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# Abnormality In Computation Of Viscous Resistance Of High-Speed Hull Forms

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***Abstract:***

*With increase in computational methods and rise in fuel prices, designers need to address a range of parameters so that a vessel may be considered as an efficient design. When 80% of world trade is carried out by sea going vessels, turnaround time in port, manoeuvring characteristics, seakeeping capabilities, bio-fouling and environmental sustainability are some of the several design factors to be considered in the design process.*

*Hydrodynamics of ship design is one area where a few of these considerations can be addressed so that an efficient design is produced. The present research attempts to address a very small segment regarding the power requirements of high speed vessels based on various skin-friction lines and form factors postulated by various authors.*

*In view of this a single model of AMECRC systematic series has been chosen which provides some useful insights to practicing naval architects to determine the calm water resistance characteristics as accurately as possible.*

## 1.Introduction

In the preliminary design stage it is necessary to evaluate as accurately as possible the calm water resistance of a particular hull form. Since model tests are quite expensive and unless the demands of a particular design so warrants, it is only a natural tendency to avoid model tests. Since the last few decades there have been a plethora of publications to help designers to achieve their goal of estimating the calm water resistance.

This paper attempts to address the total resistance estimation by use of various friction lines proposed within the last five decades and the significant influence it may exert in accurate estimation of total resistance.

## 2.Analysis Procedure

When towing tank data are available, ITTC'78 procedure recommends that the total resistance of model $R_{TM}$, be measured as that for the full scale at the same Froude number $Fn$, in Newton, or in a non-dimensional form as shown in equation 1 below:

$$C_{TM} = \frac{R_{TM}}{\frac{1}{2}\rho S V_M^2} \qquad (1)$$

This is reduced to the residual resistance coefficient by use of form factor (1+k) as depicted in equation (2)

$$C_{RM} = C_{TM} - (1+k)C_{FM} \qquad (2)$$

where $C_{FM} = \dfrac{0.075}{(\log_{10}(R_n) - 2)^2}$ (3)

which is the ship-model correlation line proposed by ITTC-57 and (1+k) is the form factor to be determined from experimental results (Prohaskas' method) by making a plot of $\frac{F_n^4}{C_{FM}}$ against $\frac{C_{TM}}{C_{FM}}$ and a tangent drawn to find the intercept on $\frac{C_{TM}}{C_{FM}}$ axis and $R_n$ is the Reynolds number given by $\frac{V_m L}{\nu}$ where ν is the kinematic viscosity of the fluid. The total resistance coefficient of a ship without bilge keels is then given by as shown in equation (4):

$$C_{TS} = (1+k)C_{FS} + \Delta C_{FS} + C_R + C_{AA} \qquad (4)$$

$\Delta C_{FS}$ is the roughness allowance $= \left[105\left(\frac{k_S}{L_{WL}}\right)^{1/3} - 0.64\right]10^{-3}$ (5)

and the surface roughness $k_S=150\times10^{-6}$ m and the air resistance is given by:

$$C_{AA} = 0.001\frac{A_T}{S} \qquad (6)$$

and $A_T$ is transverse projected area of the above waterline part of the vessel.

$C_{RS}$ is assumed to be same as $C_{RM}$ since both model and full scale ship should follow Froude's law of comparison. The total resistance coefficient of the full scale vessel is then given by as shown in equation (7).

$$C_{TS} = [(1+k)C_{FS} + \Delta C_{FS}] + C_R + C_{AA} \qquad (7)$$

**3.Towing Tank Test Data**

In this paper a single model from AMECRC systematic series has been selected as a test case (Bojovic 1996). The particulars of the model are as shown in Table 1 and body plan is shown in Figure 2.

| **Model** | **#1** |
|---|---|
| L/B | 8 |
| B/T | 4 |
| $C_B$ | 0.396 |
| $C_M$ | 0.65 |
| $C_W$ | 0.8 |
| Disp.(kg) | 6.321 |
| L/□$^{1/3}$ | 8.653 |
| WSA ($m^2$) | 0.3149 |

