### 5.5.4. Guldhammer's and Harvald's Diagrams

In the publication *Ship Resistance* (Guldhammer and Harvald, 1965, 1974) an assembly of published

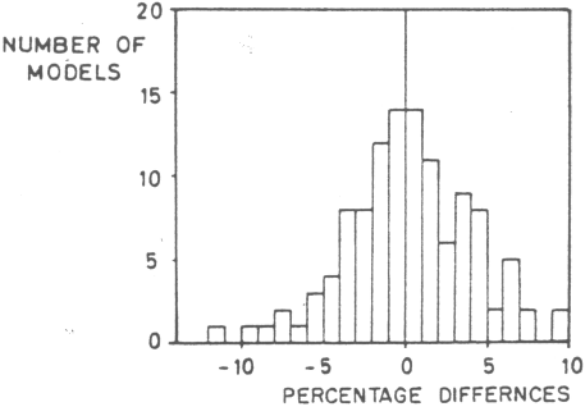


**Figure 5.5.3.** Frequency distribution of errors in the NSMB method of approximating the resistance.

results from towing tests have been coordinated. The analysis of the collected basis material has been carried out in the following way:

1. All data have been referred to the model area, and the model resistance ($R_{Tm}$) has been determined as a function of speed.
2. The specific total resistance coefficient of the model ($C_{Tm}$) has been determined:

$$C_{Tm} = \frac{R_{Tm}}{\frac{1}{2}\rho V_m^2 S_m} \qquad (5.5.5)$$

where $\rho$ is the mass density, $V_m$ is velocity of model, $S_m$ is wetted surface of model (= mean girth × length on waterline).

3. The specific residual resistance coefficient has been determined from

$$C_R = C_{Tm} - C_{Fm} \qquad (5.5.6)$$

where $C_{Fm}$ is the specific frictional resistance coefficient. The "ITTC 1957 model–ship correlation line" has been used to determine the frictional resistance coefficient

$$C_F = \frac{0.075}{(\log_{10} R_n - 2)^2} \qquad (5.5.7)$$

where $R_n$ is the Reynolds Number ($VL/\nu$, where $\nu$ is coefficient of kinematic viscosity and $L$ is the length on waterline). In Fig. 5.5.4 contours of $C_F$ are given for different values of $V$ and $F_n$. The abscissa is the length $L$ of the model. The diagram corresponds to $\nu = 1.139 \times 10^{-6}$ m s$^{-1}$, $\rho = 1.000$ t/m$^3$, and $T = 15$°C. The diagram may therefore be used at other conditions, that is, other densities and temperatures, only if the length is altered before entering the diagram to

$$L_1 = \frac{1.139}{10^6 \nu} L \qquad (5.5.8)$$

4. $C_R$ has been expressed as a function of Froude number

$$F_n = \frac{V}{\sqrt{gL}} \qquad (5.5.9)$$

(the speed–length ratio $V/\sqrt{L}$, where $V$ is measured in knots and $L$ is in feet, is found as a subscale on the $C_R$ diagrams).

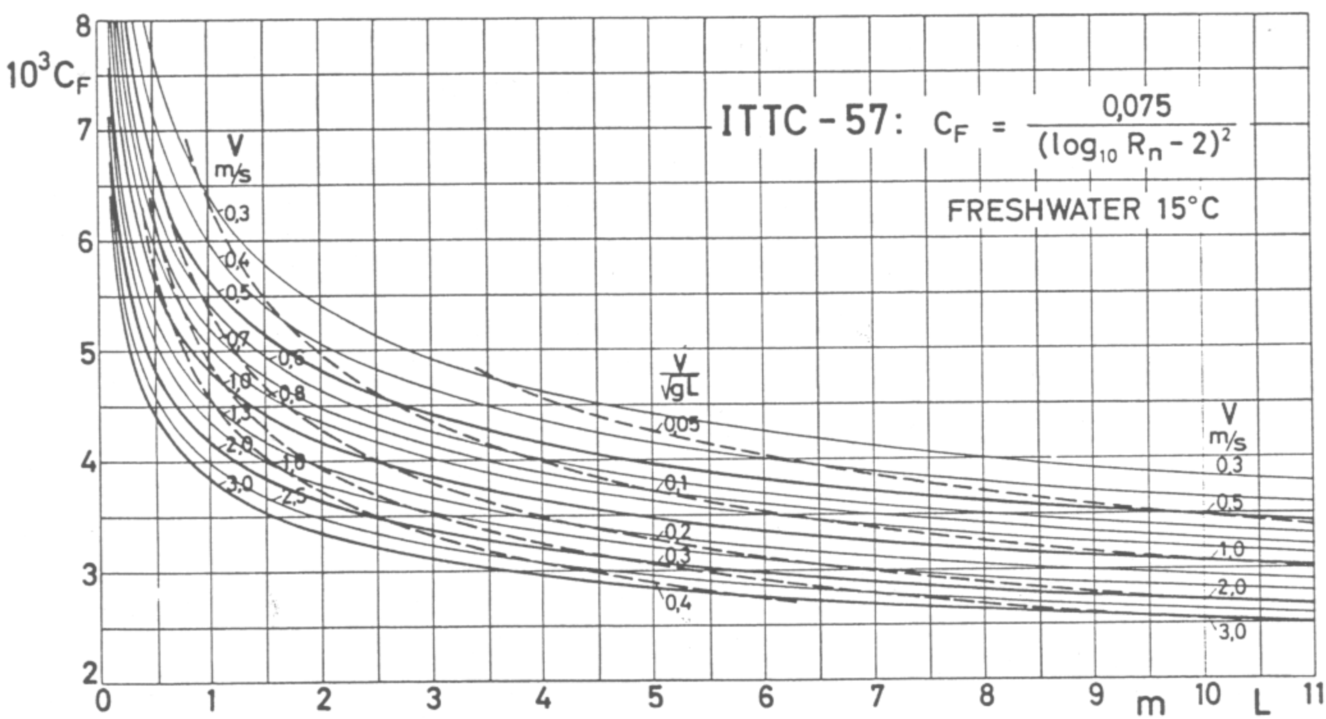


**Figure 5.5.4.** The frictional resistance coefficient $C_F$ (according to ITTC 1957) as a function of ship–model length $L$ and speed $V$.

5. The results have been arranged in groups according to length–displacement ratio $L/\nabla^{1/3}$ and the prismatic coefficient $\varphi$ of the model. Here $\nabla$ is the volumetric displacement and

$$\varphi = \frac{\nabla}{LBT\beta} \qquad (5.5.10)$$

where $B$ is breadth, $T$ is draught, and $\beta$ is midship section area coefficient.
6. The main diagrams have been drawn giving the mean curves of $C_R$ for the breadth–draught ratio $B/T = 2.5$. The diagrams are shown in Figs. 5.5.5–5.5.13.

In some places in the diagram the curves are dotted in order to indicate that they have been based either on very few test results or determined by extrapolation. The uncertainty is therefore comparatively great in these areas. Furthermore, it should be noted that the uncertainty is also great in and near the areas where the curves have pronounced humps, especially where the slope becomes negative. Small alterations in the hull form in these areas can considerably influence the $C_R$ value.

It must also be mentioned that the resistance curves correspond to vessels with a standard form, that is, a standard position of the center of buoyancy, standard $B/T$, normally shaped sections, moderate cruiser stern, and raked stem.

The resistance $R$ and the effective power $P_E$ for a new ship can then be calculated by

$$R = C_T(\tfrac{1}{2}\rho V^2 S) \quad \text{(N)} \qquad (5.5.11)$$

$$P_E = RV \quad \text{(kW)} \qquad (5.5.12)$$

where the total ship resistance coefficient is

$$C_T = C_R + C_F + C_A \qquad (5.5.13)$$

where

$C_R$ = residual resistance coefficient, which for the "standard" ship form can be taken from the diagrams (Figs. 5.5.5–5.5.13)

$C_F$ = frictional resistance coefficient, which can be calculated by

$$C_F = \frac{0.075}{(\log_{10} R_n - 2)^2} \qquad (5.5.14)$$

or can be taken from Fig. 5.5.14 where contours of $C_F$ are given from different values of $V$. The abscissa is the length $L$ of the ship. The diagram corresponds to $\nu = 1.188 \times 10^{-6}$ m s$^{-1}$, $\rho = 1.025$ t/m$^3$, and $t = 15$°C. The diagram may therefore be used at other conditions, that is, other densities and temperatures, only if the length is altered before entering the diagram to:

$$L_1 = \frac{1.188}{10^6 \nu} L \qquad (5.5.15)$$

$C_A$ = incremental resistance coefficient, which is a coefficient correcting for roughness of the surface and scale effect on the results from the model experiments. In this way $C_A$ will depend on the way in which $C_R$ and $C_F$ are fixed.

