Chapter 2
Selection of Main Dimensions and Calculation of Basic Ship Design Values

Abstract This chapter deals with the determination of the main ship dimensions (length, beam, draft, side depth), following the estimation of the ship's displacement and the selection of other basic ship design quantities and hull form characteristics (hull form coefficients, powering, weight components, stability and trim, freeboard, load line), as required in the first phase of ship design, that is, the *Concept Design*. The various effects of specific selections of ship's main dimensions etc. on the ship's hydrodynamic performance, stability and trim, structural weight and construction cost, utilization of spaces, and transport economy are elaborated. The selection procedure is supported by statistical data and empirical design formulas, design tables and diagrams allowing direct applications to individual ship designs. Additional reference material is given in Appendix A.

2.1 Preliminary Estimation of Displacement

For deadweight carriers (Sect. 1.3.7.1), which are characterized by the carriage of relatively heavy cargos (low cargo Stowage Factor (SF) and low Ship Capacity Factor), but also for every category/type of ship with sufficient comparative data from similar ships on vessel's displacement, the preliminary design starts with the estimation of ship's displacement weight Δ.

For deadweight carriers, it is possible to estimate Δ for a given deadweight DWT, for instance, as the DWT is one of shipowner's main requirements.

Typical ways of estimating Δ are the following:

a. Using DWT/Δ ratios for various types of ships (see Table 2.1);
b. Using semiempirical mathematical formulae from statistics, regression analyses of data of similar vessels (see, for example analysis of technical database for various types of ships, such as the database of IHS Fairplay (IHS WSE 2011, former Lloyds Register of Shipping), and data from regression analyses studies of

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Table 2.1 Typical sizes and percentages of weight groups for main merchant ship types (compilation of data from Strohbusch (1971), Schneekluth (1985), updated by Papanikolaou using IHS Fairplay World Shipping Encyclopedia, v. 12.01, 2011)

	1	**2**	3	4	5	6
Ship type	Limits		DWT/Δ (%)	W_{ST}/W_L (%)	W_{OT}/W_L (%)	W_M/W_L (%)
	Lower	Upper				
General cargo ships (t DWT)	5,000	15,000	65–80	55–64	19–33	11–22
Coasters, cargo ships (GRT)	499	999	70–75	57–62	30–33	9–12
Bulk carriers[a] (t DWT)	20,000	50,000	74–85	68–79	10–17	12–16
	50,000	200,000	80–87	78–85	6–13	8–14
Tankers[b] (t DWT)	25,000	120,000	78–86	73–83	5–12	11–16
	200,000	500,000	83–88	75–88	9–13	9–16
Containerships (t DWT)	10,000	15,000	65–74	58–71	15–20	9–22
	15,000	165,000[c]	65–76	62–72	14–20	15–18
Ro-Ro (cargo) (t DWT)	$L \cong 80$ m	16,000 t DWT	50–60	68–78	12–19	10–20
Reefers[d] (ft^3) of net ref. vol.	300,000	500,000	45–55	51–62	21–28	15–26
Passenger Ro-Ro/ferries/ RoPax	$L \cong 85$ m	$L \cong 120$ m	16–33	56–66	23–28	11–18
Large passenger ships (cruise ships)	$L \cong 200$ m	$L \cong 360$[e] m	23–34	52–56	30–34	15–20
Small passenger ships	$L \cong 50$ m	$L \cong 120$ m	15–25	50–52	28–31	20–29
Stern Trawlers	$L \approx 44$ m	$L \cong 82$ m	30–58	42–46	36–40	15–20
Tugboats	$P_B \cong 500$ KW	3,000 KW	20–40	42–56	17–21	38–43
River ships (towed)	$L \cong 32$ m	$L \cong 35$ m	22–27	58–63	19–23	16–21
River ships (self-propelled)	$L \cong 80$ m	$L \cong 110$ m	78–79	69–75	11–13	13–19

