UNIT 6

Naval Architectural Drawings and Plans

Abstract This chapter deals with the basic naval architectural drawings and plans (ship lines, general arrangement and capacity plan), which are required in the course of a ship's design and construction process. Modern shipyards and design offices use more and more computerized representations of the ship, from the first layout, to ship design and the production process, thus hardcopies of the plans are used less and less. However, the basic naval architectural plans are essential from a conceptual point of view and serve the needs of information exchange during the design and construction procedure, namely

- Approval of ship's design and construction by the classification society and flag registry authorities
- Information medium for ship's operation
- Information medium for the overall manufacturing process

The present chapter defines a ship's basic drawings and plans, elaborates on the design of the ship's hull form and ship lines by use of traditional methods and data of systematic hull form series, when no relevant information is available from similar ships and by use of interpolation and distortion methods, when the lines of parent ships are available. It proceeds with the elaboration of the procedure for setting up ship's general arrangement plan and closes with the preparation of ship's capacity plan. The various design steps are supported by illustrative examples of application.

4.1 General

The naval architectural drawings and plans required in the course of a ship's design and construction process may be classified into the following general categories:

- *Ship lines:* graphical representation of the ship's hull form.
- *Diagrams of results of calculations:* set of diagrams with the ship's hydrostatics, stability and Bonjean curves, diagrams of distributions of shear stresses and bending moments, etc.
- *General overview plans:* general arrangement of spaces and outfitting, capacity plan, loading plan, plans of piping/cabling systems, general construction

drawings of steel structure showing the longitudinal structural profile and midship section, of decks, bulkheads, etc.
- *Detailed construction drawings:* detailed construction plans with manufacturing instructions for the production units of the shipyard, the paneling, mechanical, piping, carpentry workshops, etc.).

The above mentioned graphical representations[1] constitute the basis for serving the following objectives:

- Information exchange during the design and construction procedure
- Approval of the ship's design and construction by the classification society and flag registry authorities
- Information medium for the ship's operation
- Information medium for the overall manufacturing process

The following Table 4.1 (Taggart 1980) lists the main drawings and plans that must be developed in the final stage of ship's *contract* design (Technical specifications of the contract between shipyard and shipowner).

4.2 Ship Lines Plan

The Ship lines plan (German: Schiffslinien Plan) is the basis for the processing the following steps of ship design:

- *Hydrostatic calculations:* development of a set of hydrostatic diagrams and ship stability curves
- *Construction of scaled ship models* for experiments of calm water resistance-propulsion and seakeeping in seaways in a towing tank or ship model basin
- Development of plans that depend on the ship's hull geometry (volumetric curves, general arrangement drawings, etc.).
- Development of the ship's outer *shell expansion,* development of cutting patterns for plates, mold frames (*lofting*[2]), etc.; inspection tool for controlling the geometry of elements relating to ship's outer shell, etc.

[1] Modern shipyards use more and more computerized representations of the ship, from the first layout, to ship design and the production process. Having digitized the whole or part of the production process, many shipbuilding projects can be planned by the yard in parallel and the production/assembly can be tested in advance. In this *virtual* production world, construction drawings and plans are hardly used. This saves time, money, and leads to higher efficiency. One of the world leaders in the use of modern computer technology in all phases of shipbuilding is the European yard *Meyer Werft* (www.meyerwerft.de). The yard, which is located in the small town of Papenburg in northwestern Germany, was founded in 1795 and is in sixth generation in the hands of the Meyer family. It is a world leader of large passenger and cruise ship design and construction.

[2] Lofting if the process of generating a large (sometimes full) scale lines plan or "lay-down" to mold ship's frames and actual ship components.

Table 4.1 Typical plans required in the contract design of a merchant ship (Taggart 1980)

Outboard profile, general arrangement
Inboard profile, general arrangement
General arrangement of all decks and holds
Arrangement of crew quarters
Arrangement of commissary spaces
Line
Midship section
Steel scantling plan
Arrangement of machinery—plan views
Arrangement of machinery—elevations
Arrangement of machinery—sections
Arrangement of main shafting
Power and lighting system—one line diagram
Fire control diagram by decks and profile
Ventilation and air conditioning diagram
Diagrammatic arrangements of all piping systems
Heat balance and steam flow diagram—normal
Power at normal operating conditions
Electric load analysis
Capacity plan
Curves of form
Floodable length curves
Preliminary trim and stability booklet
Preliminary damage stability calculations

The representation of the 3-D, nonplanar surface of the outer shell of a ship can be accomplished in the following ways:

a. Graphical representation of the 3-D ship hull on the basis of a set of graphs/curves of 2-D cuts/sections of the hull with a series of parallel to each other planes with respect to the transverse (*sections plan*), horizontal (*waterlines plan*) and longitudinal direction (*sheer plan*); see typical lines plans in Figs. 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, and 4.8
b. Numerical representation based on properly formatted coordinates of points of the hull (offsets)
c. Analytical representation based on mathematical functions and associated parameters (polynomials, cubic splines, bisplines, Coon surfaces, Bezier curves, etc)
d. Stereophotographic representation of the ship's hull or 3-D scanning with 3-D Laser
e. Three-dimensional analogue model.

All the above ways of representing the ship's hull serve specific requirements of the design and construction process and often are used simultaneously in the development of optimal hull forms and for the optimal design and construction process of the ship.

Particularly, the graphical representation (a), namely the set of 2-D ship lines, is characterized by its great expressiveness (for knowledgeable naval architects) and

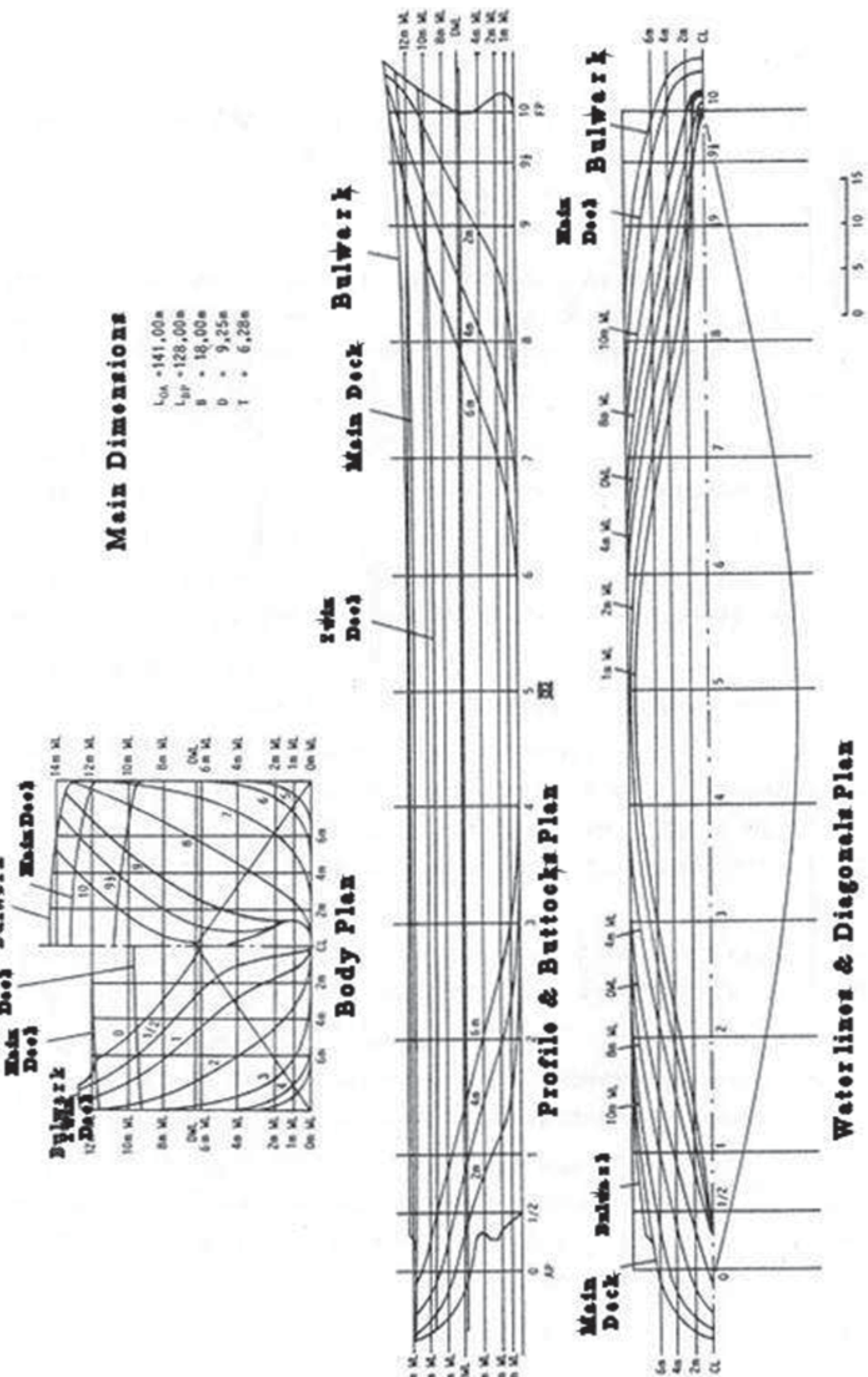

Fig. 4.1 Typical drawing of lines plan (Antoniou and Perras 1984)

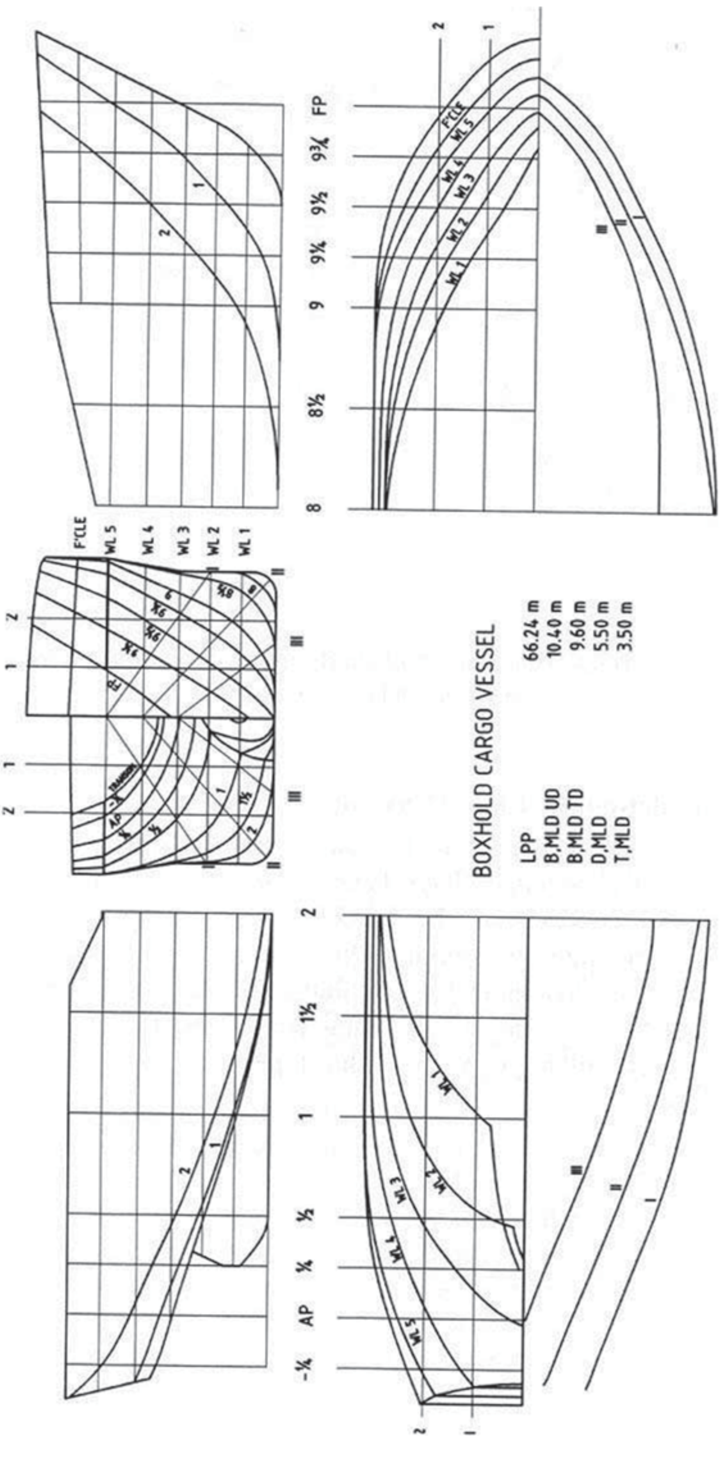

Fig. 4.2 Ship lines plan of a cargo ship (Friis et al. 2002)

