{M}	CMS	Fr coefficient de remplissage au maître couple, β G Völligkeitsgrad der Hauptspantfläche I coefficiente della sezione maestra
Midship-section area	A_{M}		Fr aire du couple milieu, G Spantfläche I area della sezione maestra
Prismatic coefficient	C_{P}	CPL	Fr coefficient prismatique, ϕ G Schärfegrad, I coefficiente prismatico o longitudinale
Vertical prismatic coefficient	C_{VP}	CVP	Fr coefficient de remplissage vertical ψ, G I coefficiente di finezza prismatico verticale
Waterplane area	A_{W}	AW	Fr aire de la surface de la flottaison G Wasserlinienfläche, I area del galleggiamento
Waterplane-area coefficient	C_{WL}		Fr coefficient de remplissage de la flottaison, α G Völligkeitsgrad der Wasserlinienflaäche I coefficiente del piano di galleggiamento

1.6 Summary

The material treated in this book belongs to the field of Naval Architecture. The terminology is specific to this branch of Engineering and is based on a long maritime tradition. The terms and symbols introduced in the book comply with recent international and corresponding national standards. So do the definitions of the main dimensions of a ship. Familiarity with the terminology and the corresponding symbols enables good communication between specialists all over the world and correct understanding and application of international conventions and regulations.

In general, the hull surface defies a simple mathematical definition. Therefore, the usual way of defining this surface is by cutting it with sets of planes parallel to the planes of coordinates. Let the x-axis run along the ship, the y-axis be transversal, and the z-axis, vertical. The sections of constant x are called **stations**, those of constant z, waterlines, and the contours of constant y, **buttocks**. The three sets must be coordinated and the curves be fair, a concept related to simplicity, curvature and beauty.

Sections, waterlines and buttocks are represented together in the **lines plan**. Line plans are drawn at a reducing scale; therefore, an accurate fairing process cannot be carried out on the drawing board. In the past it was usual to redraw the lines on the moulding loft, at the 1:1 scale. In the second half of the twentieth century the introduction of digital computers and the progress of software, especially computer graphics, made possible new methods that will be briefly discussed in Chapter 13.

In early ship design it is necessary to choose an appropriate hull form and estimate its hydrodynamic properties. These tasks are facilitated by characterizing and classifying the ship forms by means of non-dimensional coefficients of form and ratios of dimensions. The most important coefficient of form is the block coefficient defined as the ratio of the **displacement volume** (volume of the submerged hull) to the product of ship length, breadth and draught. An example of ratio of dimensions is the length–breadth ratio.

1.7 Examples

Example 1.1 – Coefficients of a fishing vessel

In INSEAN (1962) we find the test data of a fishing-vessel hull called C.484 and whose principal characteristics are:

L_{WL}	14.251 m
B	4.52 m
T_{M}	1.908 m
∇	$58.536\,\mathrm{m}^3$
A_{M}	$6.855\,\mathrm{m}^2$
A_{W}	$47.595\,\mathrm{m}^2$

We calculate the coefficients of form as follows:

$$C_{\mathrm{B}} = \frac{\nabla}{L_{\mathrm{pp}} B T_{\mathrm{M}}} = \frac{58.536}{14.251 \times 4.52 \times 1.908} = 0.476$$

$$C_{\mathrm{WL}} = \frac{A_{\mathrm{W}}}{L_{\mathrm{WL}} B} = \frac{47.595}{14.251 \times 4.52} = 0.739$$

$$C_{\mathrm{M}} = \frac{A_{\mathrm{M}}}{BT} = \frac{6.855}{4.52 \times 1.908} = 0.795$$

$$C_{\mathrm{P}} = \frac{\nabla}{A_{\mathrm{M}} L_{\mathrm{WL}}} = \frac{58.536}{6.855 \times 14.251} = 0.599$$

and we can verify that

$$C_{\mathrm{P}} = \frac{C_{\mathrm{B}}}{C_{\mathrm{M}}} = \frac{0.476}{0.795} = 0.599$$

1.8 Exercises

Exercise 1.1 – Vertical prismatic coefficient
Find the relationship between the vertical prismatic coefficient, C_{VP}, the waterplane-area coefficient, C_{WL}, and the block coefficient, C_{B}.

Exercise 1.2 – Coefficients of Ship 83074
Table 1.5 contains data belonging to the hull we called *Ship 83074*. The length between perpendiculars, L_{pp}, is 205.74 m, and the breadth, B, 28.955 m. Complete the table and plot the coefficients of form against the draught, T. In Naval Architecture it is usual to measure the draught along the vertical axis, and other data – in our case the coefficients of form – along the horizontal axis (see Chapter 4).

Exercise 1.3 – Coefficients of hull C.786
Table 1.6 contains data taken from INSEAN (1963) and referring to a tanker hull identified as C.786.

Table 1.5 Coefficients of form of Ship 83074

Draught T m	Displacement volume ∇ m^3	Waterplane area A_{WL} m^2	C_{B}	C_{WL}	C_{M}	C_{P}
3	9029	3540.8	0.505	0.594	0.890	0.568
4	12632	3694.2			0.915	
5	16404	3805.2			0.931	
6	20257	3898.7			0.943	
7	24199	3988.6			0.951	
8	28270	4095.8			0.957	
9	32404	4240.4			0.962	