W_L light ship weight, W_{ST} weight of steel structure, W_{OT} weight of outfitting, W_M weight of machinery installation

[a] Bulk carriers without own cargo handling equipment

[b] Crude oil tankers

[c] Triple E class of containerships of Maersk, DWT = 165,000 t, first launched 2013

[d] Banana reefers

[e] Oasis class cruise ship of Royal Caribbean Int., $L = 360$ m, 225,282 GT, launched 2009

the Ship Design Laboratory of NTUA (http://www.naval.ntua.gr/sdl). Illustrative examples of regressive analysis of basic characteristics for various types of ships are shown in Appendix A;

c. Using specific diagrams, for example (DWT/Δ) versus (DWT) and/or (speed) for various types of ships (see Figs. 2.1, 2.2, 2.3, and Appendix A).

It should be noted that for the volume carriers (Sect. 1.3.7.2), which are distinguished by their small DWT/Δ ratios, it is not appropriate to first estimate Δ with the above methods, nor at this initial stage, except for the cases for which there are robust comparative data from similar ships. In addition, further factors that also affect displacement, other than DWT, that is, type and required power of machinery system, the complexity of steel structure and the extent of outfitting, should be

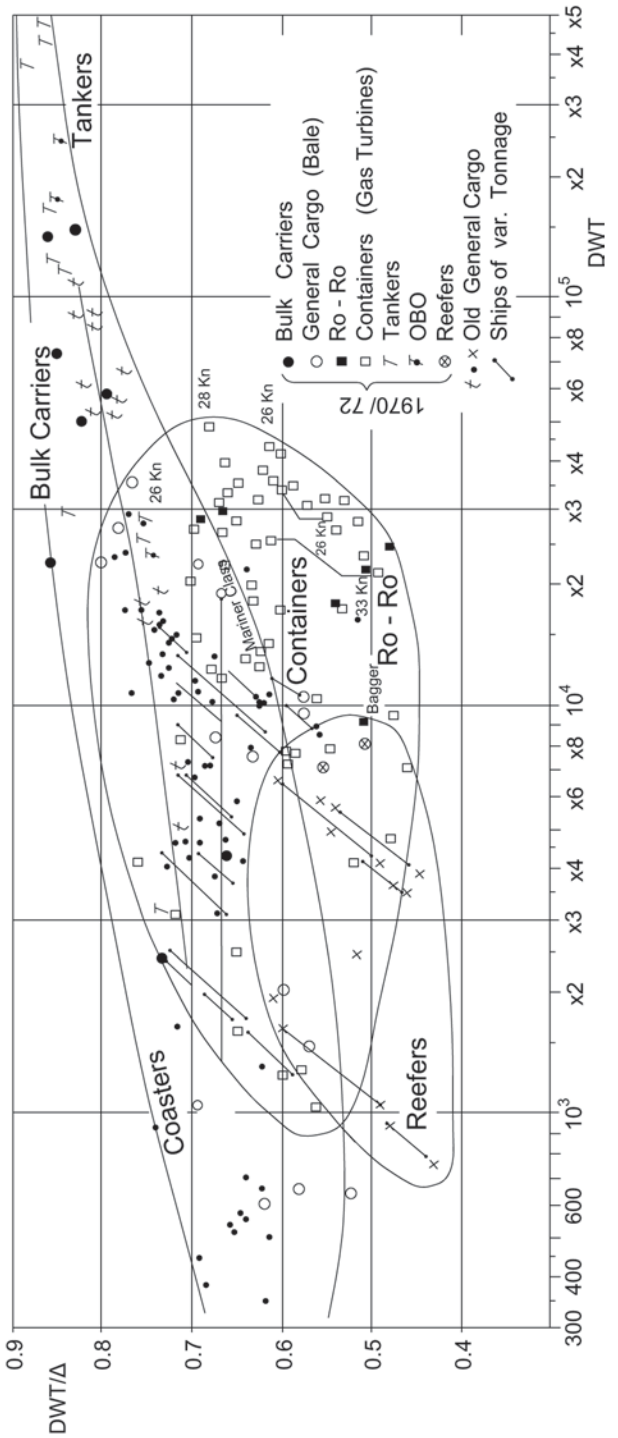

Fig. 2.1 (DWT/Δ) ratios versus DWT for cargo ships by Völker (1974)