If the ship has to tow, $R$ must be replaced by $R + F$, where $F$ is the two-rope pull.

As ships are generally different from the standard to a greater or lesser extent, the following corrections should be taken into account, when the ship resistance of the ship and the environments had to be taken into account.

## $B/T$

As the diagrams have been prepared for a breadth–draught ratio corresponding to

$$B/T = 2.5 \qquad (5.5.16)$$

a correction must be made if $C_R$ is desired for a ship with a larger or smaller breadth–draught ratio.

Examination of the present test material has shown that the following correcting formula can be recommended:

$$10^3 C_R = 10^3 C_{R(B/T=2.5)} + 0.16\,(B/T - 2.5) \qquad (5.517)$$

The correction may be positive as well as negative.

## LCB

The $C_R$ curves are intended to correspond to vessels with a longitudinal position of center of buoyancy (LCB) near to what is today considered the best possible position. The optimum LCB is a quantity that is in some doubt, and the available literature shows differences of opinion that make the picture rather confused. The dependence of ship

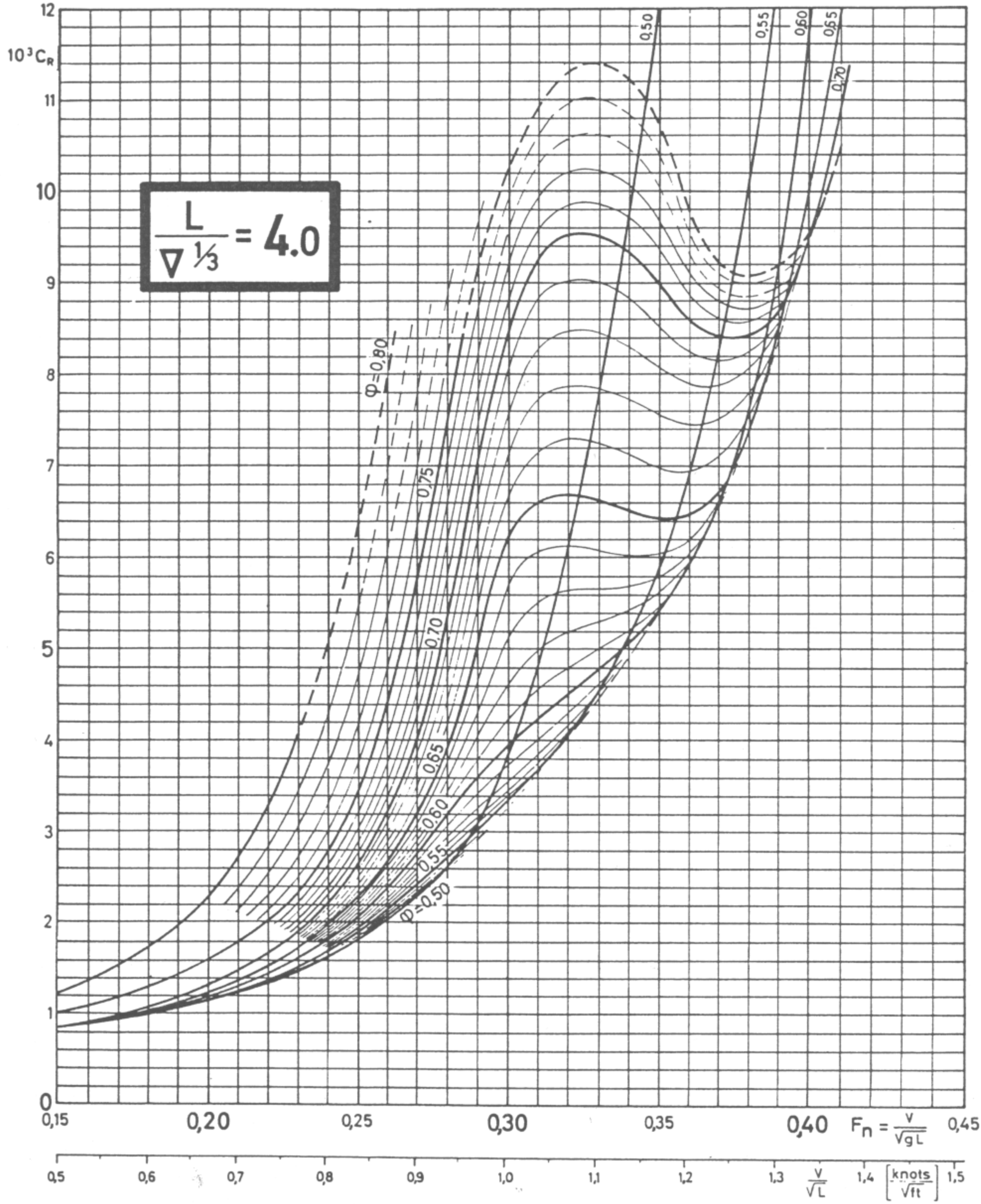


**Figure 5.5.5.** Residuary resistance coefficient versus speed–length ratio for different values of longitudinal prismatic coefficient. $L/\nabla^{1/3} = 4.0$.

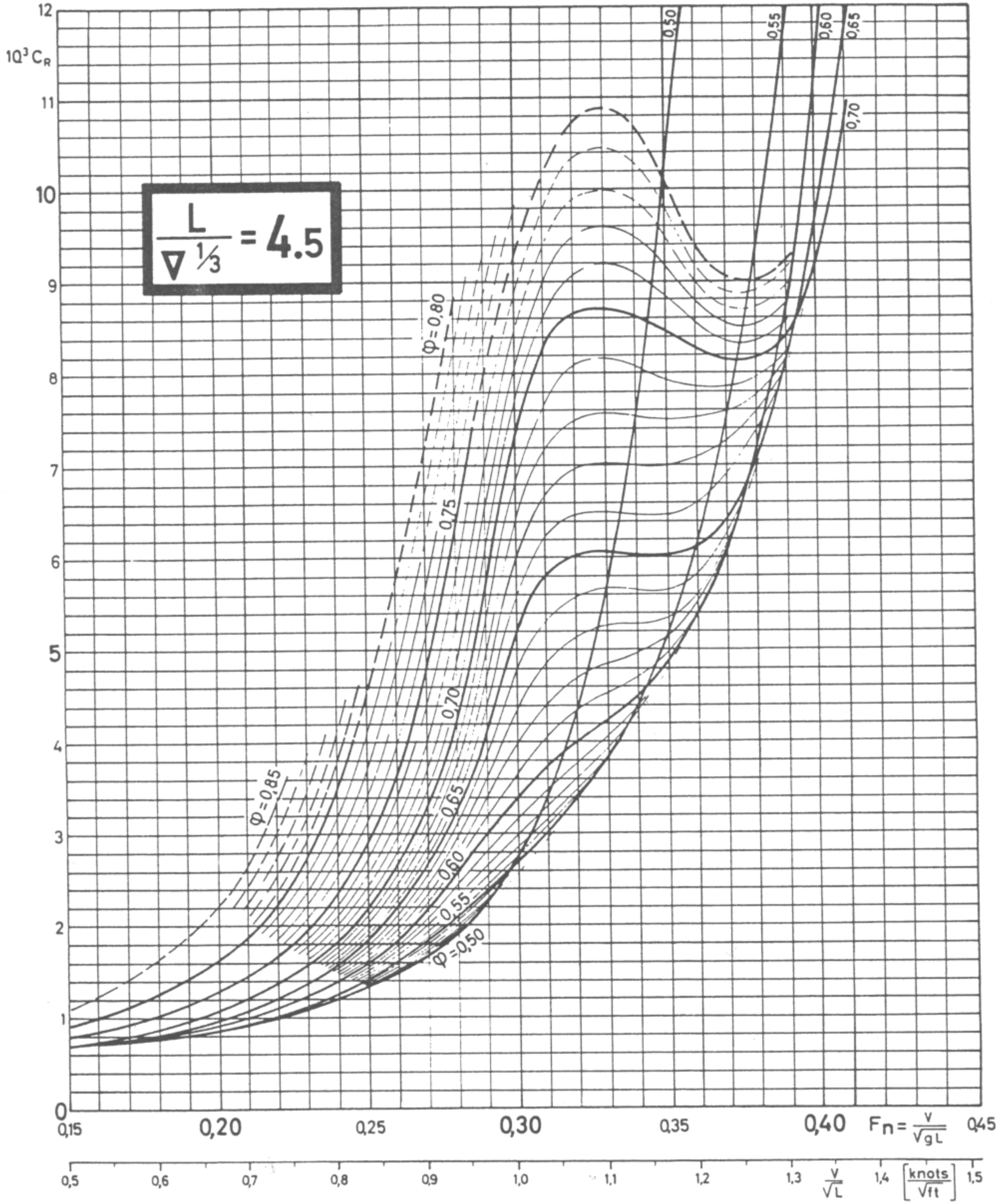


**Figure 5.5.6.** Residuary resistance coefficient versus speed–length ratio for different values of longitudinal prismatic coefficient. $L/\nabla^{1/3} = 4.5$.