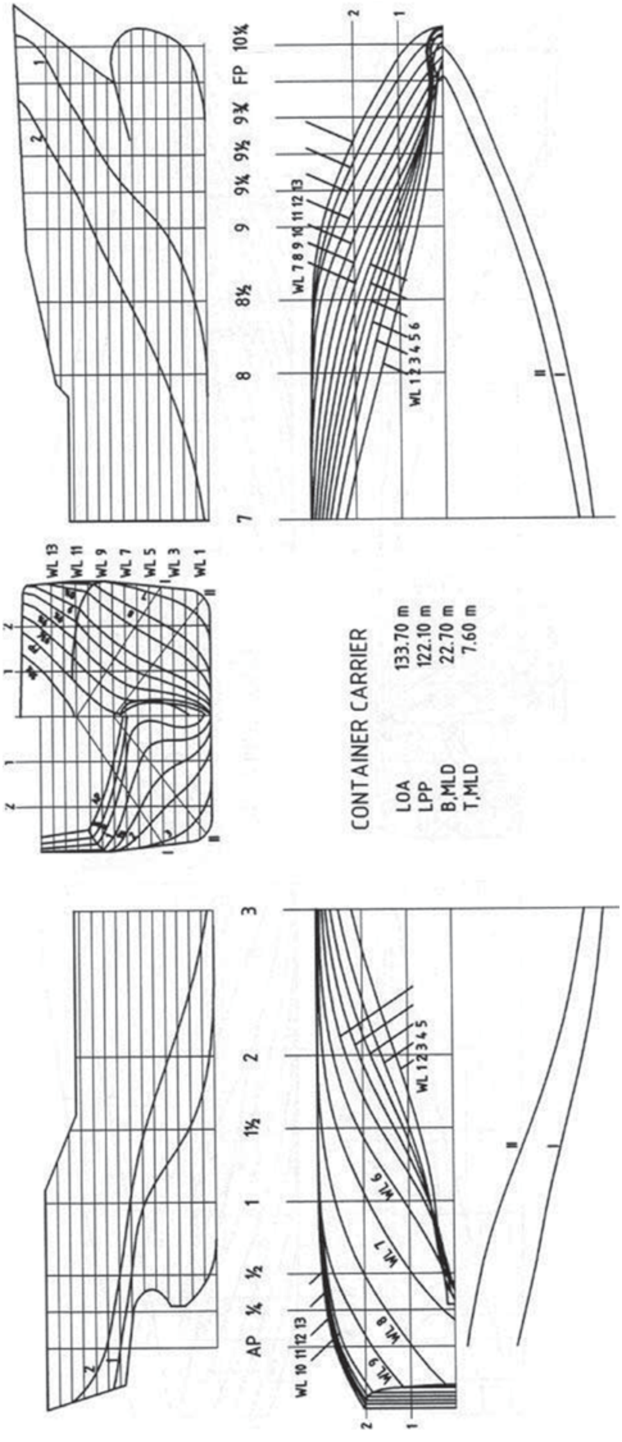

Fig. 4.3 Ship lines plan of a feeder container ship (Friis et al. 2002)

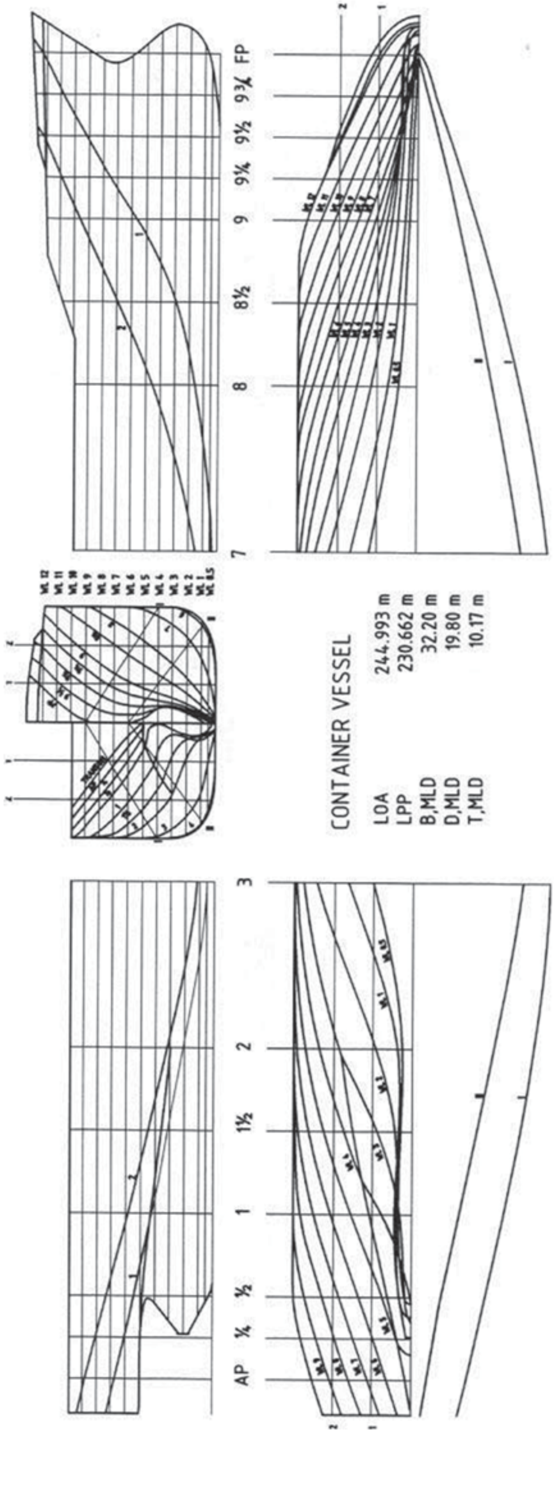

Fig. 4.4 Ship lines plan of a PANAMAX container ship (Friis et al. 2002)

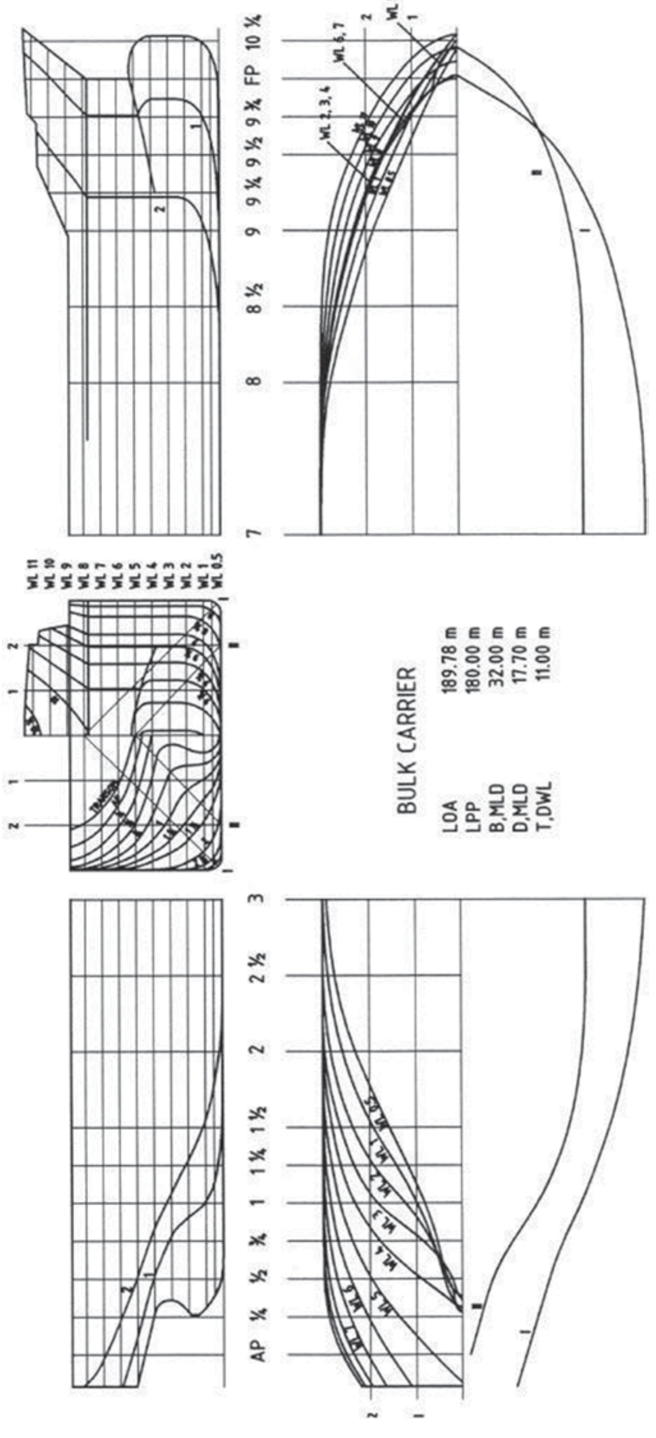

Fig. 4.5 Ship lines plan of a PANAMAX bulk carrier ship (Friis et al. 2002)