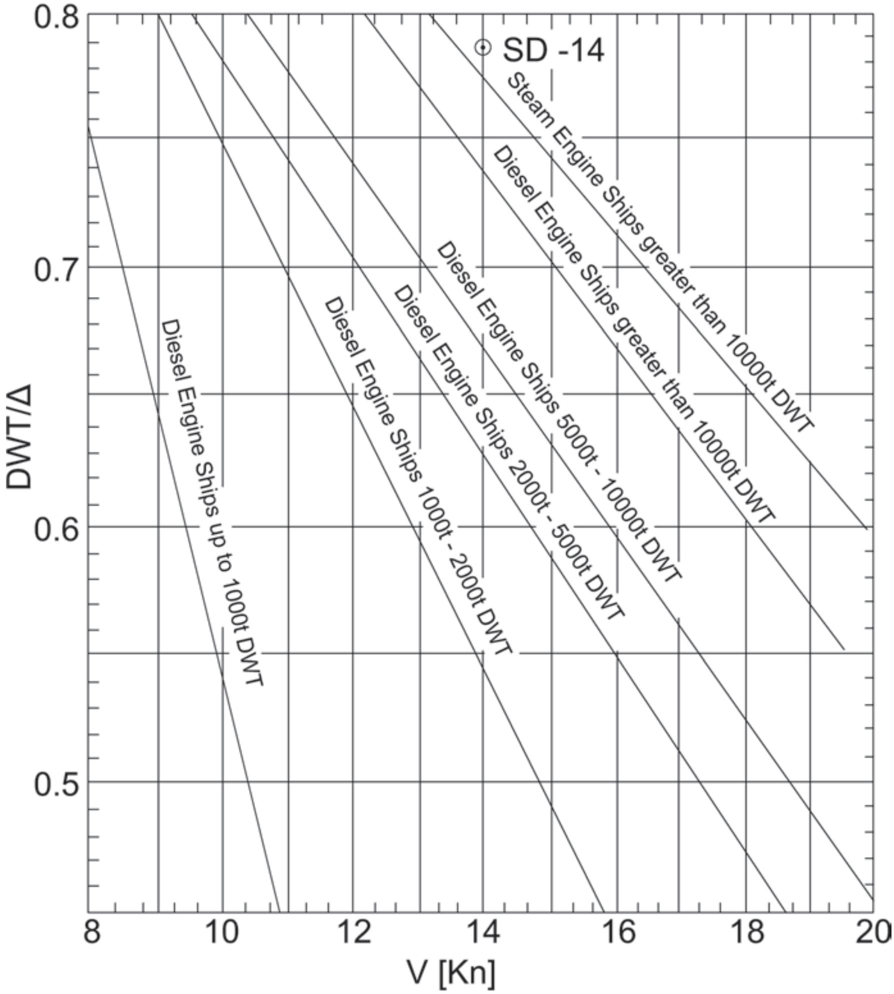

Fig. 2.2 Qualitative trend values of (*DWT/*Δ) ratios versus DWT and speed *V* for diesel engine ships by Schünemann (Henschke 1964)

checked with respect to possible deviation from typical/normal characteristics of comparative ships.

As described later on, it is possible to more accurately calculate the displacement by analysis of the various weight components that constitute the displacement weight Δ; however, this requires additional information from similar ships. E. Danckwardt's approximate method, though relying on past years' design practice, proved useful in related estimations of general cargo ships (see Papanikolaou 2009a).

