3. Resistance of a Ship

3.2 Estimates based on statistical methods

- In the preliminary stages of ship design, the resistance coefficient is estimated with approximate methods based on systematic series or statistical regressions to experimental data.

- A systematic series is a family of ship hulls obtained from a systematic variation of one or more shape parameters. Usually, the changes are based on a parent form. The resistance of all the models that constitute a series is measured experimentally. This database allows the interpolation of the resistance coefficient for other shapes originated by parametric variations of the original shape

3. Resistance of a Ship

3.2 Estimates based on statistical methods

- The Froude number is related to the fineness coefficient. Ships with a high Froude number exhibit a resistance coefficient dominated by the wave resistance and have a smaller fineness coefficient.

- The longitudinal distribution of the displacement affects the resistance and is related to the Froude number. This distribution is caracterized by the buoyancy centre. For ships with low Froude number, the resistance is dominated by the flow separation region that might occur at the stern.

3. Resistance of a Ship

3.2 Estimates based on statistical methods

- The risk of flow separation is reduced if the buoyancy centre is upstream of midship. In the case of high Froude numbers, wave resistance dominates the resistance coefficient. In these cases, the crictical region is the bow, which should be thinner moving the buoyancy centre to a location downstream of midship.

- The vertical displacement is influenced by the choice of V or U sections. U shaped sections lead to smaller wave resistance than V shapes, but to highest risk of flow separation.

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Taylor series

- Taylor performed model tests (between 1907 and 1914) for systematic variations of a parent form defined by the British cruiser “Leviathan”.
- Systematic variations of models shape:
  - 5 ratios length/displacement$^{1/3}$: $L/\Delta^{1/3}$
  - 3 ratios beam/draft: B/T 2,25, 2,92 e 3,75
  - 8 prismatic coefficients: C_p from 0,48 a 0,86
  - Only 2 values of *B/T* 2,25 and 3,75 were used by Taylor: 80 models.

$$C_R = f(V/\sqrt{L_{wl}}, B/T, C_p, \Delta/L_{wl}^{\;3})$$

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Taylor series

- Reanalysis of the results by Gertler (1954).
  - Corrections for water temperature, laminar flow and blockage.
  - Viscous resistance from Schoenherr line. Froude's method. Results give residual resistance.
  - *B/T*=2,92 was converted to 3.
  - 117 diagrams of residual resistance.

$$C_R = f(V/\sqrt{L_{wl}}, B/T, C_p, \Delta/L_{wl}^3)$$

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Taylor series

- Taylor's parent form.
- Fineness coefficient of main section 0,925.
- Hull centre at midship.
- Stern for two propellers.