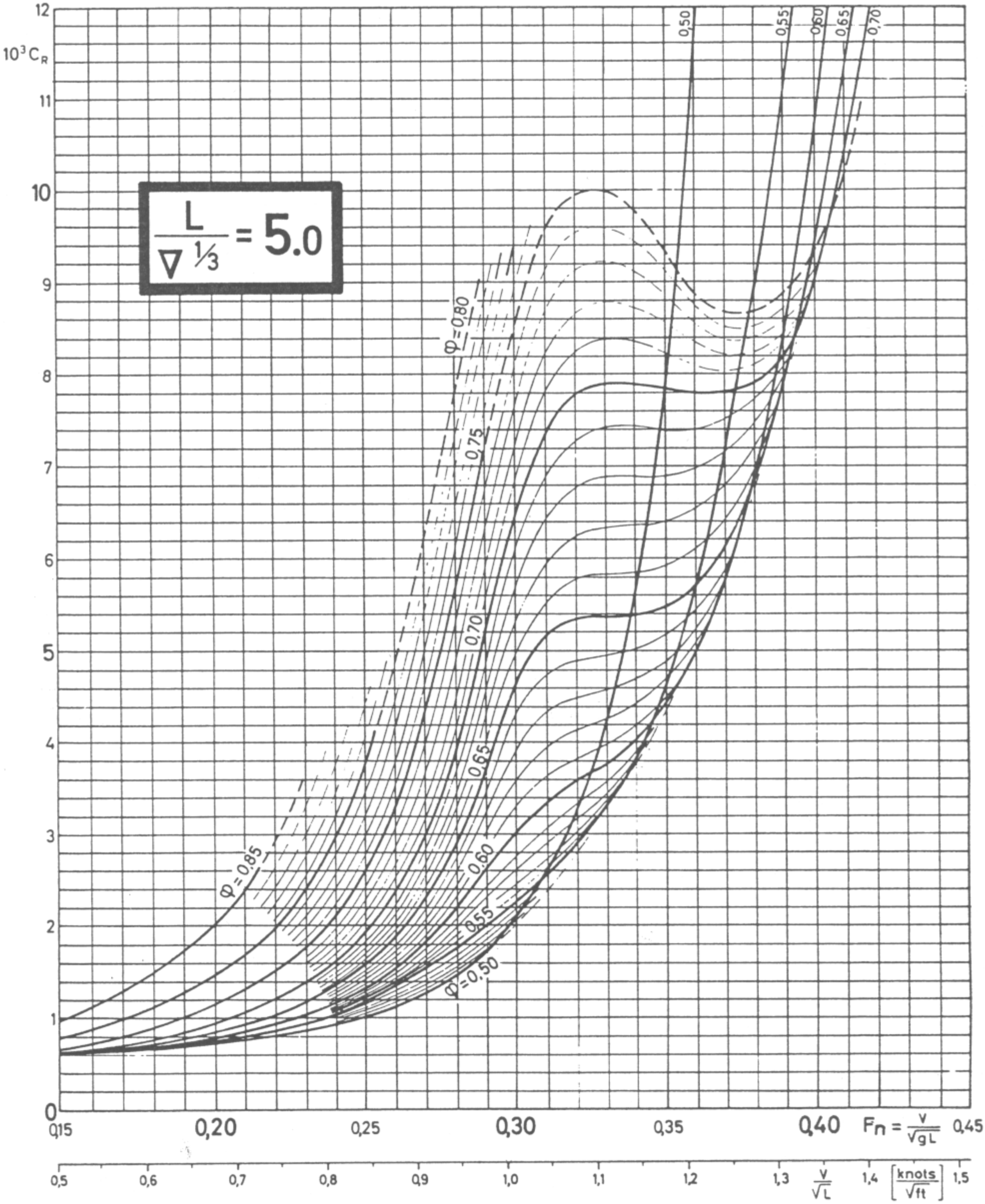


**Figure 5.5.7.** Residuary resistance coefficient versus speed–length ratio for different values of longitudinal prismatic coefficient. $L/\nabla^{1/3} = 5.0$.

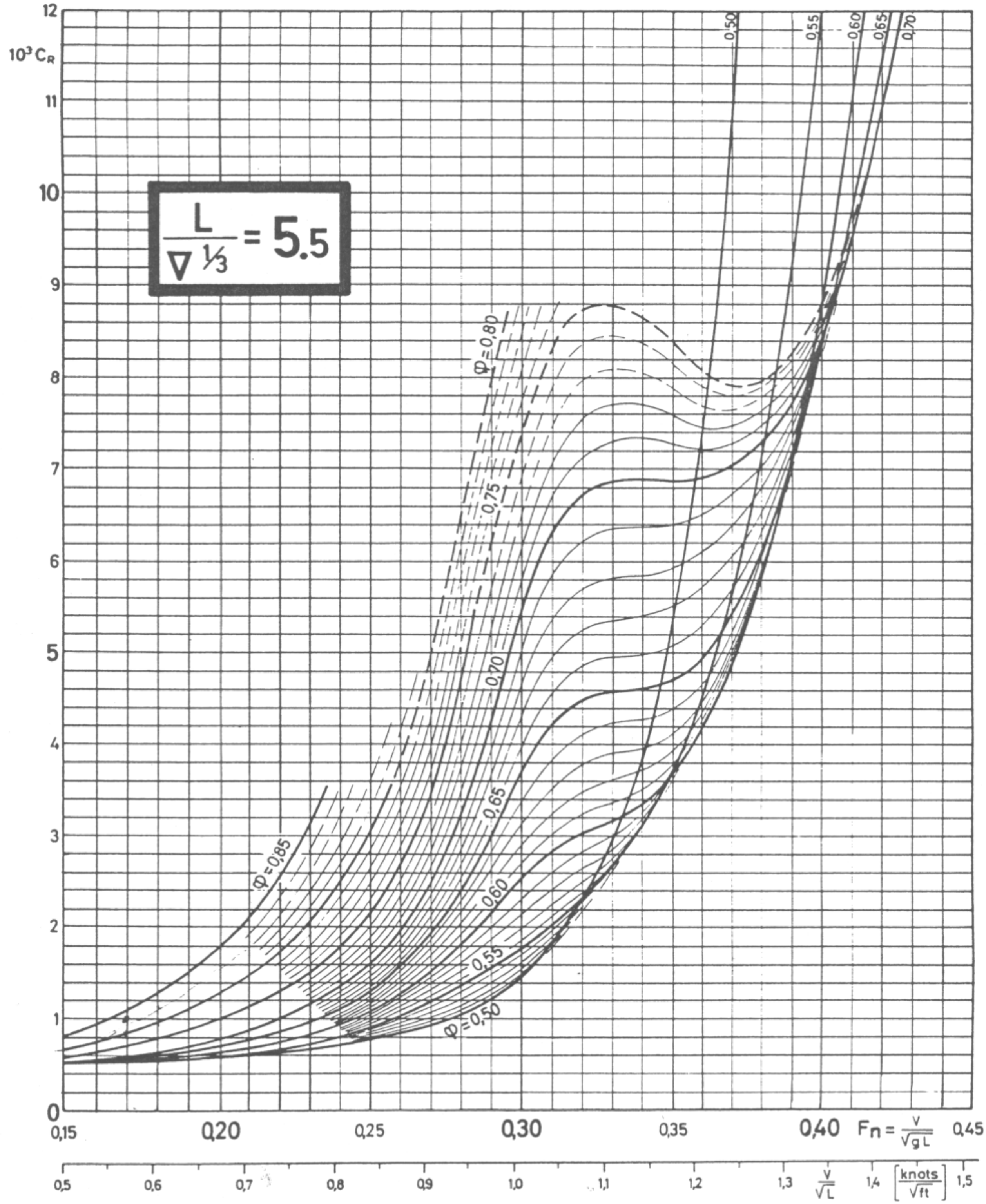


**Figure 5.5.8.** Residuary resistance coefficient versus speed–length ratio for different values of longitudinal prismatic coefficient. $L/\nabla^{1/3} = 5.5$.