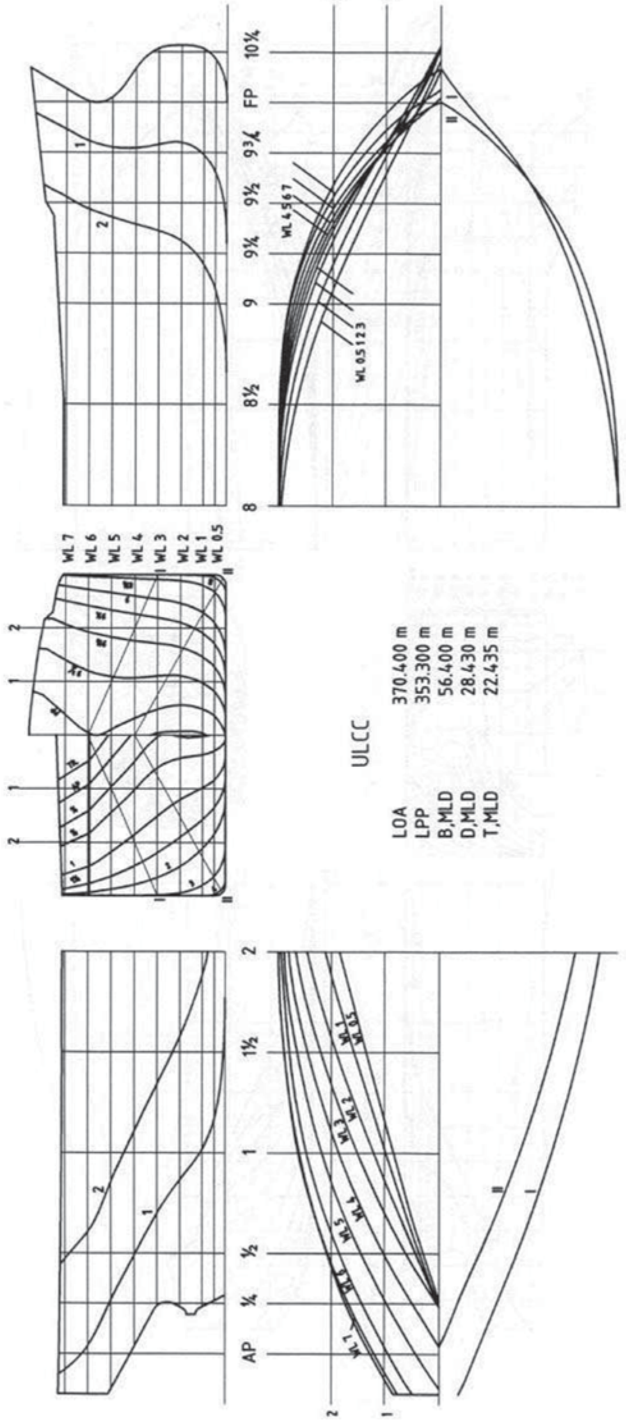

Fig. 4.6 Ship lines plan of an ultra large crude carrier (ULCC) tanker ship (Friis et al. 2002)

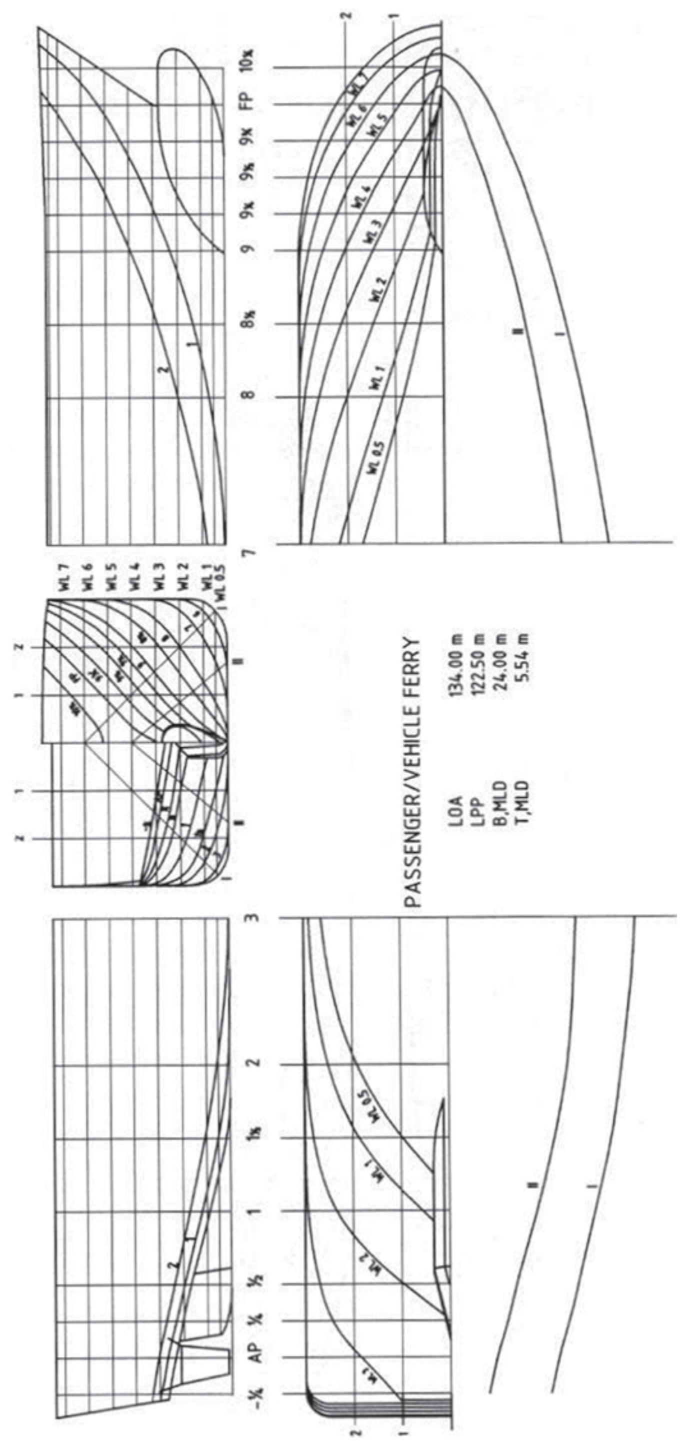

Fig. 4.7 Ship lines plan of a RoPax ship (Friis et al. 2002)

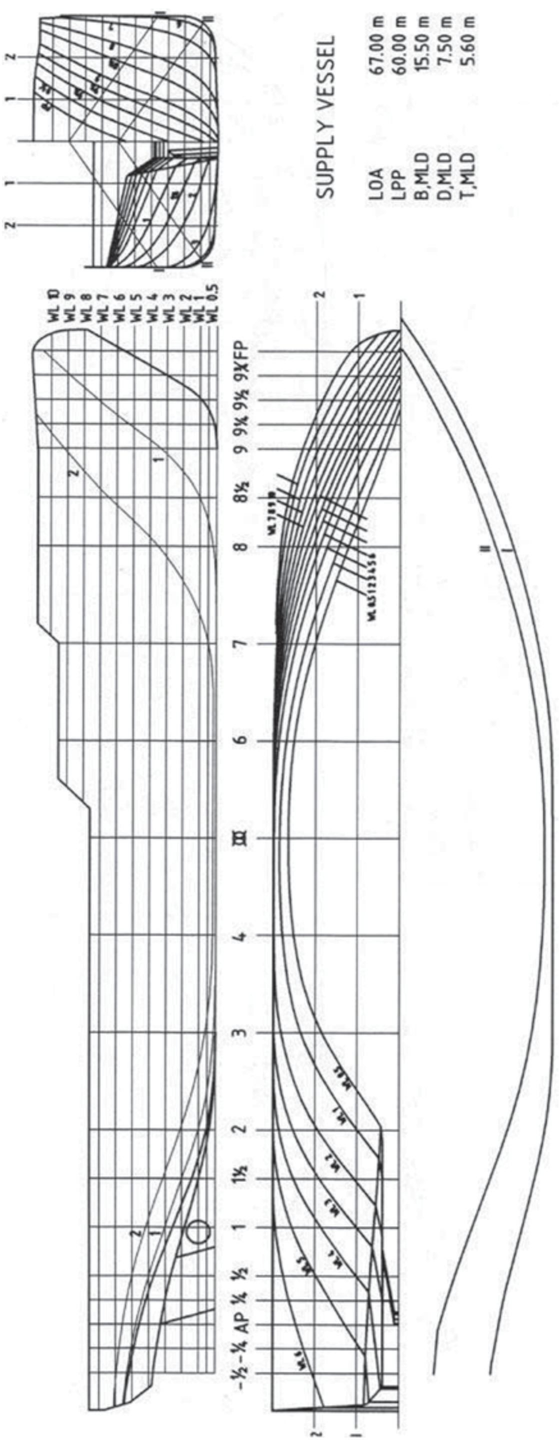

Fig. 4.8 Ship lines plan of a supply vessel (Friis et al. 2002)

allows easy modification or adjustment of the lines to the specific requirements of the ship. Furthermore, the coordinates of the lines can be easily discretized (by digitizing them) and along with the numerical representation (b) the access to computer hard and software tools is enabled in the context of computer aided ship design—CASD (Papanikolaou and Zaraphonitis 1988).

The analytical representation (c) can save computer hardware "memory" in storing a sufficient amount of coordinates for the accurate description of the ship's hull form in accordance with the requirements of the various phases of the design process. Also, the use of contemporary mathematical tools and functions, e.g. bisplines, Bezier curves, Coon's surfaces, etc., facilitates the process of optimization and of hull lines fairing during both the initial and final stages of ship design (Papanikolaou and Zaraphonitis 1988).

The stereometric, 3-D representations (d) can be used for a better representation of the curved surfaces at the bow and stern of the ship, as well as for the approximation of the flow streamlines at both ends of the ship.

4.3 Introduction to the Development of Ship Lines Plan

A. Formulation of the Problem For the development of a ship's lines plan during the initial design stage, the following data may be considered known:

- the principal ship dimensions of length, breadth, draft
- the hull form coefficients, especially C_B
- the approximate longitudinal position of the longitudinal center of buoyancy (LCB)

The most important factors affecting the form of ship's lines are:

- resistance and propulsion in calm water
- added resistance and powering in waves
- maneuvering properties
- course-keeping ability
- seakeeping behavior in seaways; roll damping
- cargo hold volume

As the main ship characteristics of L, B, T, and C_B are considered given, the flexibility on configuring a ship's lines is to a certain degree limited. The remaining basic steps are:

- determination of the longitudinal distribution of ship's displacement, i.e., the determination of the sectional area curve and LCB
- selection of midship section coefficient C_M, if it has been not yet concluded
- configuration of bow and stern

B. Conventional Design Procedure It is considered that the lengthwise distribution of ship's displacement is known from comparable data of known systematic ship model series, e.g. Series 60 or Series Wageningen (Lap, see Appendix B).

These systematic hull form series provide diagrams, in which the areas f sections 0–20 is given as a function of the ship's prismatic coefficient C_P and in percentages of the midship section area A_M. Also, the prismatic coefficients of bow and stern, C_{PF} and C_{PA}, are introduced.

After the preparation of a necessary grid of basic lines (*canvas*), which correspond to the projected basic sectional planes in the transverse, vertical and longitudinal direction, the design procedure is as follows:

1. *design of the midship section*
2. *preliminary design of the bow and stern profiles*
3. *sketch of some sections at the bow (sections No. 14–17) and stern (No. 3–5) and approximation of their areas with the help of a mechanical planimeter (or another tool)*
4. *correction of the resulting sectional areas and of the corresponding lines to match the initially given sectional area curve*
5. *design of the design waterline based on the previous data*
6. *tuning of the waterline and cross sections—control of initial stability (anticipated value of metacentric height) through the moment of inertia of the design load waterplane*
7. *design and fairing of the waterline at the height of half-draft*
8. *sketch of remaining sections up to the design waterline height*
9. *design and fairing of the above waterlines, correction of bow–stern*
10. *completion of sections up to the uppermost deck*
11. *fairing of waterlines above the design load waterline*
12. *fairing of sections*
13. *design of the diagonals*
14. *design of the buttock lines*
15. *completion of intermediate sections at the ends (bow and stern)*
16. *completion of intermediate waterlines for small draughts*
17. *final check of displacement, LCB and metacentric height above the baseline* ($\overline{KM}$)

The above procedure may be modified, particularly with respect to steps 7–11, with the simultaneous design of the diagonals and longitudinal cuts/buttock lines (13–14), so as to facilitate the fairing of the sections and the waterlines.

The fundamental principle in the fairing of ship lines is that a smooth flow and associated streamlines lines should not be sacrificed for accurately satisfying the specifications of the initially assumed sectional area curve that has been derived/concluded from systematic model series. However, any deviation of the LCB from the desired (optimal) position should be treated with great care.

The allowable tolerances with respect to the resulting displacement and center of buoyancy are a function of ship type and of other design tolerances. Typical values for the displacement are in the range of ±0.4 %, if the sum of weights tolerance is 1–2 % and for the center of buoyancy (longitudinal position) ± 0.2 % L_{PP}.