72 PRINCIPLES OF NAVAL ARCHITECTURE

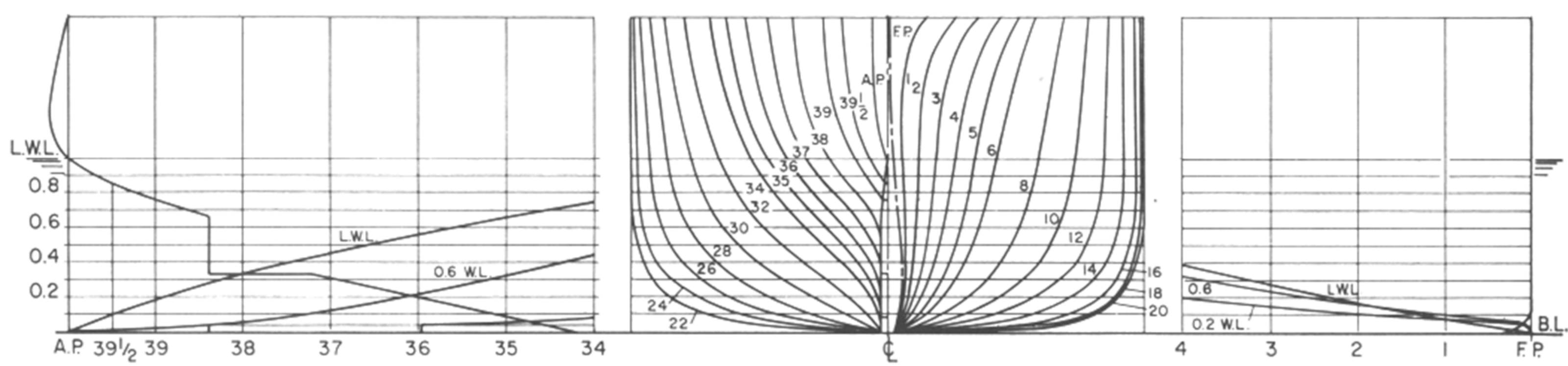
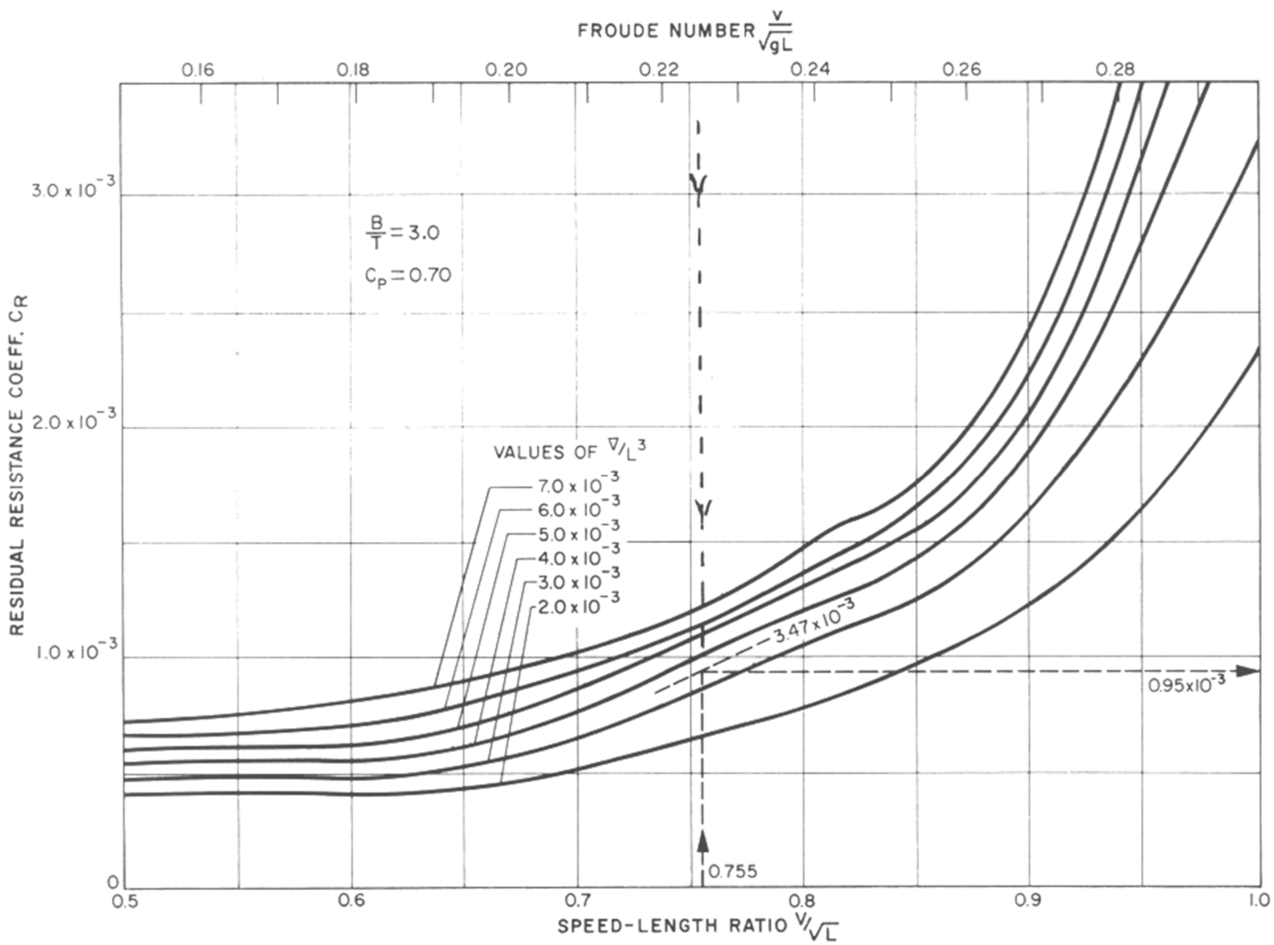


Fig. 63 Lines for the parent form of Taylor's Standard Series

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Taylor series



3. Resistance of a Ship

3.2 Estimates based on statistical methods

Other series

- Série 60 (Todd, 1960)
  - Single screw merchant ship
  - 5 parent forms with fineness coefficients: 0,60, 0,65, 0,70, 0,75 and 0,80.
  - For each fineness coefficient, the location of the hull centre was optimized.
  - Variations of *L/B, B/T,* etc.