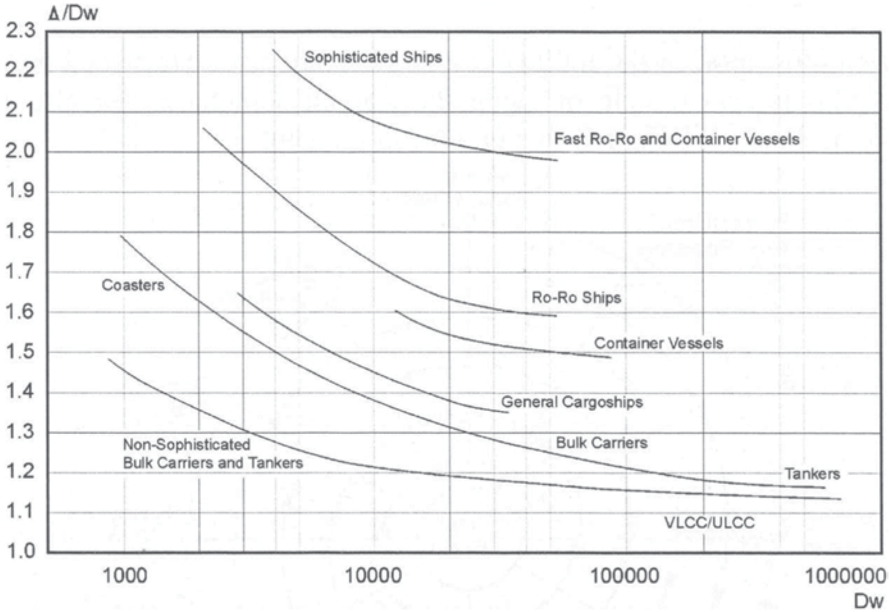

Fig. 2.3 (Δ/DWT) ratios versus DWT for various ship types, Harvald (1986) (see Friis et al. 2002)

2.2 Selection of the Main Dimensions and Form Coefficients

The procedure of determining the main dimensions, that is length *L*, beam *B*, draft *T*, side depth *D*, and hull form coefficients (initially the block coefficient $C_B$and then the other coefficients C_P, C_M and C_{WP}) should be conducted considering the following basic factors:

1. Ship's hydrodynamic performance (resistance and propulsion, seakeeping, maneuverability)
2. Satisfactory stability
3. Sufficient volume of cargo holds
4. Adequate structural strength
5. Construction cost

The common sequence of determining the main dimensions, form coefficients, and other basic sizes has been briefly described in Sect. 1.3.7. In this section we present first the general principles governing the selection of the main dimensions and secondly various useful semiempirical formulas, which are analyzed from both the phenomenological and scientific point of view; they express relationships of ship's main dimensions and ship's fundamental properties.

The main objective in the determination of the main dimensions is to fulfill the set shipowner's requirements, which mainly concern the following:

a. Transport capacity (DWT, payload, and cargo hold volume)
b. Service speed and endurance range
c. IMO and national safety regulations (SOLAS-IMO 2013b, MARPOL-IMO 2013a, ICLL 1988, etc.) and construction standards of a recognized classification society.

The fulfillment of the aforementioned requirements should be associated with the best possible economic (optimal) solution, in terms of the minimum cost for ship's construction and operation, or even with respect to more complex economic criteria, like required freight rate (RFR), net present value (NPV), and return on investment (ROI).

The selection of the main dimensions, that is, of length *L*, beam *B*, draft *T*, side depth *D*, and essentially of the freeboard F_b (=D−T), as well as of the block coefficient C_B, determines to which extent the under-design ship will satisfy the aforementioned owner's requirements. Typically, improper selections and combinations thereof for the basic dimensions are almost impossible to be corrected retrospectively; they generally lead to uneconomic and/or technically insufficient solutions.