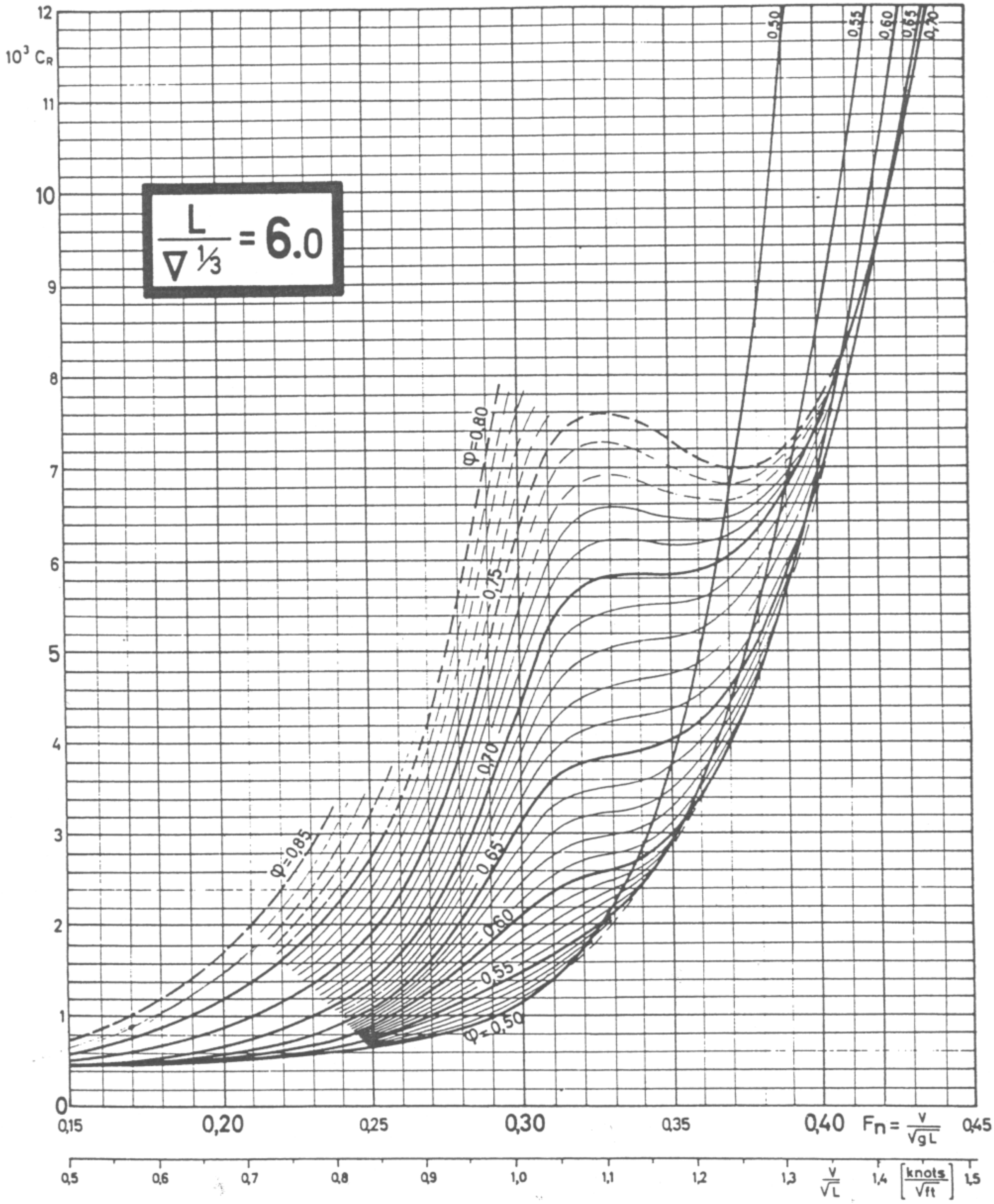


**Figure 5.5.9.** Residuary resistance coefficient versus speed–length ratio for different values of longitudinal prismatic coefficient. $L/\nabla^{1/3} = 6.0$.

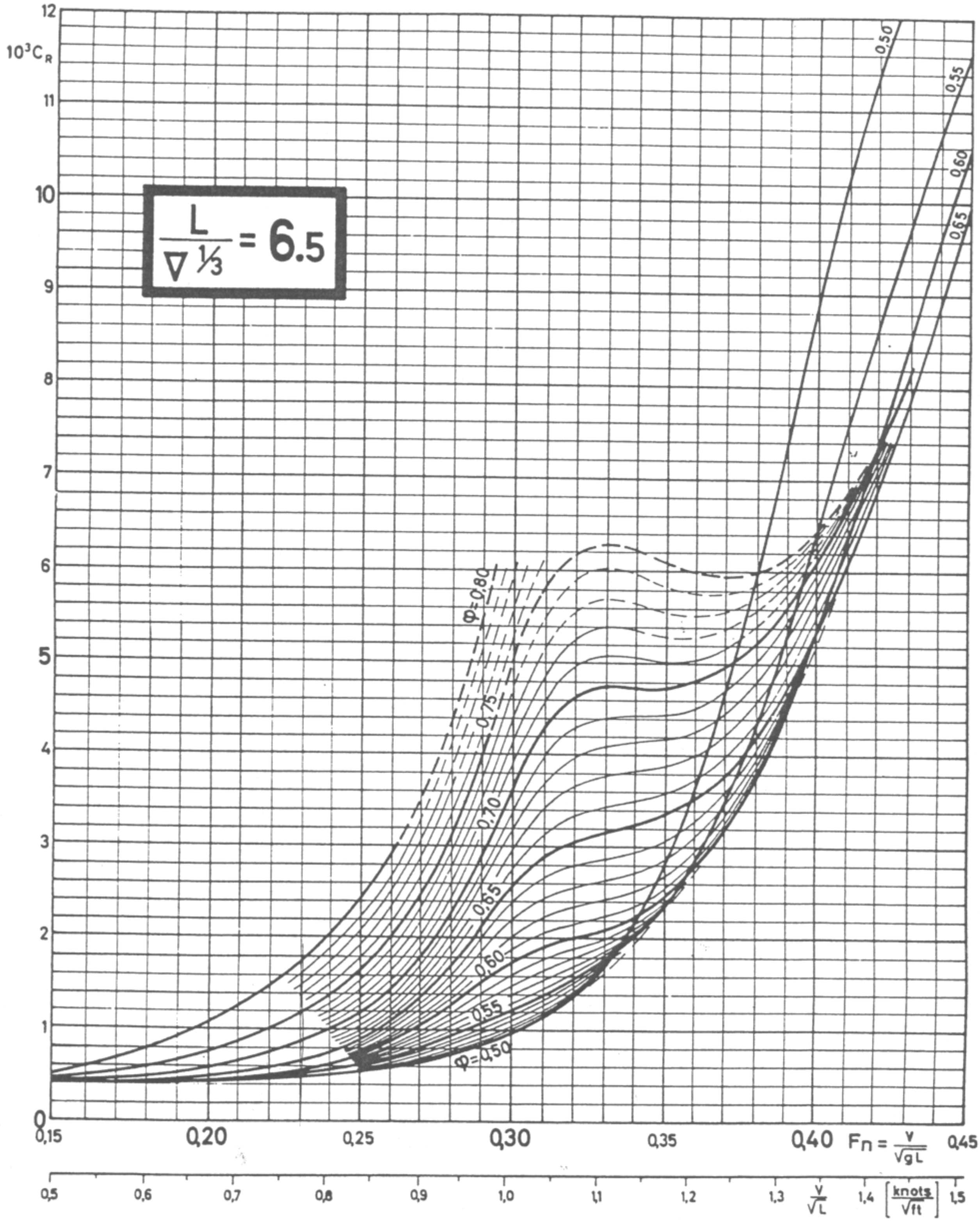


**Figure 5.5.10.** Residuary resistance coefficient versus speed–length ratio for different values of longitudinal prismatic coefficient. $L/\nabla^{1/3} = 6.5$.