*Table 1: Main Pariculars of Model #1*

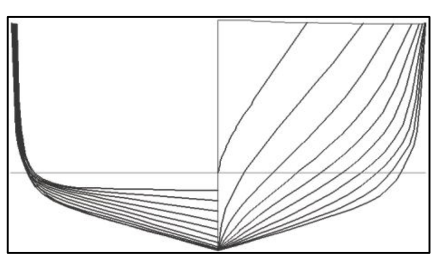

*Figure 2: Model #1 BODY PLAN*

The model's experimental test data is as shown in Tables 2 and 3:

| | | |
|---|---|---|
| $L_{WL}$ | 1.6 | m |
| S | 0.3149 | $m^2$ |
| Δ | 6.321 | kg |
| ∇ | 0.006321 | $m^3$ |
| Water temperature | 18.5 | $^0C$ |
| υ, at above temperature | 1.03894E-06 | $m^2/s$ |
| ρ, at above temperature, FW | 998.472 | $kg/m^3$ |
| Block Coefficient, $C_B$ | 0.396 | |
| Slenderness ratio $L/\nabla^{1/3}$ | 8.653 | |

*Table 2: Model #1 (Test Condition )*

| **Fn** | **Fn□** | **Speed (m/s)** | **Drag (grams)** |
|---|---|---|---|
| 0.31 | 0.9 | 1.208 | 128.59 |
| 0.36 | 1.05 | 1.412 | 168.58 |
| 0.41 | 1.2 | 1.619 | 241.91 |
| 0.46 | 1.35 | 1.822 | 318.35 |
| 0.51 | 1.5 | 2.018 | 388.76 |
| 0.56 | 1.65 | 2.224 | 448.15 |
| 0.61 | 1.8 | 2.419 | 514.04 |
| 0.67 | 1.96 | 2.633 | 587.63 |
| 0.72 | 2.1 | 2.831 | 653.55 |
| 0.77 | 2.25 | 3.035 | 732.87 |
| 0.82 | 2.4 | 3.231 | 811.58 |
| 0.87 | 2.55 | 3.436 | 892.1 |
| 0.92 | 2.7 | 3.638 | 982.92 |
| 0.97 | 2.86 | 3.846 | 1078.87 |

*Table 3: Test data f Model #1*

**4.Data Analysis**

ITTC Performance prediction method which became effective in 1999 recommends that any of the following friction formulations can be used (ITTC 2005):

- ITTC'57, $C_F = \dfrac{0.075}{(\log_{10} R_n - 2)^2}$ (8)
- Hughes (1954), $C_F = \dfrac{0.066}{(\log_{10} R_n - 2.03)^2}$ (9)
- Prandtl-Schlichting (1932),

$$C_F = \frac{0.455}{(\log_{10} R_n)^{2.58}} \quad (10)$$

- Schoenherr (1932) also known as ATTC 1942 line, $\dfrac{0.242}{\sqrt{C_F}} = \log_{10}(R_n C_F)$

  (11)
- Katsui, $C_F = \dfrac{0.0066577}{(\log_{10} R_n - 4.3762)^{0.042612 \log_{10} R_n + 0.56725}}$

  (12)

In the present paper friction formulation of Grigson (1993) has also been added, which are shown for model scale ($1.5\times10^6<R_n<2\times10^7$) and full scale vessel ($10^8<R_n<4\times10^9$) in equations 13 and 14 respectively.

$$C_F = \begin{bmatrix} 0.9335 + 0.147(\log R_n - 6.3)^2 \\ -0.071(\log R_n - 6.3)^3 \end{bmatrix} \times \frac{0.075}{(\log R_n - 2)^2} \quad (13)$$

$$C_F = \begin{bmatrix} 1.0096 + 0.0456(\log R_n - 7.3) \\ -0.013944(\log R_n - 7.3)^2 \\ +0.0019444(\log R_n - 7.3)^3 \end{bmatrix} \times \frac{0.075}{(\log R_n - 2)^2} \quad (14)$$

In the Figure 3 below the variation of with respect to Reynolds number for model scale has been shown. It is clear from the graph that Hughes (1954) formulation under predicts $C_F$ by a significant amount when compared with ITTC'57 formulation. Grigson's (1993) formulation lies in the narrow band of the rest of the formulations.