The procedure of selecting the main dimensions and characteristic sizes is based on an iterative approach with appropriate sequence, for example, estimation of displacement, selection of length, determination of C_B, determination of the beam, draft and side depth. This order applies to deadweight carriers and should be adjusted accordingly for volume carriers (see Sects. 1.3.7.1 and 1.3.7.2).

The basic factors on determining the main sizes are summarized in the following:

1. **Length *L*:** This is a function of displacement and speed. It has a significant influence on the weight of steel structure and accommodation/outfitting, hence on the construction cost. Also, it strongly affects both the ship's calm water resistance and seakeeping performance (motions, accelerations, dynamic loads, added resistance, and speed loss in seaways).
2. **Block coefficient C_B:** This is a function of the Froude number and is influenced by the same factors as for the length L.
3. **Beam *B*, Draft *T*, side depth *D*:** The determination of these dimensions is actually coupled and is affected by the following basic factors:

   - hold volume (*D*)
   - stability (*B*)
   - required freeboard (*D*, *T*)
   - safety against flooding and capsize (*B*, *D*, *T*)
   - propulsive and manoeuvring devices (*T*)

The main dimensions *L*, *B*, and *T* are often affected as well by the topological *limits of the route*, that is, the dimensions of canals, ports, channels, and confined waters that the under-design ship needs to pass through. Mostly the restrictions are referring to allowable drafts.

Some typical dimensions of well-known canals and channels (maximum allowable ship dimensions) are:

Panama Canal	$L<289.56$ m (in general for merchant ships)
	$L<299.13$ m (passenger ships and containerships up to 5,000 TEU)
	$B<32.31$ m (exceptionally 32.61 m, if $T<11.28$ m)
	T < 12.04 m (as the maximum allowable draft for tropical fresh water TFW, as applicable)
Suez Canal	L: no limit
	$B<71.02$ m (233 ft)
	$T<10.67$ m (concerning stern draft in ballast condition)
	$T<12.80$ m (maximum allowable draft for $B<47.55$ m, concerning fully loaded voyages southbound)
	$T<16.15$ m (maximum allowable draft for $B<42.67$ m, concerning fully loaded voyages northbound)
Canal St. Lorenz (North America—Canada Great Lakes)	$L<222$ m
	$B<23$ m
	$T<7.6$ m
Northeast Sea Channel (Nord-Ostseekanal—Northern Europe)	$L<315$ m
	$B<40$ m
	$T<9.5$ m
Malacca Straits (between Malaysia Peninsular and Sumatra island)	$T<25$ m

New Panamax maximum passing dimensions (expected, as of 2014): length: 366 m, width: 49 m, draft: 15.2 m, capacity of containers: 12,000 TEU

Finally, in rare cases, the ship length may be constrained by the length of slipways or docks of selected shipyards, with which the shipowner has long-term collaboration in new buildings and/or maintenance of his fleet.

For shaping the ship's hull form, both below the waterline and above, it is required to determine a series of other naval architectural characteristics that are either numerically identifiable sizes or typical qualitative features. It should be noted, however, that the shaping of the hull form cannot be reduced to the determination of certain individual characteristic numerals, but includes quantitative and qualitative interactions among them.

The main numerical values/quantities that describe the hull form of a ship (symbols and definitions according to ITTC (International Towing Tank Conference 2008) are:

a.1 The block coefficient, C_B
a.2 The midship section coefficient, C_M
a.3 The prismatic coefficient, C_P
a.4 The waterplane area coefficient, C_{WP}