C. Ship Lines Design by Use of Existing Lines

Bibliography

Lackenby, M., Transactions RINA 1950, p. 289
Schneekluth, H., Journal Schiffstechnik, 1959, p. 130
Söding, H., Journal Schiff und Hafen, 1971, p. 991
Nowacki, H., Lectures Notes CASD, Univ. of Michigan, Summer School, 1970
Nowacki H, Five decades of Computer-Aided Ship Design, Journal Computer-Aided Design 42 (2010) 956-969
Lechter, J., The Geometry of Ships, The Principles of Naval Architecture Series, ed. J. R. Paulling, SNAME Pub., 2009

Basic Procedure Based on the available lines/data offsets of similar ships the wetted part of the hull is first developed; in the following the remaining (above waterplane) part of the hull is developed following the conventional way of hull form design.

Advantages Compared to the conventional way of designing ship's hull form (see **B**), the present method is superior in terms of the following points:

1. reduced effort due to the decoupling of the tuning of the sectional area curve and the lines development
2. cecause of the availability of the hull form characteristics of the parent ship, it is possible to estimate at an early stage many of the hydrostatic values of the study ship, even before the completion of her hull form design (see e.g., paragraphs 2.18.5 and 2.18.6).

Distortion Methods (in German: Verzerrungsmethoden**)** The distortion of an existing lines plan of a parent ship to other dimensions and characteristics can be achieved in different ways, namely by methods falling into two main categories:

C1. Distortion of existing lines, which may be given through drawing plans or tables of coordinates (offset tables), by multiplying the hull form coordinates with constant coefficients and/or by shifting of the hull form cutting planes, leading to modified waterlines, sections, and diagonals

C2. Distortion of lines given by analytical/mathematical formulas

The following subgroup of methods belong to the C1 category of methods, which are all characterized by the existence of hull offset points:

C1.1. The *simple affine (homologous) distortion,* in which the offsets in the longitudinal, transverse and vertical direction change by a constant scale ratio, which may be different for each direction. If the three ratios are the same, this obviously leads to a proportional *enlargement or reduction* of the hull (*geometric similarity*)

C1.2. The *modified* affine (*homologous) distortion*

C1.3. The non-affine (*heterologous) distortion,* in which one or more ratios change continuously in one or more directions

The C2 type of methods that are based on the mathematical representation of the hull surface, are practically applicable, when dealing with the hull form of normal ships, only section-wise, i.e. the mathematical representation of individual sections of the hull is enabled through different mathematical functions. Thus, for a point on the boundary of two or more sections, represented by two of more mathematical functions, the satisfaction of two or more equations associated with the relevant sections, is required. For avoiding discontinuities and potential knuckles on the hull surface, thus for achieving faired ship lines and surfaces, it is required to obtain at least equality of the resulting offset ordinates and of the first derivatives of the equations in both horizontal and vertical directions, at best also of the second derivatives for good fairing, depending on the methods used (see Papanikolaou and Zaraphonitis 1988). Note that modern computer-aided design (CAD) software platforms dispose today powerful "graphical editors" enabling the distortion of existing lines to the desired form in efficient ways.

Simple Affine Distortion (C1.1) by H. Schneekluth

a. Linear Distortion

Procedure

a1. Multiplication of the offsets/coordinates of an existing hull in one or more directions with one or more (constant) scaling factors, e.g. *a, b,* and *c,* for the longitudinal, transverse, and vertical directions, so as to conclude to the required main dimensions.

a2. The distorted principal dimensions $a{\cdot}L$, $b{\cdot}B$, and $c{\cdot}T$ lead to the new ratios of length/beam, $(a/b){\cdot}L/B$, beam/draft $(b/c){\cdot}B/T$ and volumetric coefficient $(b{\cdot}c/a^2){\cdot}\nabla/L^3$. It is noted that because the linear character of the distortion, the hull form coefficients (block coefficient, etc.), the centers of buoyancy (KB and LCB), of waterlines (LCF) and of sections (KB), as well as the character of the latter, remain unchanged.

a3. It is possible to combine the bow and stern part of different ships/hulls, so as to generate a new hybrid hull form with modified hull form coefficients and centroids, compared to the parent ships. For the practical application of this method, the preliminary estimation of the resulting block coefficient and the position of the center of buoyancy through simplified empirical formulas are very helpful.

Assuming for the block coefficient C_B:

$$C_B = 1/2(C_{BF} + C_{BA}) \tag{4.1}$$

where

C_{BF} the partial, forebody block cofficient, $= \nabla_F / (0.5 \cdot L \cdot B \cdot T)$ (4.2)

C_{BA} the partial, aftbody block coeficient, $= \nabla_A / (0.5 \cdot L \cdot B \cdot T)$ (4.3)

the following relationships were derived empirically from statistical data by Schneekluth (1985):

Longitudinal position of center of buoyancy (measured from the aft perpendicular, AP):

$$\overline{AB}\,[\%L_{\mathrm{PP}}] = 50 + (C_{\mathrm{BF}} - 0.973\cdot C_{\mathrm{B}} - 0.0211)\cdot 44, \quad \text{for } C_{\mathrm{M}} > 0.94 \tag{4.4}$$

$$\overline{AB}\,[\%L_{\mathrm{PP}}] = 50 + (C_{\mathrm{BF}} - 0.973\cdot C_{\mathrm{B}})\cdot(43/C_{\mathrm{M}}) - 0.89 \text{ (independently of } C_{\mathrm{M}}) \tag{4.5}$$

Block coefficients:

$$C_{\mathrm{BF}} = C_{\mathrm{B}} + \left(0.0211 + \frac{\overline{AB}\cdot[\%L_{\mathrm{PP}}] - 50}{44} - 0.027\cdot C_{\mathrm{B}}\right) \tag{4.6}$$

$$C_{\mathrm{BA}} = C_{\mathrm{B}} - \left(0.0211 - \frac{\overline{AB}\cdot[\%L_{\mathrm{PP}}] - 50}{44} - 0.027\cdot C_{\mathrm{B}}\right) \quad \text{for } C_{\mathrm{M}} > 0.94 \tag{4.7}$$

and

$$C_{\mathrm{BF,\,BA}} = C_{\mathrm{B}} \pm \left[(\overline{AB}[\%L_{\mathrm{PP}}] - 50 + 0.89)\cdot\frac{C_{\mathrm{M}}}{43} - 0.027\cdot C_{\mathrm{B}}\right] \tag{4.8}$$

for arbitrary C_{M} values.

The above formulas actually apply only to ships without bulbous bow; the calculation error is estimated to be about $\delta\left(\overline{AB}\right) = 0.1\%\ L_{\mathrm{PP}}$. When dealing with ships with bulbous bows, the resulting values for the center of buoyancy can be easily corrected, by taking into account the effect of the corresponding moment, due to the volume of a given bulb, on $\overline{AB}$.

b. Interpolation Methods (Modified Affine Distortion)

Procedure

b1. Interpolation between the coordinates of two linearly distorted ship lines (derived from two parental ships), which have been adjusted by constant scaling factors to the requested main dimensions

b2. Interpolation between the existing parental lines is achieved by keeping a constant percentage distance from the distorted curves of the parent ships (see Fig. 4.9)

b3. The interpolation can be done either graphically or numerically.

c. Shifting of Waterplane Procedure

c1. Shifting of the design waterplane of the parental ship to larger or smaller drafts and corresponding change of C_{B}

c2. Linear distortion of the resultant new hull

d. Variation of Parallel Middle Body (Schneekluth 1985) This method is extensively applied when changing the length of ship's parallel body[3] with a correspond-

[3] Though the length of the parallel body increases, the overall ship length remains constant; thus, this should not be confused with the lengthening of a ship by adding a parallel body, which is a very popular ship conversion (see Papanikolaou 2009).

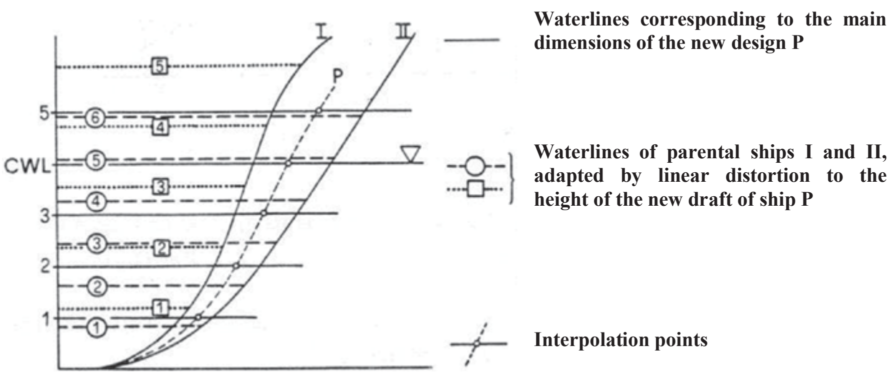

Fig. 4.9 Development of ship lines by interpolation method according to Schneekluth (1985)

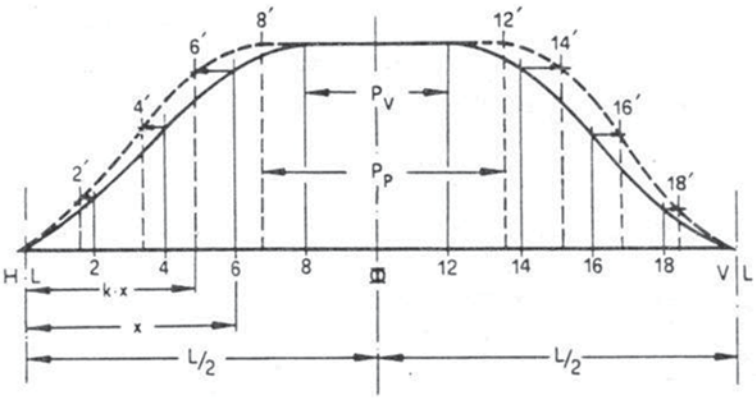

Fig. 4.10 Variation of section spacing with the change of the length of parallel body δL_P, where $P_V \cong (L_P)_0$, $P_P = (L_P)_1$, $k \equiv K$, $L = L_{PP}$

ing effect on the block coefficient C_B, which increases. Likewise, the fullness of the hull can be decreased, by shortening of the parallel body.

Procedure d1. We first consider the sectional area curve of a parent ship. Assuming the forward and aft perpendiculars at first fixed, the sectional spacing between AP and forward perpendicular (FP) is varied by altering the distances of the sectional area curve ordinates (which here correspond to sectional areas) proportional to a constant factor K (see Fig. 4.10).

d2. The resulting new displacement can be determined as follows:

Difference in lengths of parallel body

$$\delta L_P = (L_P)_1 - (L_P)_0 \tag{4.9}$$

where

L_P length of parallel body
$(L_P)_0$ of parent ship, index $()_0$
$(L_P)_1$ of new design ship, index $()_1$

New Displacement Assuming the length, breadth and draft of the ship to change due to linear distortion, the following results for the new displacement:

$$(\nabla)_1 = \nabla_0 \cdot \frac{(L_1 - \delta L_P) \cdot B_1 \cdot T_1}{L_0 \cdot B_0 \cdot T_0} + \delta L_P \cdot B_1 \cdot T_1 \cdot C_M \tag{4.10}$$

where

$L_1 = aL_0$
$B_1 = bB_0$
$T_1 = cT_0$

If the ship has been already linearly distorted, thus *L, B,* and *T* are fixed, the formula simplifies to:

$$(\nabla)_1 = \nabla_0 \cdot \frac{L_{PP} - \delta L_P}{L_{PP}} + \delta L_P \cdot B \cdot T \cdot C_M \tag{4.11}$$

d3. The length of the new parallel body and the factor for the proportional change of the section spacing from the fore and APs are derived as follows:

Length of new parallel body

$$(L_P)_1 = K \cdot (L_P)_0 + \delta L_P \tag{4.12}$$

Factor of section spacing

$$K = \frac{(L_{PP} - \delta L_P)}{L_{PP}} \tag{4.13}$$

and

$$\delta L_P = (1 - K) \cdot L_{PP} \tag{4.14}$$

New block coefficient

$$(C_B)_1 = \frac{(C_B)_0 \cdot (L_{PP} - \delta L_P) \cdot B \cdot T + \delta L_P \cdot B \cdot T \cdot C_M}{L_{PP} \cdot B \cdot T} \tag{4.15}$$

and by substituting δL_P, the *K* factor is obtained as:

$$K = \frac{\left[C_M - (C_B)_1\right]}{\left[C_M - (C_B)_0\right]} \tag{4.16}$$

Thus, based on the existing block coefficient $(C_B)_0$ and the targeted $(C_B)_1$, the factor *K* for the proportional shift of sections can be calculated.