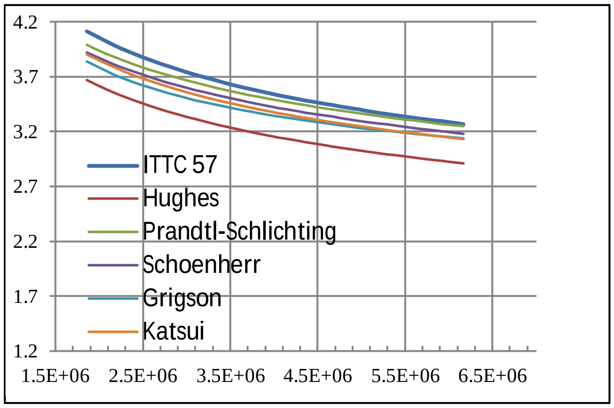


*Figure 3: Rn against $10^3C_F$ at model scale*

In the case of full scale vessel the opposite has been observed. Grigson's (1993) formulation over predicts all other formulations. The friction lines of Schoenherr and ITTC'57 are overlapping each other. In both model and full scale Hughes formulation is under predicted when compared with ITTC'57, Prandtl-Schlichting, Schoenherr and Katsui's formulations. In view of the above variations it was necessary to undertake the influence of form factor by use of each of the above formulations using the standard procedure of Prohaska (1966). The table below shows the form factors as evaluated. An additional column has been added to the Table 4 to show the influence of scale factor on full scale form factor. As per Garcia-Gomez (2000) one needs to adjust the model form factor to suit the full scale form factor for which the author has proposed the equation (15) as shown:

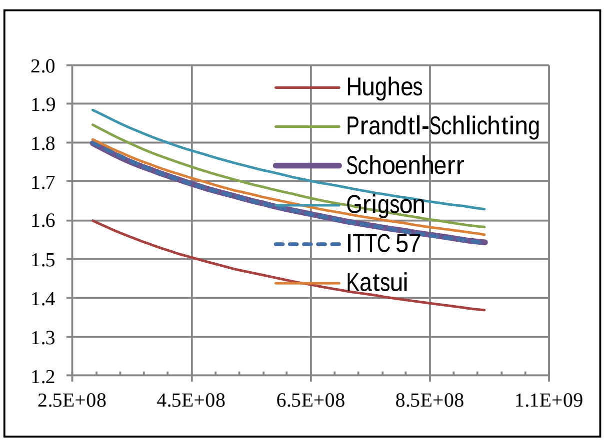


*Figure 4: Rn against $10^3C_F$ at full scale ( $\lambda$=31.25)*

| | □□= 31.25 | Model | Full Scale |
|---|---|---|---|
| ITTC'57 | $(1+k)_{ITTC57}$ | 1.12 | 1.178 |
| Hughes | $(1+k)_{H}$ | 1.24 | 1.298 |
| Prandl-Schlichting | $(1+k)_{PS}$ | 1.14 | 1.198 |
| Schoenherr | $(1+k)_{S}$ | 1.18 | 1.238 |
| Grigson | $(1+k)_{G}$ | 2.82 | 2.878 |
| Katsui | $(1+k)_{K}$ | 1.16 | 1.218 |

*Table 4: Form Factors as per Pohaska (1966) and Full Scale (Gomez (2000))*

$$k_s - k_m = 1.91(\lambda - 1)10^{-3} \qquad (15)$$

where $k_s$ is the form factor of full scale vessel and $k_m$ is form factor of model as determined from models tests and λ is the scale factor between ship and model. In our case the scale factor is 31.25.

It is now necessary to compare the full scale values against $F_{n\nabla}$ using equation 7 for all proposed formulations. In order to keep the uniformity the last term of equation 7, $C_{AA}$, has been ignored as this can always be introduced at a later stage. $\Delta C_{FS}$ is the only term which is constant for all proposed methods. Figure 5 illustrates the trend of $10^3 C_{TS}$ against $F_{n\nabla}$.

**5.Conclusion**

This paper has attempted to show the variations in the various formulations and its effect on total calm water resistance of a vessel. While one arbitrary model has been chosen to show these variations, probably it would be prudent to say that several models of the same systematic series could have been used to validate the efficacy of the various formulations. Other important conclusions that can be drawn are:

- All four formulations namely ITTC-57, Prandtl-Schlichting, Schoenherr and Hughes are equally good in evaluation of friction lines.
- Although Grigsons (1993) formulation under predicts in model scale and over predicts in full scale, it is not to say that this formulation in any way erroneous. It

appears that this formulation is probably inappropriate for high-speed round bilge displacement hull forms.