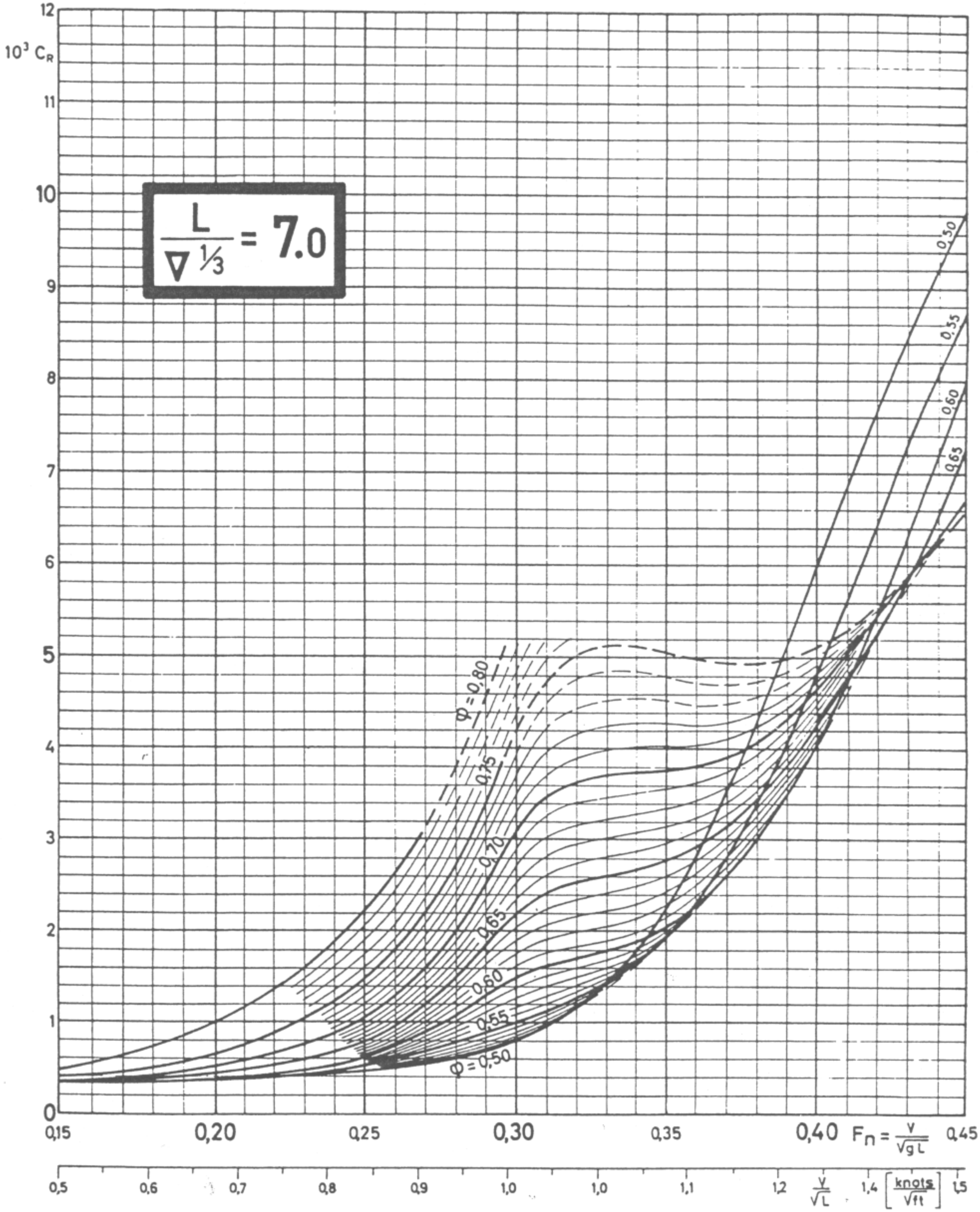


**Figure 5.5.11.** Residuary resistance coefficient versus speed–length ratio for different values of longitudinal prismatic coefficient. $L/\nabla^{1/3} = 7.0$.

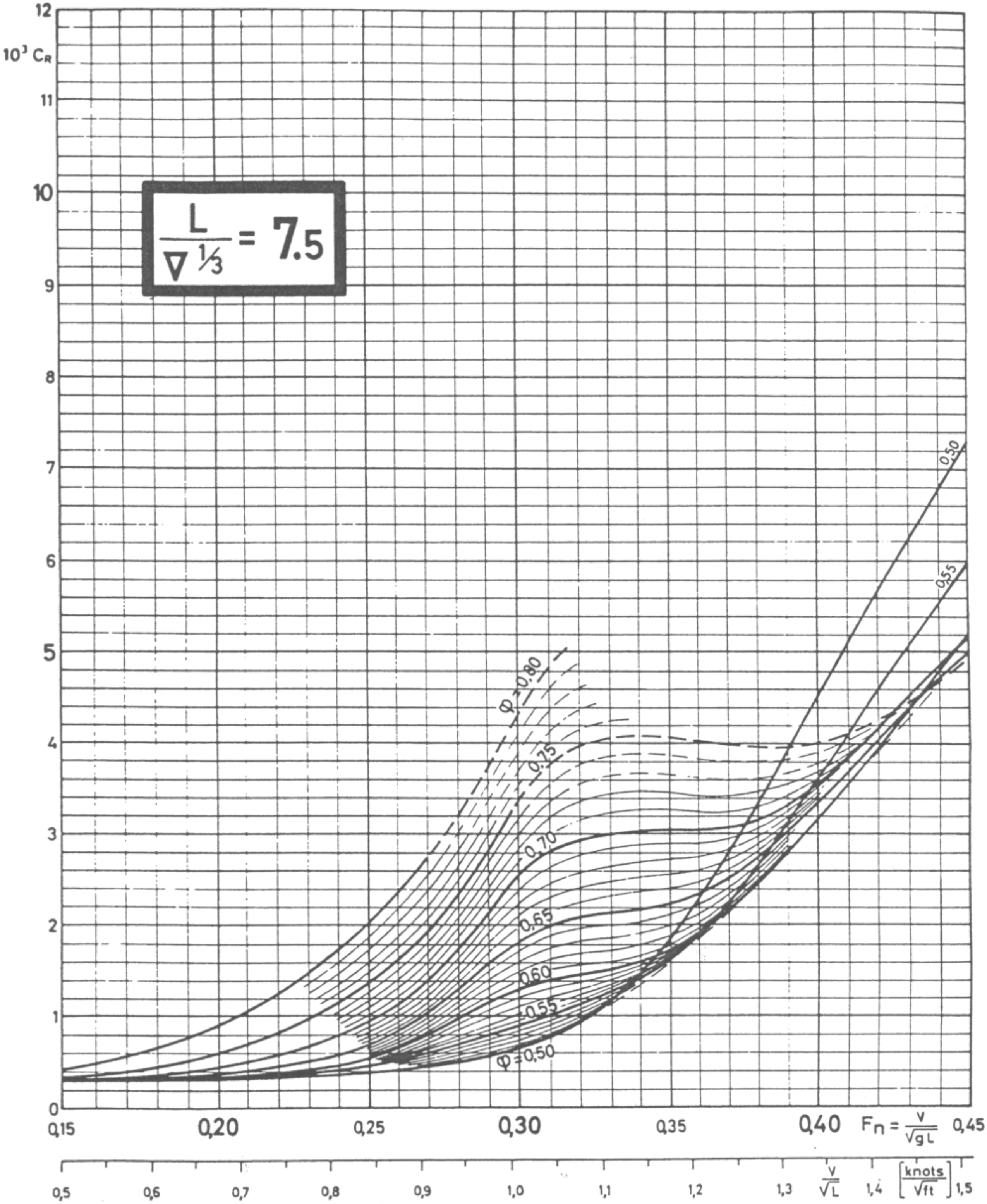


**Figure 5.5.12.** Residuary resistance coefficient versus speed–length ratio for different values of longitudinal prismatic coefficient. $L/\nabla^{1/3} = 7.5$.