Initial Stability Check Assuming the linear, affine distortion, as described in the preceding paragraphs, the waterplane area coefficient C_{WP} remains unchanged, even if the length, breadth and draft of the ship are being changed proportionally. Thus, the control of the initial ship stability, based on the data of a parent ship that has been linearly distorted (method A), can be achieved with respect to the metacentric height by use of the formula:

$$(\overline{KM})_1 = (\overline{BM})_0 \frac{(B_1/B_0)^2}{(T_1/T_0)} + (\overline{KB})_0 \frac{T_1}{T_0} \tag{4.17}$$

If the interpolation method (method B) is being used, then based on the above formula the data for the linearly distorted lines of the two parent hulls can be calculated and subsequently by linear interpolation the data for the desired ship are obtained.

In the distortion method C (shifting of waterplane), the moment of inertia of the new waterplane can be calculated based on that of the parental ship:

$$(I_T)_1 = (I_T)_0 \cdot (B_1/B_0)^3 \cdot L_1/L_0 \tag{4.18}$$

and this can be used for the calculation of $\overline{BM}$, in the known manner.

Finally, when using the distortion method D (variation of parallel body), due to the change of the waterplane area, the new waterplane area coefficient and transverse moment of inertia need to be derived:

$$(C_{WP})_1 = \frac{\left|(C_{WP})_0 \pm \frac{\delta L_P}{L_{PP}}\right|}{\left(1 \pm \frac{\delta L_P}{L_{PP}}\right)} \tag{4.19}$$

$$(I_T)_1 = (I_T)_0 \cdot (B_1/B_0)^3 \frac{L_1 - \delta L_P}{L_0} + \delta L_P \cdot B_1^3/12 \tag{4.20}$$

Note that all the above formulas are clearly the result of geometric relationships, thus they do not involve any empirical relationships that would diminish the accuracy of the calculations/estimations.

4.4 Design Based on Data of Systematic Ship Hull Form Series

Such important ship hull form series are typically the following ones:

1. **Series of the Wageningen Laboratory (Netherlands) according to Lap-Auf'm Keller**

Bibliography

Lap, A., J., W., Journ. Int. Shipbuilding Progress, 1954

Auf'm Keller, Journ. Int. Shipbuilding Progress, 1974

2. Series 60 according to Todd et al. (USA)

Todd, Pien, Transactions of SNAME, 1956

3. FORMDATA Series, Lyngby Laboratory (Denmark) according to H. E. Guldhammer

Guldhammer, H., E., FORMDATA I-IV, Danish Techn. Press, Copenhagen, 1969

Outline of Systematic Hull Form Series The first two of the above mentioned series, i.e. Series Wageningen (Lap) and Series 60 (Todd), dispose the lengthwise distribution of the preliminarily estimated displacement for single- and twin-screw ships without bulbous bow, that is, the sectional areas are given as percentages of the given midship section area and as a function of the pre-estimated prismatic coefficient. Application examples are given in course material of NTUA-SDL, Papanikolaou and Anastassopoulos (2002).

The subsequent design procedure for the development of the ship lines plan is similar to that described under **B** in the present chapter. A serious drawback of the above two systematic series is that they are outdated with respect to the associated hull forms; the main advantage, when using systematic hull form series, is, however, the availability of semiempirical calm water resistance data (resulting from systematic model experiments) enabling the reliable estimation of powering for the resulting hull forms.

The FORMDATA systematic series, which is still today the most complete and advanced hull form series available in the public domain, is considered satisfactorily representing modern hull forms of merchant ships, even though processed data stem from the 70s; they refer to three basic hull forms, i.e., sections of U, N, and V character, which are combined with two basic series of stern and bow forms, namely A and F. Unlike the previously mentioned series (Wageningen-Lap and Series 60), FORMDATA considers bulbous bow and transom stern options. Typically in the FORMDATA series the offsets of the model sections are given in dimensionless form, i.e., as percentages of the reference breadth and draft (which are assumed predetermined values). In this way the procedure of developing the ship lines is significantly facilitated, as the work of the designer reduces to the fairing of the resulting ship lines.

The FORMDATA series is described in more details in Appendix B, where also the aforementioned series by Lap and Series 60 are outlined. A full set of the FORMDATA diagrams and instructions how to use them is included in Perras (1979).

Ship Lines Plan for Design Stages The initial design stage involves the draft design of the ship lines plan in a relatively large scale (about 1:200 up to 1:250 for normal ships) without accurate fairing of lines. This draft design is mainly used for the preliminary examination of various ship form data, such as displacement, stability and trim, volume of holds, etc.

In the second stage of design, during the preliminary design, a smaller scale (typically 1:100 to 1:50 for typical ship sizes) and a drawing accuracy in the order 0.1 mm (corresponds to an error margin of 2.5 cm for a 250 m ship in full scale, if drawn in a scale of 1:100) are required.

Finally, in the last design stage, because the developed ship lines constitute the basis for the development of the construction drawings of the various elements of

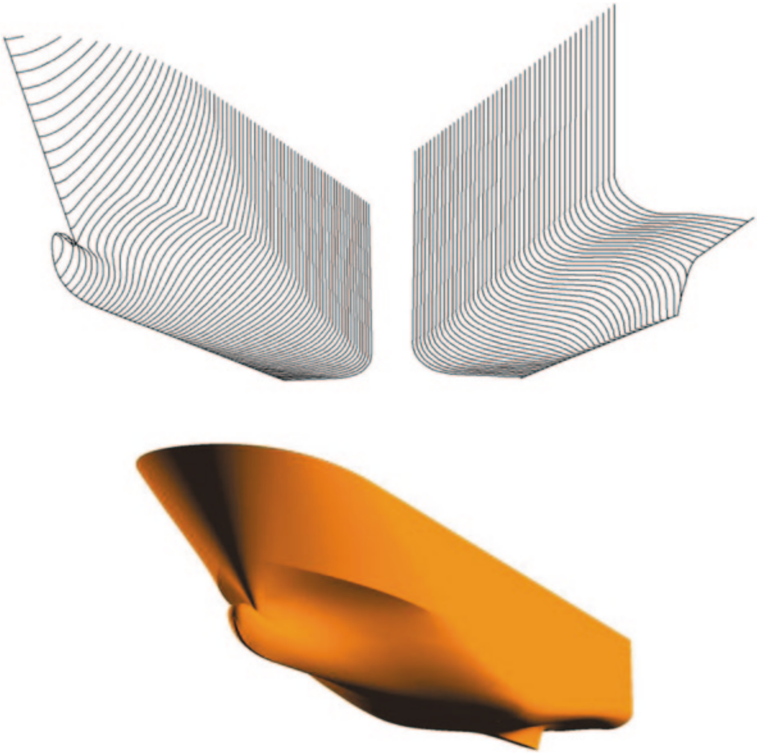

Fig. 4.11 The 2-D wire-frame and 3-D lines plan of a modern RoPax ship developed by NAPA®. (Ship Design Laboratory-NTUA, Research project "EPAN–Transport," 2007)

ship's structure (plates, stiffeners, etc.), a smaller scale, in the order of 1:10, is used to develop the *plan of building frames* of the ship, which corresponds to the actual *transverse stiffeners* of the ship (drawing of building frames); the building frames are certainly much more in number (about 1–2 building frames/m) than the *mold* sections of the lines plan (usually 21 mold sections for the overall length of the ship, including AP and FP sections, but with intermediate sections at ship's ends; Figs. 4.1 to 4.8 and Fig. 4.11).

4.5 General Arrangement Plan

The general arrangement (GA) plan (German: Generalplan) of a ship involves the *arrangement of spaces and the arrangement of the ship's main equipment and outfitting*.

General Arrangement of Spaces The general arrangement of a ship's spaces is the outcome of a study involving the determination and examination of the space requirements for every basic function[4] of the ship and the establishment of the physical interfaces between design spaces as necessary for the orderly operation of the ship.

The space planning and the design of the physical interfaces of spaces involves:

- the demarcation of spaces for the basic ship functions
- the rational planning of the flow of functional operations
- the identification of associations/relationships of onboard operations
- the determination of the various onboard supply/distribution systems (energy, water, sewage, etc.)
- the determination of the access to the functional spaces and their mutual interfaces

The outcome of the procedure for the general arrangement of ship spaces is the subdivision of the ship's enclosed volume in the vertical direction through horizontal decks, transversely and longitudinally through bulkheads and walls into compartments, which serve certain functions, and the determination of communication routes on and between the decks and between the compartments.

Arrangement of Equipment/Outfitting This is the process of controlling the space requirements for the installation/fitting of a ship's equipment related to a functional ship subsystem inside the allocated ship spaces and their access/communication for proper function (e.g., layout of engine room, interior layout of accommodation rooms/cabins, detailed layout of fully equipped spaces, etc.).

The GA plan includes a side view/elevation plan of the ship (above the main deck as side view, below the main deck as lateral plane, cut at the centerplane of the ship), as well as top down views of the ship's decks, as cuts of horizontal planes slightly above the decks of the ship, from the ship's bridge and down to the double bottom (see example, reefer ship "Polar Ecuador,"Figs. 4.12 and 4.13).

The GA plan enables to check the interior arrangement of the ship and of her superstructures. Also, it includes information about the arrangement of the main equipment/outfitting of the ship.

During the initial design stage, a sketch drawing of ship's side view is recommended, which should include the basic internal arrangement of ship's main spaces, according to their functions. This sketch does not require any drawing precision and is usually drawn at a scale of 1:750 to 1:1,000. At the preliminary design stage, the scale is reduced and commonly taken from 1:200 to 1:100, depending on the absolute size of the design ship (1:50 for small boats with a length of up to about 50 m, 1:100 for ship lengths up to about 200 m, 1:200 for ship lengths between 200 m and 300 m, and 1:400 for ship lengths over 300 m).

[4] Basic functions of merchant ships:

- Transport and handling of cargo
- Provision of accommodation for crew and passengers
- Provision of energy generation-machinery/propulsion/navigation
- Provision of fuel and provisions for specified range.