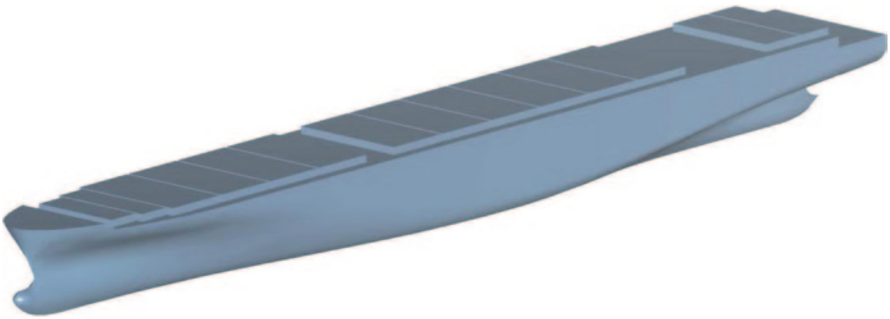

Fig. 2.4 Three-dimensional hull of a container ship designed with software TRIBON® at Ship Design Laboratory of NTUA

a.5 The slenderness ratio ($L/\nabla^{1/3}$) or the volumetric coefficient (∇/L^3)
a.6 The longitudinal center of buoyancy, $\overline{AB}$
a.7 The vertical position of center of buoyancy above baseline, $\overline{KB}$
a.8 The parallel body length, L_P
a.9 The length of entrance/run of sectional areas, L_E/L_R

The above sizes will be discussed in subsequent paragraphs.

The qualitative characteristics, which supplement the determination of the hull form of a ship, are:

b.1 Sections' character below waterline
b.2 Sections' character above waterline
b.3 Shaping of bow section (bow type, profiles of waterlines and sections in bow region, bulbous bow)
b.4 Shaping of stern section (stern type, profile of waterlines and sections in stern region, stern bulb, flow to propeller and rudder)
b.5 Freeboard and sheer deck

These features will also be discussed in subsequent paragraphs (Fig. 2.4).

2.3 Selection of Length

Satisfaction of the owner's main requirements (with respect to transportation capacity, service speed, endurance/range, and safety regulations) is possible with different choices of ship length. However, it is logical to look ultimately for the optimal length with respect to some economic criteria determined by the interests of the yard and/or the owner. In the first case, the employed economic criterion is the "minimum construction/building cost", whereas in the second case, ship's economy is generally evaluated by the "minimum required freight rate (RFR) per ton of cargo" criterion.

Two examples of optimization of the ship length with respect to the "minimum construction cost" and alternatively the "maximum return on investment" are given in Papanikolaou (2009a, Vol. 2). From the available data, it is concluded that for fixed/given hold volume and displacement, increasing the length generally leads to an increase of the ship's structural weight and to a reduction of the ship's required propulsion power for achieving the specified speed.

As to the effect of a length increase on the other ship weight components (for fixed displacement), it also increases the accommodation/outfitting weight, what generally leads to a reduction of the ship's payload. The resulting reduction of propulsion power and the corresponding reduction of machinery and fuel weights, cannot balance the increases of the other weight components; thus, in order to maintain a certain payload level specified by the shipowner, it is required to increase the displacement, what induces some increase in propulsion power (proportional to $\Delta^{2/3}$), etc.

Regarding the building cost, the increase of length implies an increase of the steel cost, while a limited reduction of the cost of machinery propulsion system may be expected (see Chap. 6: estimation of shipbuilding cost). In simple approaches (apart from parametric mathematical optimizations) , the identification of the optimum, most economical solution may be accomplished by systematic variation of the ship's length around an estimated initial length. The latter results from comparisons with similar ships, by use of empirical diagrams or semiempirical formulas (see Appendix A and examples in Papanikolaou (2009a, Vol. 2).

2.3.1 Effect of Length on Resistance

It is assumed that, the total resistance R_T of a ship, with a wetted area S, sailing at speed V in calm water of density ρ, can be decomposed according to the hypothesis of W. Froude[1] (1868) as follows:

$$R_T = R_F + R_R \tag{2.1}$$

where R_T is the **T**otal **R**esistance or **T**owing **R**esistance, which has two components,

- the Frictional Resistance R_F and
- the Residuary Resistance R_R

that are elaborated in the following.

The qualitative characteristics of the per ton displacement total ship resistance and of its main components for various speed–length ratios $V\ (kn)/\sqrt{L\ (\text{ft})}$ are illustrated in the following graph (Fig. 2.5).