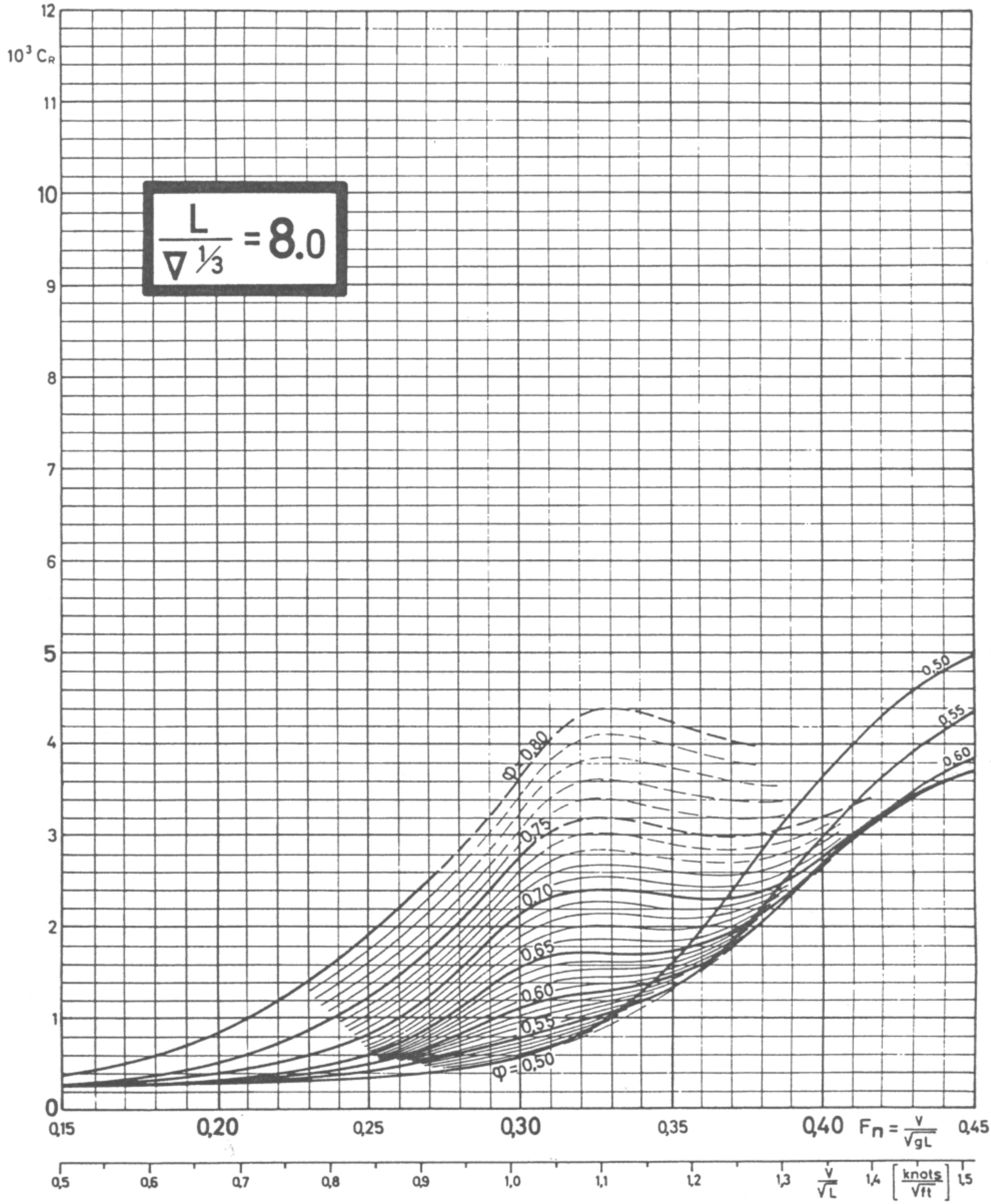


**Figure 5.5.13.** Residuary resistance coefficient versus speed–length ratio for different values of longitudinal prismatic coefficient. $L/\nabla^{1/3} = 8.0$.

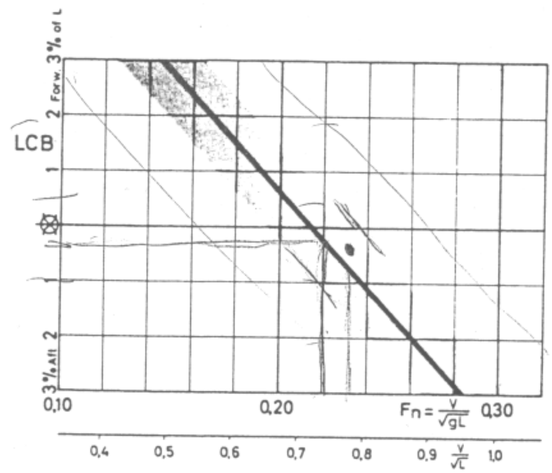


**Figure 5.5.15.** Standard LCB. The longitudinal position of the center of buoyancy that is considered the best possible.

resistance on LCB is, however, evident at higher speeds. In an attempt to make some order out of the confusion, the available information has been collected and condensed in the Fig. 5.5.15, which must be regarded as the standard LCB of the method.

The standard LCB has in this way been defined as a linear function on the Froude number $F_n$. As no safe dependency on other parameters have been recorded, the standard LCB is represented in the diagram by a single line, and the shaded area around this line illustrates the spread of the examined material.

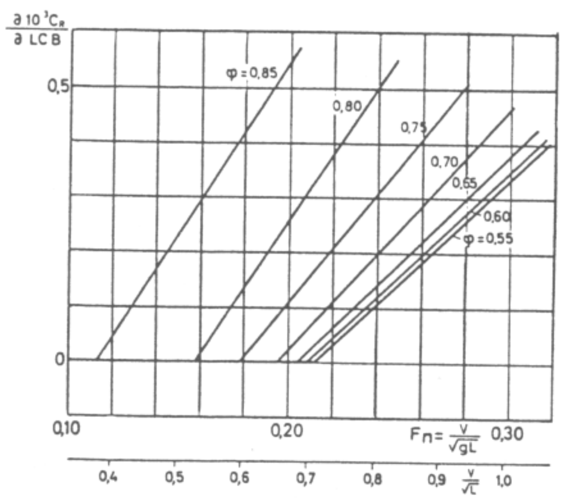


**Figure 5.5.16.** The correction of the residual resistance coefficient for LCB 1% forward of standard. The correction is thus $(\partial 10^3 C_R/\partial \mathrm{LCB})|\Delta\mathrm{LCB}|$, where $\Delta$LCB is the longitudinal distance between actual and standard LCB in percent of $L$. There is no correction for LCB aft of standard. The correction is always positive.

As the standard position of LCB is, as mentioned earlier, assumed to give the smallest possible resistance, all other positions must in principle give resistances that are larger. The increase in resistance is to be found by multiplying the deviation of LCB from standard

$$\Delta\mathrm{LCB} = \mathrm{LCB} - \mathrm{LCB}_{\text{standard}} (\mathrm{LCB \ in\ \%\ of\ } L) \tag{5.5.18}$$

by a factor $\partial 10^3 C_R/\partial\mathrm{LCB}$. The values of the factor may be obtained from the Fig. 5.5.16. which is valid for the case where LCB is forward of $\mathrm{LCB}_{\text{standard}}$. When LCB is aft of the $\mathrm{LCB}_{\text{standard}}$, the sources are very contradictory, and as the tendencies are very slight, no serious error will be introduced by neglecting the correction in such cases.

The corrected residual resistance coefficient for a ship with LCB forward of standard is consequently determined by:

$$10^3 C_R = 10^3 C_{R(\text{standard})} + \frac{\partial 10^3 C_R}{\partial \mathrm{LCB}} |\Delta\mathrm{LCB}| \tag{5.5.19}$$

The hull form dealt with in *Ship Resistance* is the hull form that was common for merchant ship types around 1960, that is, up to the time of publication of Guldhammer and Harvald (1974). This hull form has the aft perpendicularly placed in the axis of the rudder stock and the fore perpendicular in the fore end point of the design waterline. Since 1960 the hull forms have been developed further, and they have also become more varied, for instance, various bulbous bows have become widely used. The formulas given here for resistance calculation can be used for the modern and more varied bulb forms as well as for the traditional forms, provided the following more suitable definitions of $L$ and LCB are used. The calculation length $L$ is defined as the length between the fore and aft limits of the displacement, that is, the ultimate length of the submerged part of the hull, $L_{OS}$ according to ITTC standard. For ships of traditional form with no bulb this length is exactly the waterline length.

LCB defines the longitudinal position of the center of buoyancy as the distance from this point to the midship section, positive aft of this section. The midship section is defined as the section at a distance of 48.5% of $L$ from the fore limit of the displacement. $L$ is the calculation length described above. The midship section thus defined is therefore the midpoint between the auxiliary perpendiculars $AP_1 - FP_1$; compare Fig. 5.5.17. $AP_1 - FP_1$ for a normal form will coincide with the perpendiculars defined in the usual way $AP - FP$.

### Hull Form (Shape of Sections and Bow)

As previously stated it is assumed that the resistance curve (deduced from Figs. 5.5.5–5.5.13) applies to a ship having a "standard" form, that is, the sections are neither distinctly U shaped nor V shaped. Therefore, in calculating the effective power of a preliminary ship design it should not normally be necessary to make a correction for shape of hull sections. If the sections are extremely U or V shaped, the $10^3C_R$ values may be corrected as follows: Corrections to $10^3C_R$ for shape of sections

| | | |
|---|---|---|
| Fore Body | Extreme U<br>−0.1 | Extreme V<br>+0.1 |
| After Body | Extreme U<br>+0.1 | Extreme V<br>−0.1 |

(5.5.20)

These corrections cover the speed range $V/\sqrt{gL} =$ 0.20–0.25. Furthermore, it must be considered that the "standard" form is a form with well-designed lines. If it is necessary to alter the lines due to the operating requirements of the ship, or allowance to the power must be made, it is recommended that $C_R$ be increased by 10% and perhaps 20% or more for nonoptimal lines.