- Other series include BSRA, SSPA, NPL,...

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Method of Holtrop and Mennen

- The method estimates the resistance of displacement ships.
- Statistical regression of model tests and results from ship trials.
- The database covers a wide range of ships. For extreme shapes the number of cases in the database is small. Therefore, the accuracy of the estimates is worse.
- The method may be used to assess qualitatively the resistance of a ship design.

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Method of Holtrop and Mennen

- Two formulations:
  - Standard method – Method of Holtrop and Mennen: J. Holtrop, “A statistical re-analysis of resistance and propulsion data”, ISP, Vol. 31, No. 363, November 1984.
  - “Improved” method: J. Holtrop, “A statistical resistance prediction method with a speed dependent form factor”, SMSSH’88, Varna, Oct. 1988.

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Method of Holtrop and Mennen

- Resistance decomposition:

$$R_T = (1+k_1)R_F + R_w + R_B + R_{TR} + R_{APP} + R_A$$

  - R_T = Total resistance
  - R_F = Friction resistance from the ITTC 1957 line
  - $1+k_1$ = Form factor of bare hull
  - R_w = Wave resistance of bare hull
  - R_B = Wave resistance of the bulbous bow

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Method of Holtrop and Mennen

- Resistance decomposition:

$$R_T = (1 + k_1) R_F + R_w + R_B + R_{TR} + R_{APP} + R_A$$

  - R_{TR} = Additional resistance from the immersed Transom
  - R_{APP} = Appendage resistance
  - R_A = Correlation allowance

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3. Resistance of a Ship

3.2 Estimates based on statistical methods

Method of Holtrop and Mennen

- Form factor of bare hull:

$$1 + k_1 = f(L/B, L/T, LCB, \nabla/L^3, C_p)$$

- Wave resistance:

$$\frac{R_w}{\nabla \rho g} = f(F_n, C_M, \nabla/L^3, L/B, B/T, A_{BT}/BT, A_T/BT, T_f, h_b, C_p)$$

  - ∇ = Displacement
  - C_M = Fineness coefficient
  - L = Length at fluctuation
  - B = Beam
  - T = Draft
  - LCB = Longitudinal position of hull centre

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Method of Holtrop and Mennen

- Wave resistance:

$$\frac{R_w}{\nabla \rho g} = f(F_n, C_M, \nabla / L^3, L/B, B/T, A_{BT}/BT, A_T/BT, T_f, h_b, C_p)$$

  - C_p = Prismatic coefficient
  - A_T = Tranversal section of transom at rest
  - A_{BT} = Transversal section of bulbous bow
  - T_f = Vertical distance from the bulbous section centre to the keel line (m)
  - h_b = Draft at the bow (m)
  - F_n = Froude number

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Method of Holtrop and Mennen

- Regression formula for the wetted surface

$$S = f(L, B, T, C_M, C_b, C_{wp}, A_{BT})$$

  - C_{wp} Fineness coefficient at fluctuation

$$R_{APP} = \frac{1}{2}\rho V^2 S_{APP}(1 + k_2)C_F$$

- Additional resistance of the bulb depending on bulb characteristics and its immersion.

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Method of Holtrop and Mennen

- Resistance of the appendages

$$R_{APP} = \frac{1}{2}\rho V^2 S_{APP}(1+k_2)C_F$$

  - V = Ship speed
  - S_{APP} = Wetted surface of the appendages
  - $1+k_2$ = Form factor of the appendages
  - C_F = Friction resistance coefficient of the ship

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Method of Holtrop and Mennen

- Resistance of the immersed area of the transom A_T and of other parameters related to the immersed transom

- Correlation allowance for the model-ship extrapolation

$$R_A = \frac{1}{2}\rho V^2 S C_a$$

  – The correlation allowance depends on L and other parameters

3. Resistance of a Ship

3.2 Estimates based on statistical methods

Improved method of Holtrop and Mennen

- Differences to the standard method
  - Form factor depending on the ship speed
  - Revised formulas for the wave resistance
  - Separate relations for the air resistance. In the standard method it was included in the correlation allowance

- Other improvements:
  - Added resistance due to incoming waves
  - Added resistance from head wind
  - Shallow water corrections