Fig. 4.12 Reefer ship "Polar Ecuador," built in 1967 by the German yard Blohm & Voss for Hamburg Südamerikanische Dampfschifffahrts-Gesellschaft; operated later for a Greek owner as "Chios Spirit"; is representative of a successful series of fast reefer ships (service speed at banana draft: 23.5 knots) built by Blohm & Voss in the 60s, transporting bananas from South America to Europe (in German: Banana-Dampfer)

Preparation of General Arrangement Drawings[5] The process of preparing the initial drawing of the general arrangement of a ship includes the following basic steps and drawing plans (Fig. 4.14):

a. Separation/identification of ship's functional spaces (hold spaces, engine room, superstructures, cargo-handling equipment, and tanks)
b. Determination of the ship's watertight bulkheads in accordance with the requirements of recognized classification societies and international regulations on watertight subdivision of SOLAS
c. Determination of ballast and fuel tanks
d. Determination of the number and location of decks, depending on the requirements of the freight/cargo to be transported
e. Study of the impact of specific requirements for certain types of cargo (refrigerated cargo, containers, etc.)

1. **Side Elevation Plan** The development of the side elevation plan (profile) starts with first drawing the baseline, the line of the fully loaded waterline (design waterline) and the forward and after perpendiculars of the ship, which

[5] The development of the general arrangement of a ship is one the main subjects of the course "Ship Design and Outfitting II" of the curriculum of the School of Naval Architecture and Marine Engineering, NTUA (Papanikolaou 2003).

Length o.a.	486 ft 1⅜ in	148.20 m
Length b.p.	436 ft 2⅝ in	133.00 m
Breadth, moulded	64 ft 3⅝ in	19.60 m
Depth, to third deck	23 ft 2⅜ in	7.07 m
Depth, to second deck	31 ft 4⅜ in	9.56 m
Camber, first deck and focsle	9⅞ in	0.25 m
other decks	nil	nil
Draught, summer freeboard open shelterdeck to IMCO recommend.	21 ft 6⅜ in	6.575 m
Draught, summer freeboard closed shelterdeck	26 ft 11⅝ in	8.222 m
Deadweight, open	4,800 tons (m)	
Deadweight, closed	7,950 tons (m)	

Hold capacity without bins banana capacity	423,354 ft³	11,987.9 m
Gross tonnage, open	3,815	
Gross tonnage, closed	5,617	
Block coefficient	0.52	
Machinery output, max.	14,880 bhp at 500 rev/min	
Speed on banana draught at 96 per cent output	23.5 knots	
Heavy fuel, approx.	1,150 tons (m)	
Ballast water, approx.	290 tons (m)	
Fresh water, approx.	180 tons (m)	

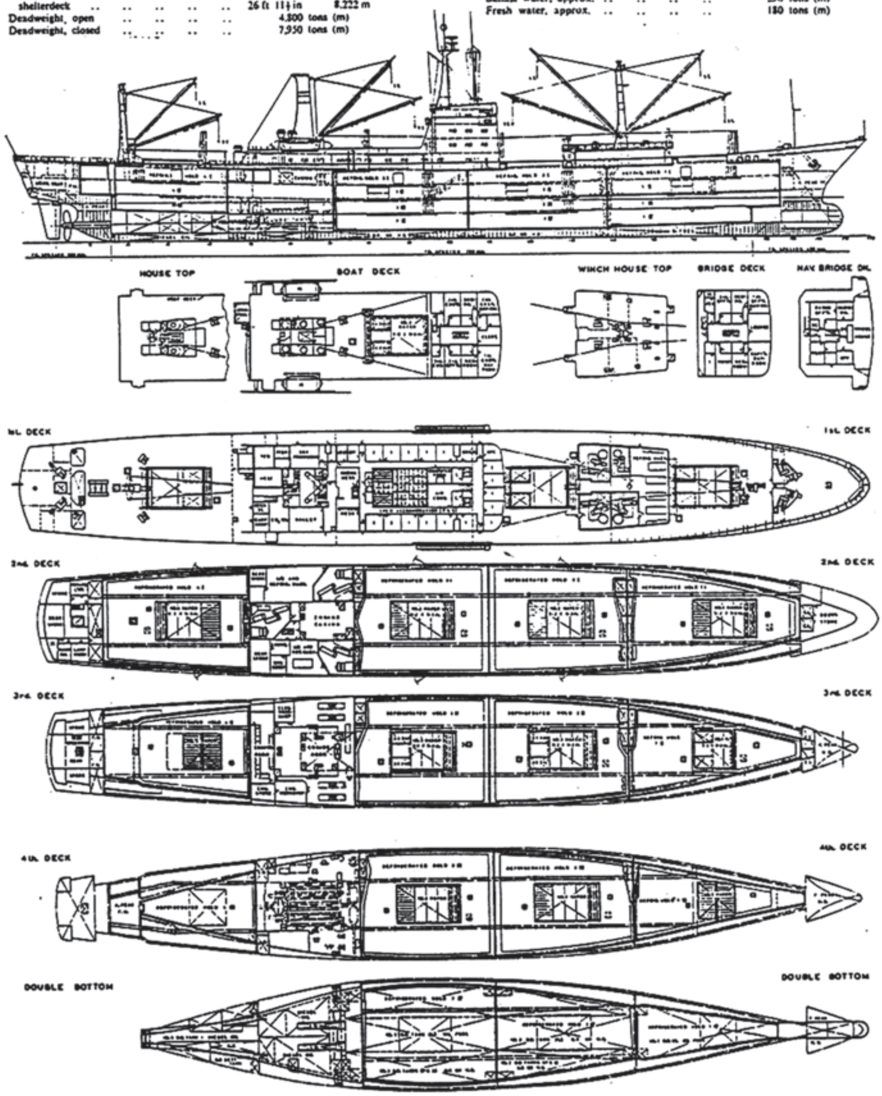

Fig. 4.13 General arrangement of reefer ship "Polar Ecuador," DWT = 4800/7950 t

are defined by the preestimated length between perpendiculars (L_{PP} or L_{BP}, length between perpendiculars). The position of the AP coincides with station/section/frame 0 and by definition passes through the rudder axis/shaft (centerline of rudderstock), while the FP by definition passes through the intersection

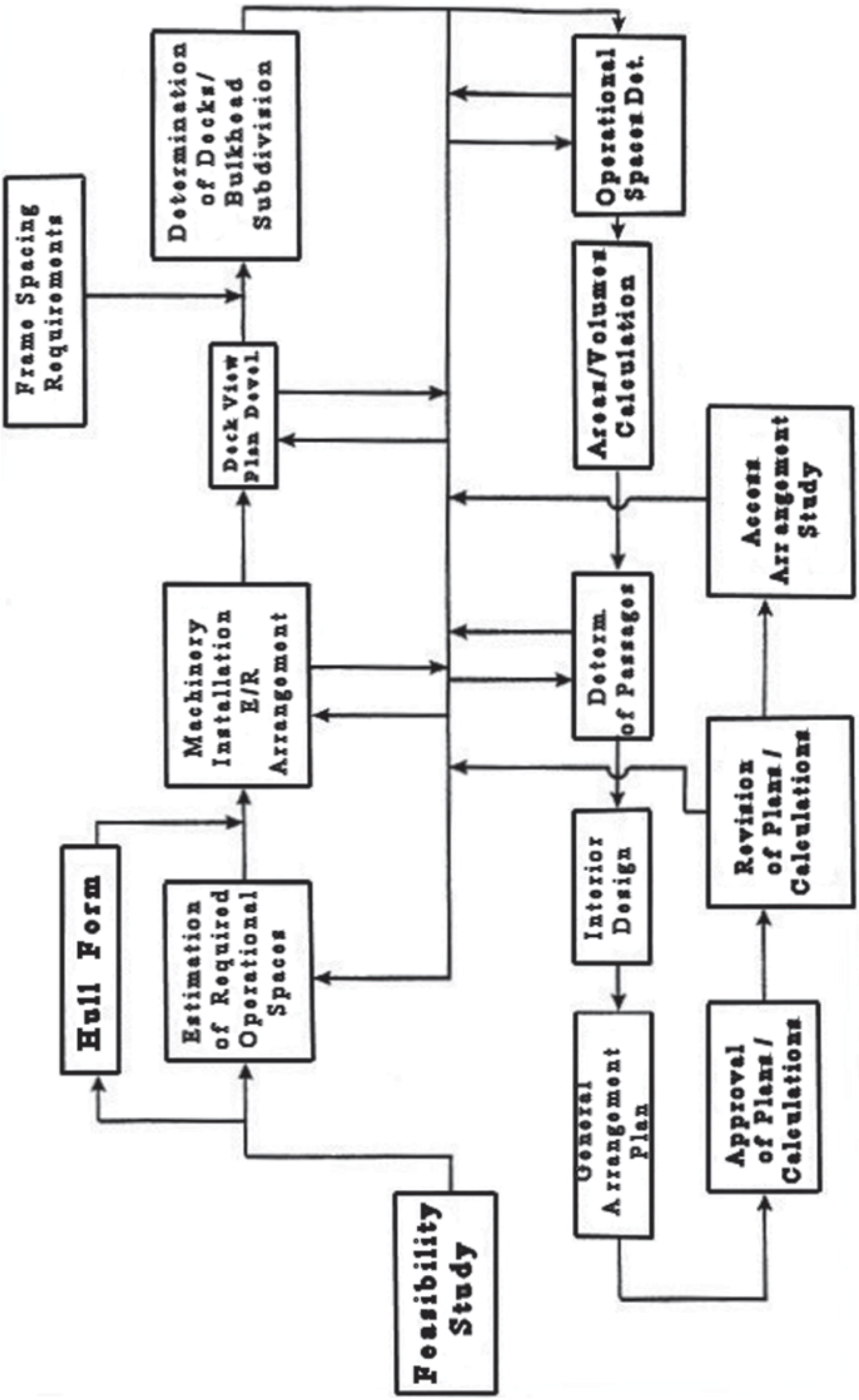

Fig. 4.14 Flowchart of development of a ship's general arrangement

of the design waterline and bow–stern profile. The *building frames/stations* of the ship, whose distance is determined by the specifications of classification societies (see later), are also marked on the baseline.

The elevation of the general arrangement of the ship is drawn as a side profile view above ship's main (strength) deck, and as longitudinal cut view to the ship's centerplane below it. In the elevation plan, the decks and the double bottom upper boundaries are shown as horizontal lines (vertically subdividing the ship), and the transverse bulkheads as vertical lines (lengthwise subdividing the ship).

- The *minimum* height of the double bottom is determined by relevant regulations of recognized classification societies as a function of ship's beam B and draft T; regulations differs (slightly) among different class societies.
  - Det Norske Veritas, DNV [mm]: 250 + 20 B[m] + 50 T[m], with minimum height 650 mm
  - Lloyd's Register, LR [mm]: 28 B[m] + 205 $T^{1/2}$[m], also with minimum height 650 mm
  - American Bureau of Shipping, ABS [mm]: 32 B[m] + 190 $T^{1/2}$[m], for ships with $L \leq 427$ m

The height of the double bottom is increased in the engine room compartments and at the bow for operational and constructional reasons (size of double bottom tanks, accessibility, and strength).

- The *number and the position of the transverse watertight bulkheads* are determined by many factors and depends on:
  - The desired number of cargo holds, engine rooms etc., which, if not specified by the owner, must be determined at the conceptual design stage.
  - The type and size of the ship and the different regulations of watertight subdivisions that govern it. From January 1, 2009, the harmonized probabilistic rules of SOLAS 2009 for the assessment of stability and buoyancy after damage (IMO 2013b, SOLAS, Part B, Chapter II for the passenger ships and Part B-1, Reg. 25 for the dry cargo ships, IMO 2013b) apply to all passenger and dry cargo ships (length over 80 m) built after that date. Within this regulatory framework, the attained subdivision index A[6] must be *greater* than the required *R* (required subdivision index). The level of the index *R* is defined by the SOLAS rules and is dependent on the ship type (passenger or cargo ship), the ship size (expressed by the length), and the number of persons on board (for passenger ships). Obviously, for the same ship size (length), passenger ships have increased requirements of watertight subdivision (and index *R*).