Concerning the bow, the standard form must be regarded as having an orthodox nonbulbous bow. For a vessel with bulbous bow having $A_{BT}/A_X \geqq 0.10$ ($A_{BT}$ is the sectional area of the bulbous bow at the fore perpendicular and $A_X$ is the area of the midship section) the following corrections to $10^3C_R$ are suggested:

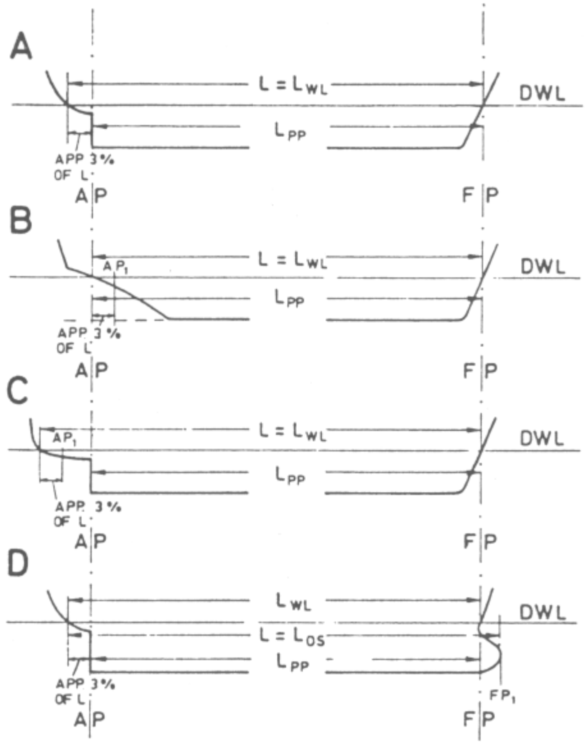


**Figure 5.5.17.** Definition of $L$ and LCB. (a) Normal form. Length of the stern in the waterline is normally approximately 3% of $L$. (b) Hull with no sternpost. AP often placed in the endpoint of DWL. For LCB correction $AP_1$ 3% of $L$ before the endpoint of the waterline is used. (c) Hull with stern of extreme length. For the LCB correction $AP_1$ 3% before the endpoint of the waterline is used. (d) Hull with bulbous bow. $FP_1$ is the fore limit of the displacement.

With $A_{BT}/A_X = 0.10$ the bulbous bow is rather pronounced. For $0 < A_{BT}/A_X < 0.10$ the corrections are assumed to be proportional with size of bulb.

These corrections are valid for loaded conditions only. At ballast conditions the corrections due to bulbous bows will give an opposite picture. Full forms ($\varphi > 0.70$) will show a remarkable decrease in resistance, the corrections having two to three times these values, whereas the resistance for fine forms ($\varphi < 0.60$) generally will tend to increase.

| $F_n = 0.15$ | 0.18 | 0.21 | 0.24 | 0.27 | 0.30 | 0.33 | 0.36 | $\varphi$ $C_P$ |
|---|---|---|---|---|---|---|---|---|
| | | +0.2 | 0 | −0.2 | −0.4 | −0.4 | −0.4 | 0.50 |
| | | +0.2 | 0 | −0.2 | −0.3 | −0.3 | | 0.60 |
| | +0.2 | 0 | −0.2 | −0.3 | −0.3 | | | 0.70 |
| +0.1 | 0 | −0.2 | | | | | | 0.80 |

(5.5.21)

### Appendages

| | | |
|---|---|---|
| Rudders | No correction. The standard form is intended to include a rudder. | |
| Bilge keel | No correction. | (5.5.22) |
| Bossings | For full ships add 3–5% to $C_R$. | |
| Shaft brackets and shafts | For fine ships add 5–8% to $C_R$. | |

### Incremental Resistance

For many years it has been general practice to apply a correction to the $C_{FS}$ for the ship, in order to include the effect of the roughness of the surface of the ship, which will never be "model-smooth" even when brand-new and freshly painted. This incremental resistance coefficient for model–ship correlation has very often been fixed at $C_A = 0.0004$. More recent experience has shown that this cannot be true in all cases. Therefore, the following correction for roughness and scale effect is proposed for the trial condition:

$$
\begin{aligned}
\text{For vessels with } L &\leqq 100\ \text{m}, & 10^3 C_A &= 0.4 \\
&= 150\ \text{m} & &= 0.2 \\
&= 200\ \text{m} & &= 0 \\
&= 250\ \text{m} & &= -0.2 \\
&\geqq 300\ \text{m} & &= -0.3
\end{aligned}
\tag{5.5.23}
$$

Some find the corrections given in Section 5.2.4 more suitable, that is,

| Displacement | | | |
|---|---|---|---|
| 1 000 t | $C_A =$ | $0.6 \times 10^{-3}$ | |
| 10 000 t | | $0.4 \times 10^{-3}$ | (5.5.24) |
| 100 000 t | | 0 | |
| 1 000 000 t | | $-0.6 \times 10^{-3}$ | |

It must be mentioned that these corrections of the frictional resistance coefficients are still rather uncertain.

### Appendages

The correction of $C_F$ for appendages is made by simply increasing $C_F$ proportionally to the wetted surfaces of the appendages. Thus

$$C_{F'} = C_F \frac{S_1}{S} \tag{5.5.25}$$

where $S$ is the wetted surface of the hull and $S_1$ is the wetted surface of the hull and appendages.

### Air Resistance and Steering Resistance

The air resistance may be determined by use of data for the abovewater structure and the air. The magnitude of the air resistance is, however, very often of minor importance and the expenditure of effort in making an accurate calculation may not be justified. Therefore, in the absence of knowledge of the windage of a ship design it is suggested that $10^3 C_R$ be corrected by

$$10^3 C_{AA} = 0.07 \tag{5.5.26}$$

The correction for steering resistance may be about

$$10^3 C_{AS} = 0.04 \tag{5.5.27}$$

but may for course stable ships under favorable conditions be negligible.

It can be seen that both corrections are small and that for a preliminary design they may be assumed to be included in the incremental resistance.

### The Service Condition

The resistance and the effective power calculated by use of the diagrams given here correspond to the values for a ship in the trial condition, that is, for ideal conditions as regards winds and waves, deep sheltered water, and smooth hull. For the mean service condition an extra allowance has to be made for the resistance and the effective power because of wind, sea, erosion, and fouling of the hull. This extra allowance is dependent on the shipping route. The following average service allowances (sometimes called sea margin or service margin) on the calculated resistance or effective power are proposed:

North Atlantic route, eastward, 15–20% in summer and winter, respectively
North Atlantic route, westward, 20–30% in summer and winter, respectively (5.5.28)
Pacific route, 15–30%
South Atlantic and Australian routes, 12–18%
East Asiatic route, 15–20%

The total resistance has to be calculated from

$$R_T = C_T(\tfrac{1}{2}\rho V^2 S) \qquad (5.5.29)$$

where $S$ is the wetted surface of the hull.

Numerous methods for approximate determination of $S$ exist. Use of one of the following two methods is recommended:

1. The publications FORMDATA I–V (Guldhammer, 1962, 1963, 1967, 1969, 1973) contain hydrostatic data for a comprehensive series of systematically varied ship forms. The wetted surface of these forms are mapped (volumes III–V) using the coefficient

$$\boxed{S} = \frac{S}{L(B + 2.5T)} \qquad (5.5.30)$$

If the actual form for the preliminary ship design largely coincides with one of the FORMDATA forms, an error of less than 1% in the determination of $S$ will be obtained.

2. For normal merchant ship forms the wetted surface can be obtained from the following formula (a version of Mumford's formula):

$$S = 1.025L_{PP}(\delta_{PP}B + 1.7T) \qquad (5.5.31)$$

The FORMDATA $\boxed{S}$ diagrams and the preceding formula correspond to ship forms having a vertical stern and stem at the perpendiculars. Most ships will have a wetted surface corresponding to this assumption as the plus and minus areas will balance each other. For ships with a large underwater overhang or with large cutouts, these conditions ought to be allowed for in the calculations.

The calculations of the resistance and the effective power can be carried out as shown in Sample Form for the Calculation of Effective Power (see p. 132). The calculations can be performed using minicomputers. Many naval architects now have computer programs for such calculations.

In the design stage the main question to be settled is the type and size of the engine (e.g., number and dimensions of cylinders if diesel machinery). The determination of the resistance must be sufficiently exact so that, on the basis of effective power $P_E$, it is possible to determine the shaft power accurately enough to arrive at a safe solution to this vital question.

On the other hand, trying to attain greater accuracy than needed to solve this problem makes little sense. The uncertainty of the factors involved is considerable, and readers are warned against wasting time in attempting to squeeze the last ounce of accuracy out of a calculation that can only be an estimation.

In diesel-engined ships a change in the number of cylinders from, say, 6 to 7 or from 11 to 12 means that the power is changing by about 17% or 8%, respectively. By modifying the mean effective pressure and number of revolutions it is possible to vary the continuous output by about 10%.

Turbine manufacturers have corresponding steps between types.

On the basis of these considerations perhaps the required accuracy in the determination of $P_E$ for a preliminary ship design can be fixed at 1 up to 5%. This accuracy will be easily obtained in many cases by using the diagrams and the calculation forms in this section.

The diagrams and the formulas can also be used in the following manner. Every time the naval architect has a result from his or her own towing experiments the results are pricked in on the diagrams. Then when making an estimation of the resistance for a proposal for a new ship, the naval architect uses his or her own data as basis material and uses the diagrams and the formulas in this section to correct the data. Often the results will be very good when using such a procedure.