The frictional resistance is determined as

$$\text{Frictional resistance: } R_F = \tfrac{1}{2} C_F \rho S V^2 \tag{2.2}$$

[1] William Froude (1810–1878) Eminent English engineer, naval architect and hydrodynamicist; he was the first to formulate correctly the law for ship's water resistance and to set the foundations for modern ship model testing, by introducing a unique dimensionless similitude number (Froude number) by which the results of small-scale tests could be used to predict the behaviour of full-sized ships; of importance are also his contributions to ship's stability in waves.

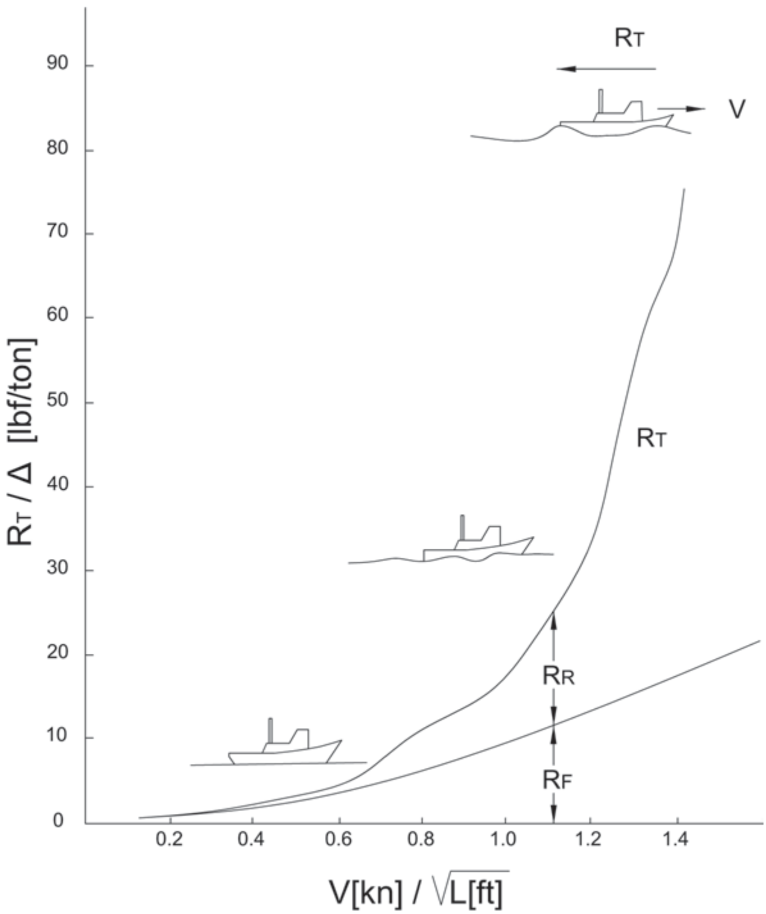

Fig. 2.5 Typical total resistance (per ton displacement) curve as a function of the speed–length ratio $V/\sqrt{L}$ for displacement ships (without dynamic lift)

where

$C_F = f(R_n)$: nondimensional frictional resistance coefficient dependent on the nondimensional Reynolds number, that is, $R_n = V \cdot L/\nu$, ν: sea water's kinematic viscosity ($= 1.19 \cdot 10^{-6}$(m²/s) at 15 °C), $L = L_{WL}$, V ship's speed (m/s).

$C_F = 0.075/(\log_{10} R_n - 2)^2$
according to ITTC 1957.

S: wetted hull surface, $\approx (3.4 \cdot \nabla^{1/3} + 0.5 L_{WL}) \cdot \nabla^{1/3}$ according to Lap (Figs. 2.6 and 2.7).

$$\text{Residuary resistance } R_R = \tfrac{1}{2} C_R \rho S V^2 \tag{2.3}$$

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