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[6] The attained subdivision index A expresses the survival probability of the ship in case of flooding due to side collision (with the ship assumed being struck by another ship of *similar size*). Consequently, A = 0.60 means that the ship is predicted to survive (does not capsize and/or sink) in *60 % of possible side collisions cases, which lead to the ship's flooding after loss of the ship's watertight integrity (LOWI)* (breach of hull shell). Note that the probability that a ship is engaged in a collision accident is in the range of 10^{-2} to 10^{-3}/shipyear, see, e.g., containership casualty statistics, period 1990–2012, collision frequency 7.04×10^{-3}/shipyear according to published research of Eliopoulou et al. (2013).

– For certain ship types the position of bulkheads is determined by the dimensions of the carried cargo (e.g. containerships), but also by other requirements regarding minimum distances between bulkheads.
– Regarding the minimum number of transverse bulkheads the following needs to be taken into account:

  ◦ The classification societies' rules specify the minimum number of bulkheads form the point of view of ship's structural strength; it depends on the type and length of the ship; bulkheads need to be uniformly distributed for structural adequacy. Furthermore, it is also specified that every ship needs to dispose a forward and aft collision bulkhead, as well as two watertight bulkheads on each side of the engine room; the bulkhead on the stern side of the engine room may coincide with the aft collision bulkhead in case the engine room is located astern. The distance of the forward collision bulkhead from the FP must be within the limits set by SOLAS regulation (between 5 % and 8 % of the ship's length from FP).

– Typical numbers of cargo holds

  ◦ General cargo ships, small containerships, and bulkcarriers
    (1) 4, 100 m $\leq L \leq$ 110 m
    (2) 5, 110 m $\leq L \leq$ 140 m
    (3) 6, 140 m $\leq L \leq$ 170 m
  ◦ *Large containerships:* The length of the holds considers generally the stowage of 40-ft containers (FEU) or 2×20-ft containers (TEU), thus 12.192 m plus margins for cell guides.
  ◦ *Large bulkcarriers:* 7 up to 10
  ◦ *Tankers*: The number is determined in line with the requirements of MARPOL (IMDC 2013a). According to the latest provisions, which follow the specifications of the Oil Pollution Act (OPA 90) of the USA after the catastrophic accident of Exxon Valdez (1989), all tankers must be nowadays of double hull/skin type (see Figs. 4.15 and 4.16). Large tankers (very large crude carrier, VLCC, and ultra large crude carrier, ULCC) have commonly three tanks across (two longitudinal bulkheads) and five tanks lengthwise (3×5), whereas the smaller ones in the category of large tankers (DWT greater than about 50,000 t, PANAMAX, AFRAMAX, and SUEZMAX) have typically two holds across and five to six (seven) lengthwise. MARPOL specifies the maximum size (volume) of each tank and requires that the resulting probabilistic oil outflow index (OOI) is less than a required index, which depends on ship's deadweight.

– *Passenger and Ro-Ro-Passenger (RoPax) ships*: There are no typical values for the number of watertight compartments of passenger ships, which are located below their bulkhead deck, noting that the bulkhead deck is trivially the main car deck for the RoPax ships (Fig. 4.17). The watertight subdivision of passenger ships can be accomplished by fitting of both transverse and longitudinal bulkheads and combinations of both. The density of the watertight

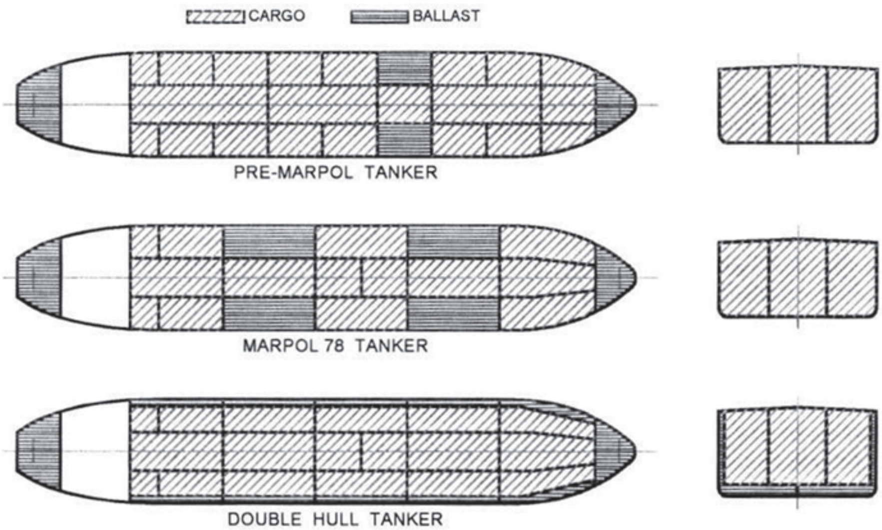

Fig. 4.15 Typical arrangements of tankers (Lamb 2003)

subdivision is determined by the damage stability regulations of SOLAS. These regulations were until recently deterministic (SOLAS 90) and led to the requirement of nonsinking/capsizing in case of flooding of one, two, or three or more watertight compartments of the ship, depending on her size (length) and the number of persons on board.[7] This led commonly to 8–9 transverse bulkheads for one compartment small ships, 11–15 for the two compartments, medium size ships, and 14–16 for the three compartment large ships. The most recent SOLAS regulations, which came into force on January 1, 2009 (SOLAS 2009), are based on the *probabilistic assessment model of damage stability* and lead to the assessment of damage stability in case of flooding of even more than three compartments, according to the probability of occurrence of the likely damage scenarios; consequently, they can lead to different designs of the watertight subdivision. However, it is assumed that the watertight subdivision requirements of the deterministic regulations of SOLAS 90 are practically (on average) *equivalent* to the requirements of the probabilistic SOLAS 2009, except for extreme situations (very small and very large passenger ships; see Papanikolaou 2007).

[7] For Ro-Ro passenger ships, we must additionally take into account that an amount of water may enter the ship's car deck in seaways (water on deck—WOD problem); this greatly affects the ship's stability and buoyancy and may lead to catastrophic accidents (see RoPax *Estonia* accident 1994). These additional WOD requirements apply to all Ro-Ro passenger ships operating in the EU (so-called *Stockholm Agreement*), as well as in other developed countries worldwide (USA, Canada, etc.). The amount of water that is taken into account is a function of the ship's freeboard in a damage situation and the significant wave height in the ship's operational area (see also, Appendix E).

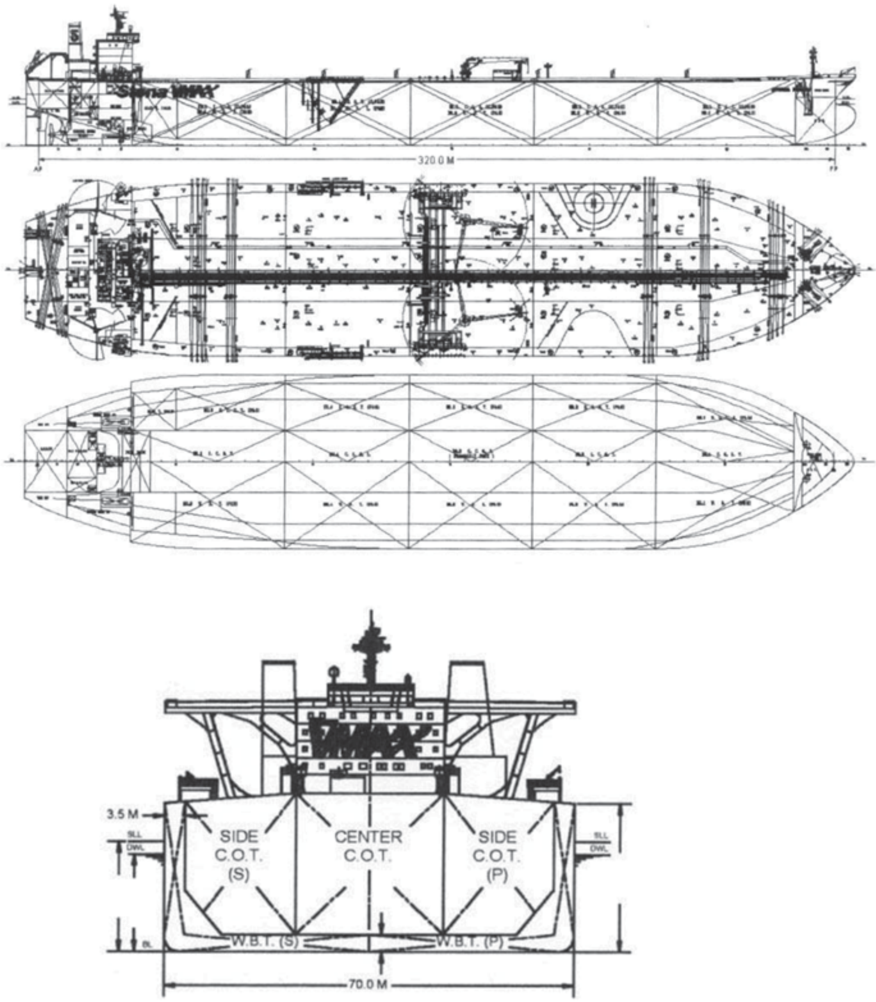

Fig. 4.16 General arrangement of a shallow draft VLCC tanker STENA VISION (Lamb 2003). (Dimensions: $L_{BP}=320.0$ m, $B=70.0$ m, $T_d=16.76$ m, $D=25.60$ m, $\Delta(T_d)=311{,}210$ t, DWT $(T_d)=268{,}000$ t)

- The *frame spacing,* which defined as the distance between the transverse strengthenings/frames of the ship, is specified by the relevant classification society's regulations. The exact distance is determined after specifying the (preliminary) location of the watertight bulkheads lengthwise, taking into account the following:
  - *Minimization* of ship's steel weight: decide on the distance of frames in conjunction with the fitting of reinforced web frames in between the simple frames