**Sample Form for the Calculation of Effective Power**

| **Dimensions** | | | **Coefficients, etc.** | | |
|---|---|---|---|---|---|
| Length between perpendiculars | $L_{PP}$ | ________ m | Breadth–draught ratio | $B/T$ | ________ |
| Length on waterline | $L$ | ________ m | Block coefficient | $\delta$ | ________ |
| $\sqrt{gL}$ ________ m/s | | | Midship-section coefficient | $\beta$ | ________ |
| Breadth | $B$ | ________ m | Longitudinal prismatic | | |
| Draught | $T$ | ________ m | coefficient | $\varphi$ | ________ |
| Displacement | $\Delta$ | ________ t (1000 kg) | Length–displacement ratio | $L/\nabla^{1/3}$ | ________ |
| | | | $L/\nu$ ________ s/m | | |
| Volume | $\nabla$ | ________ $m^3$ | Longitudinal position of Center of buoyancy | | |
| $\nabla^{1/3}$ ________ m | | | ________ percent of $L$ aft of ⊠ $(L_{PP}/2)$ | | |
| Wetted surface | $S$ | ________ $m^2$ | $\Delta LCB = LCB_{actual} - LCB_{standard} =$ ________ percent | | |
| $\frac{1}{2}\rho S$ ________ N $s^2/m^2$ | | | Shape of sections: Aft: Forward: | | |
| Wetted surface (appendages included) | $S_1$ | ________ $m^2$ | Lines: | | |
| $S_1/S$ ________ | | | Shape of bow: | | |

| Column | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $10^3C_R$ | | | Corrections to $10^3C_R$ for | | | | | |
| | $F_n = \frac{V}{\sqrt{gL}}$ | Speed $V$ | | $V^2$ | $\frac{1}{2}\rho SV^2$ | $L/\nabla^{1/3}$ | | | $B/T$ | LCB | Sections lines | Bow | Append-ages | |
| Source (Formula) | | | | | | Diagrams Figs. 5.5.5–5.5.13 | | | (5.5.17) | Figs. 5.5.15–5.5.16 | (5.5.20) | (5.5.21) | (5.5.22) | |
| Unit | — | m/s | knots | $m^2/s^2$ | N (or kN) | — | — | — | — | — | — | — | — | — |

Note! The figures in parentheses indicate formula numbers in the text.

Columns 20–22 are intended to be used for supplementary resistance calculations for air, steering, etc.

In a preliminary estimate the calculations in columns 9–14 and 20–22 may be wholly or partly omitted.

| 2 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $V$ | Resul-tant $10^3C_R$ | $10^{-6}R_n$ | $10^3C_F$ ITTC 57 | $10^3C_{F'}$ | $10^3C_A$ | | | | $10^3C_T$ | $R_T$ | $P_E$ | |
| | 8 + 9 + 10 + 11 + 12 + 13 + 14 | $10^{-6}\frac{VL}{\nu}$ | Fig. 5.5.14 or (5.5.14) | $\frac{S_1}{S}$ [17] | (5.5.24) | | | | 15 + 18 + 19 20 + 21 + 22 | $10^{-3}$[5] × [23] | [2] × [24] | $\frac{[25]}{k_{hp}}$ |
| m/s | — | — | — | — | — | — | — | — | — | N (or kN) | W (or kW) | hp (metric) |

$$k_{hp} = \begin{cases} 735.5 \\ 0.7355 \end{cases} \text{for force measured in} \begin{cases} \text{N} \\ \text{kN} \end{cases}$$

# SYMBOLS AND ABBREVIATIONS

## Ship Dimension

$L$ = length on waterline
$L_{pp}$ = length between perpendiculars
$B$ = breadth on waterline
$T$ = draught
$A_X$ = immersed midship section area
$A_{BT}$ = section area of bulbous bow (measured at FP)

$S$ = wetted surface ($L \times$ mean girth) (including rudder)
$S_1$ = wetted surface as S but including appendages
$\Delta$ = displacement
$\nabla$ = volumetric displacement
LCB = longitudinal position of centre of buoyancy (also used to denote the distance of CB abaft amidships (⊗))
⊗ = amidships ($L_{pp}/2$)

Suffix $_m$ denotes that the quantity concerned is valid for model only

## Kinematic and Dynamic Symbols

$V$ = speed of ship
$R$ = resistance
$R_A$ = air resistance
$R_F$ = frictional resistance
$R_R$ = residual resistance
$R_S$ = steering resistance
$R_T$ = total resistance
$P_B$ = brake power
$P_E$ = effective power
$\rho$ = density of water
$\nu$ = kinematic viscosity of water

## Dimensionless Coefficients and Ratios

$\delta = \frac{\nabla}{L\,B\,T}$ = block coefficient

$\delta_{pp} = \frac{\nabla}{L_{pp}\,B\,T}$ = block coefficient

$\beta = \frac{A_X}{B\,T}$ = midship section coefficient

$\varphi = \frac{\nabla}{A_X\,L}$ = prismatic coefficient

$\frac{L}{B}$ = length-breadth ratio

$\frac{B}{T}$ = breadth-draught ratio

$\frac{L}{\nabla^{\frac{1}{3}}}$ = length-displacement ratio

$Fn = \frac{V}{\sqrt{g\,L}}$ = Froude number

$\frac{V}{\sqrt{L}}$ = speed-length ratio (V in knots and L in ft)

$Rn = \frac{VL}{\nu}$ = Reynolds number

$C_F = \frac{R_F}{\frac{1}{2}\rho V^2 S}$ = specific frictional resistance coefficient

$C_R = \frac{R_R}{\frac{1}{2}\rho V^2 S}$ = specific residual resistance coefficient

$C_T = \frac{R_T}{\frac{1}{2}\rho V^2 S}$ = specific total resistance coefficient

$C_A$ = incremental resistance coefficient for model-ship correlation

# UNITS AND CONVERSION FACTORS

Metric units (the SI-system) are used throughout with the following exceptions: The speed length ratio $V/\sqrt{L}$ and the length $L$ in feet have been added as sub scales.

1 m (metre) = 3,281 ft
1 t (metric ton) = 1000 kg = 0,984 tons (1 ton British = 2240 lb)
1 knot (metric) : 1852 m/hour = 0,999 British knots = 0,5144 m/s
1 N (Newton) unit for force. 1 kN = 1000 N
1 W (Watt) unit for power. 1 kW = 1000 W
1 W = 1 N m/s
1 hp (metric) = 75 kp m/s = 735,5 W = 0,986 British hp

If the mass unit ton (1 t = 1000 kg) is used, the corresponding force unit will be kilo-Newton, kN, which will correspond to the power unit kilo-Watt, kW, being a convenient unit.

It must be emphasized that the units t and kg are mass, and N (Newton) is force. The units are connected by the equations:

Force = Mass × Acceleration

or with units:

$1 \text{ N} = 1 \text{ kg} \times 1 \text{ m/s}^2$

Readers using the old "technical" metric system use the force unit 1 kp (kilo-pond) and the mass unit is derived thus:

$1 \text{ kp} = 1 \text{ mass unit} \times g = 1 \text{ m.u.} \times 9{,}8066 \text{ m/s}^2$

Therefore

$1 \text{ kp} = 9{,}8066 \text{ N}$

By utilizing non-dimensional coefficients it is possible to use any system of consistent units: e.g. Meter/Kilogram/Second, or Meter/Kilopond/Second, or Foot/Pound-mass/Second (ft/lb/s), or Foot/Pound-force/Second (ft/lbf/s).

Confusion may arise from the different systems, and care must be taken to use - within the same expression - units belonging to one system only; i.e. when the Mass kilogram is used the specific mass will be in $\text{kg/m}^3$ and the force must be measured in N but if the Force kilopond is used the specific mass $\rho$ must be measured in $\frac{\text{kp s}^2}{\text{m}^4}$

The following values have been used:

$\rho$ , density of sea water: 1025,9 $\text{kg/m}^3$ or 104,61 $\frac{\text{kp s}^2}{\text{m}^4}$ (or 1,990 $\frac{\text{lbf s}^2}{\text{ft}^4}$)

$\rho$ , density of fresh water: 999,0 $\text{kg/m}^3$ or 101,87 $\frac{\text{kp s}^2}{\text{m}^4}$ (or 1,938 $\frac{\text{lbf s}^2}{\text{ft}^4}$)

$\nu$ , kinematic viscosity of sea water: 1,191 $10^{-6}\text{m}^2 \text{ s}^{-1}$ (=1,28 $10^{-5}\text{ft}^2\text{s}^{-1}$) $t = 15°C$

$\nu$ , kinematic viscosity of fresh water: 1,141 $10^{-6} \text{ m}^2 \text{ s}^{-1}$ (= 1,23 $10^{-5} \text{ ft}^2 \text{ s}^{-1}$)