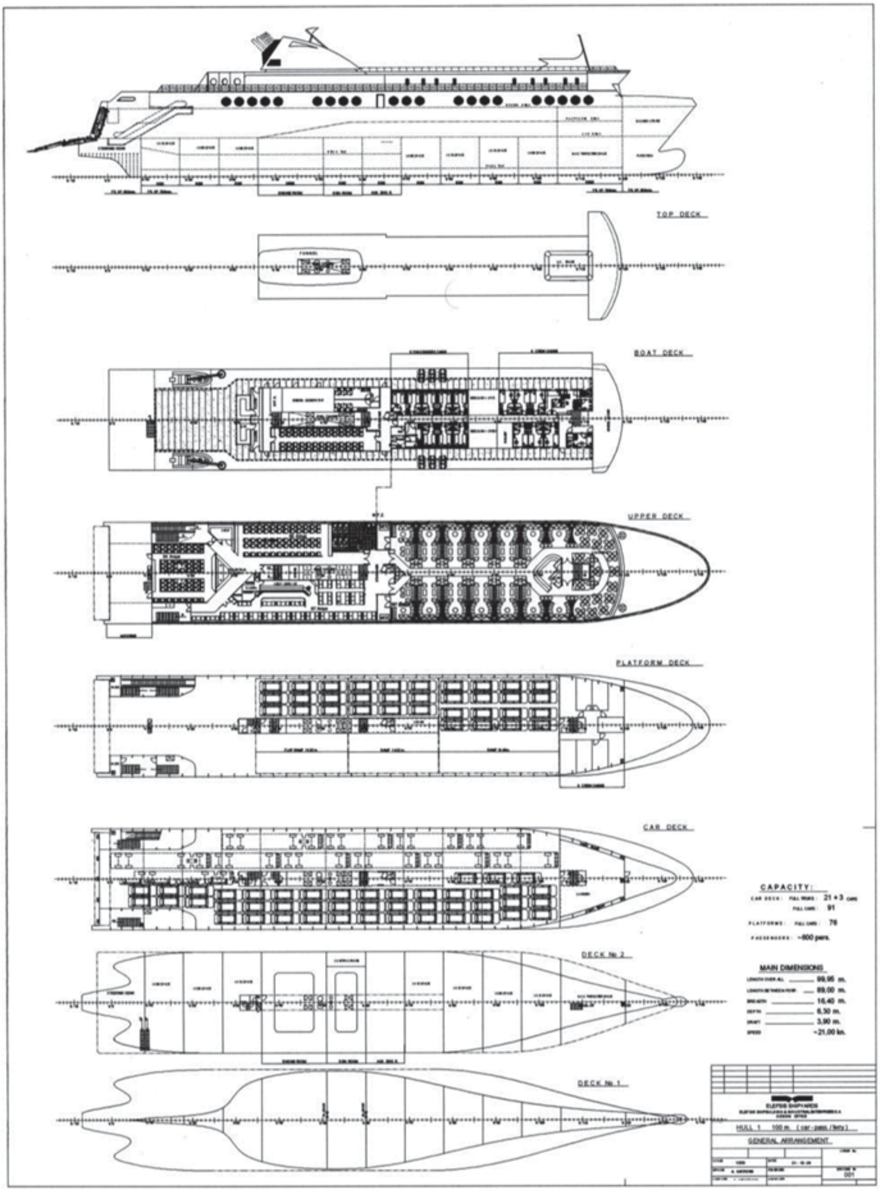

Fig. 4.17 General arrangement of a RoPax ship. Research project EPAN—Transport, NTUA—Elefsis Shipyard (2005–2007)

- *Uniform* distribution of structural elements, particularly keeping fixed distances of the web frames in the holds
- *Positioning* of the building frames along the ship's general arrangement in such a way that coplanar structural frameworks are formed, e.g.,

The length of holds must correspond to a number of frames with a constant distance between them; transverse bulkheads are fitted exactly on building frames' position.

The lengthwise boundary of the superstructures and of their compartments must also correspond to a number frames with a constant distance between them.

- For the estimation of the frame spacing *around amidships* the directive of the Norwegian Classification Society, DNV, can be used:
  $s[mm] = 2(240 + L[m])$
- At the two ends of the ship (especially at the bow), the classification societies require *higher frame density* (smaller distances), compared to that at amidships, to account for the increased loads of the steel structure from wave loads at ship's ends (slamming).

2. **Top-Down Views of Deck Plans** The top-down views of the deck plans include:

- An intersection of the ceiling of double bottom and view of the plan of the tanks
- Intersections and plan views for all the decks, from the bridge down to the double bottom; the transverse and longitudinal subdivision of deck spaces is shown. Top-down plan views of the forecastle, bridge and poop, and generally of all the deckhouses (cargo ships) are included.
- In passenger ships, the main vertical *fire safety zones* are also shown; typically, they are extensions of the watertight bulkheads extending below the main deck. The distance of these fire zones should not exceed 40 m (according to the SOLAS regulations), and any exceedance of this limit must be justified by dedicated studies and approved by competent authorities.

3. **Midship Section Plan** It is presented as a transverse plane intersection below the main deck of the ship and as a view from ship bow above the main deck. However, very often it is omitted in the general arrangement of the ship in the preliminary design stage.

4.6 Capacity Plan

The *capacity plan* complements the main set of plans describing a ship's hull (lines plan) and the arrangement of spaces and equipment/outfitting of the ship (GA). This plan specifies the amount of cargo, fuel, fresh water, supplies, and seawater ballast, which the ship can carry, shows the spaces for their carriage. For the development of this plan, the *volumetric capacity curves* of the ship can be used (see Sect. 2.17.2).

This plan includes at least the following:

- Longitudinal (later profile) view of the ship as cut/intersection in ship's centerplane; it shows the arrangement of spaces and their use. The building frames of the ship are plotted on the baseline.
- The principle dimensions and other basic characteristic values of the ship

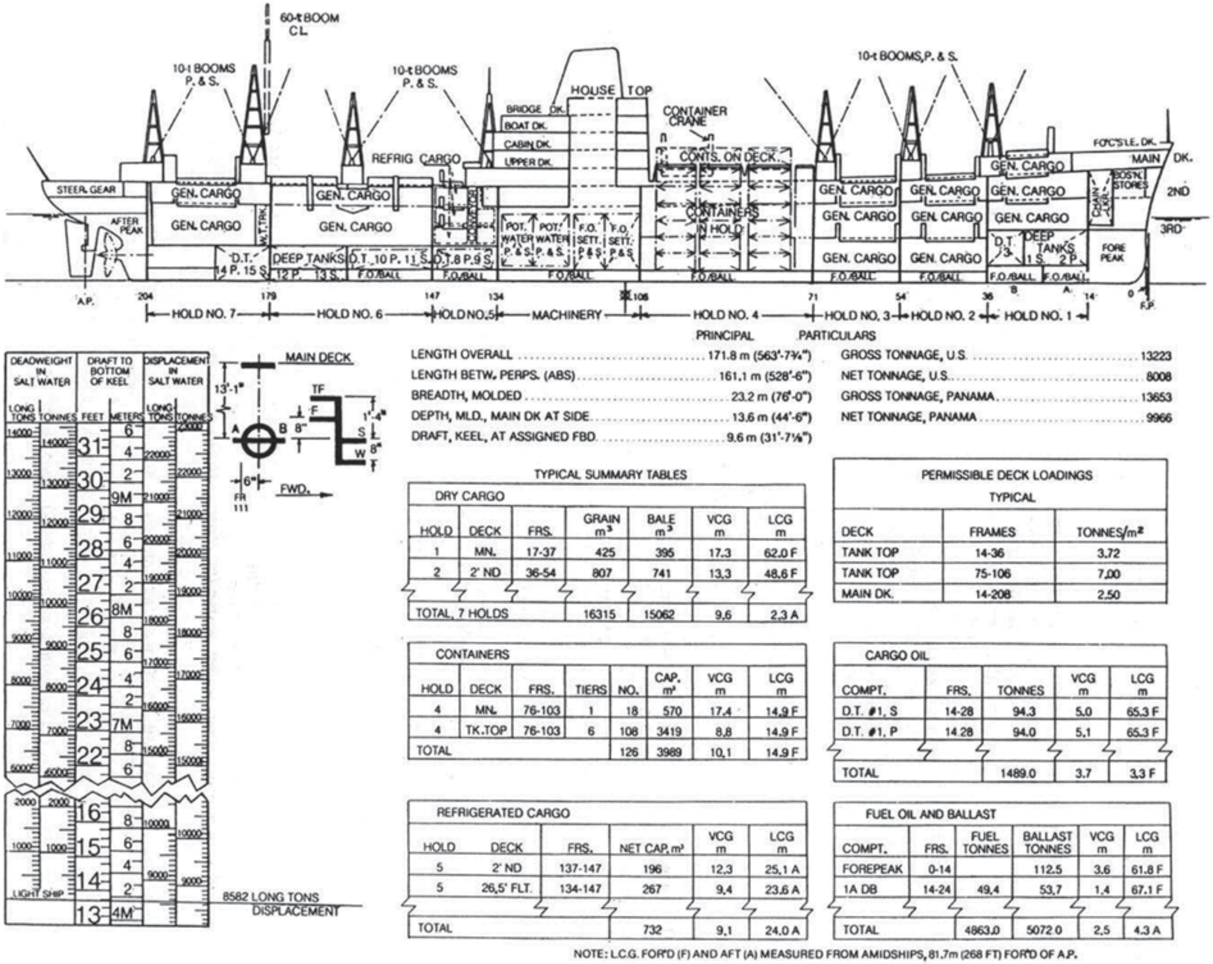

Fig. 4.18 Plan of a multipurpose cargo ship (Lamb 2003)

- The carried cargo quantities, fuel, fresh water, supplies, and seawater ballast and their location, including the longitudinal and vertical position of each weight group. In cases of asymmetric loading, the transverse position of the center of mass of each weight group is also required.
- *Deadweight scale* in correspondence to the scales of drafts and displacement[8]. Alongside these scales, also the corresponding TPcm and MTcm scales are often shown.[9]
- The freeboard marking and Load Line mark (Plimsoll mark).

The below example (Fig. 4.18, Lamb 2003) refers to the capacity plan of a multipurpose cargo ship, with transport capacity of 14,250 tons DWT, with 7 cargo holds, including one hold to accommodate containers in cells and a refrigerated cargo hold. The ship can carry in certain holds (deep tanks) oil, as well as containers on deck.

References

Antoniou A, Perras P (1984) Ship design—special chapters (in Greek: Μελέτη Πλοίου - Ειδικά Κεφάλαια), Rev. 2. Foivos Publisher, Athens

Eliopoulou E, Hamann R, Papanikolaou A, Golyshev P (2013) Casualty analysis of cellular containerships. Proceedings of the 5th international design for safety conference (IDFS 2013), Shanghai, Nov 2013

Friis AM, Andersen P, Jensen JJ (2002) Ship design (Part I & II). Section of Maritime Engineering, Dept. of Mechanical Engineering, Technical University of Denmark. ISBN 87-89502-56–6

International Maritime Organization, IMO (2013a) SOLAS, consolidated edition. Consolidated text of the International convention for the safety of life at sea, 1974, and its protocol of 1988: articles, annexes and certificates

International Maritime Organization, IMO (2013b) MARPOL 73/78, consolidated edition

Lamb T (ed) (2003) Ship design and construction. SNAME, New York (revision of the book: D'Arcangelo AM (ed) (1969) Ship design and construction. SNAME, New York)

Papanikolaou A (2003) Ship design and outfitting II—detailed design (support course material, in Greek: Μελέτη και Εξοπλισμός Πλοίου II, Στοιχεία Αναλυτικής Σχεδίασης), National Technical University of Athens, Athens

Papanikolaou A (2007) Review of damage stability of ships—recent developments and trends. Proceedings of PRADS 2007, Houston, Oct 2007

Papanikolaou A (2009) Ship design—methodologies of preliminary ship design (in Greek: Μελέτη και Εξοπλισμός Πλοίου I, Μεθοδολογία Προμελέτης Πλοίου), Vol 1. SYMEON, Athens, ISBN 978-960-9600-09-01 and Vol. 2, ISBN 978-969-9400-11-4, Oct 2009

Papanikolaou A, Anastassopoulos K (2002) Ship design and outfitting I (support material to the course, rev. 2 (in Greek: Μελέτη και Εξοπλισμός Πλοίου I, Μεθοδολογία Προμελέτης Πλοίου, Συλλογή Βοηθημάτων). National Technical University of Athens, Athens

Papanikolaou A, Zaraphonitis G (1988) Computer applications in ship design. Hellenic Technical Chamber, Athens

Perras P (1979) Formdata series of diagrams and instruction booklet. National Technical University of Athens, Laboratory of Ship Hydrodynamics, Rep. No. 10–79

Schneekluth H (1985) Ship design (in German). Koehler, Herford

Taggart R (ed) (1980) Ship design and construction. SNAME, New York

[8] The draft scales refer to amidships.

[9] *TPcm: tons per centimeter immersion; MTcm: moment to change trim 1 cm.*