- Evaluation of form factor necessitates use of model test results and its determination by use of Prohaska plot. Should this not be feasible then one of the several empirical formulae could be used.

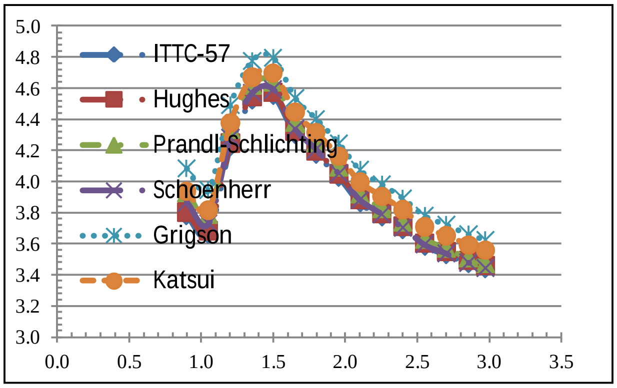


*Figure 5: $10^3 C_T$ against $F_{n\nabla}$*

## 6.Acknowledgement

The authors is greatly indebted to Florida Institute of Technology for providing all necessary help and support in carrying out this research work.

- **NOMENCLATURE**

| Symbols | Definition | Units |
|---|---|---|
| AMECRC | Australian Maritime Engineering CRC | |
| *B* | Beam of vessel | m |
| $C_B$ | Block coeffocient | |
| $C_F$ | ship-model correlation line | |
| $C_R$ | Residuary Resistance Coefficient | |
| $C_T$ | Total Resistance Coefficient | |
| □$C_{FS}$ | Roughness Allowance | |
| Fn | Froude Number | |
| Fn□ | Volumetric Froude Number | |
| *1+k* | Form factor | |
| $k_s$ | Surface Roughness (150□$10^{-6}$) | m |
| *L* | Length of vessel | m |
| $L/□^{1/3}$ | Slenderness Ratio | |
| M & S | Subscripts to distinguish between model and full scale | |
| *Rn* | Reynolds Number | |
| *V* | Velocity of vessel | m/s |
| □ | Volumetric displacement | $m^3$ |
| □ | Fluid density | $t/m^3$ |
| □ | Scale factor | |
| *S* | Wetted Surface Area | $m^2$ |
| □ | Kinematic viscosity of fluid | $m^2/s$ |

**7.Reference**

1. ITTC-2005; Proceedings of 24th ITTC, Vol II, pp 601-638
2. Bojovic, P. 1996, "Reanalysis of AMECRC Systematic Series Calm Water Testing Results", AMECRC IR 96/10
3. Garcia-Gomez, A (2000): "On the form factor Scale effect", Ocean Engineering, pp 97-109
4. Bertram, V (2000): Practical Ship Hydrodynamics, Butterworth-Heinemann, ISBN 0 7506 4851 1

## 8.Appendix

Empirical expressions for estimation of form factors for mono-hull forms, when not available through Prohaska (1966) procedure:

| | |
|---|---|
| Granville 1956 | $1+k=1+18.7\left(C_B\times\frac{B}{L}\right)^2$ |
| Watanabe | $1+k=1.017+\frac{20C_B}{\left(\frac{L}{B}\right)^2\left(\frac{B}{T}\right)^{0.5}}$ |
| Wright 1984 (deep water) | $1+k=2.4806C_B^{0.1526}\left(\frac{B}{T}\right)^{0.0533}\left(\frac{B}{L}\right)^{0.3856}$ |
| Granville (1974) | $1+k=0.97+\frac{32.8C_B^2}{\left(\frac{L}{B}\right)^2\left(\frac{B}{T}\right)}$ |

Empirical expressions to determine the wetted surface area of mono-hull forms:

This is based on the regression analysis of AMECRC Systematic Series.

$$\begin{aligned}\frac{S}{\nabla^{2/3}} &= 3.328344+0.74494\left(\frac{L}{B}\right)^{2/3}(C_B)^{-2/3}\\ &+0.35227\left(\frac{B}{T}\right)(C_B)^{-2/3}\\ &+0.04630664\left(\frac{L}{B}\right)^{2/3}\left(\frac{B}{T}\right)C_B^{-1}\\ &-0.0379448\left(\frac{L}{B}\right)^{4/3}C_B^{-1}\\ &-1.367162\left(\frac{B}{T}\right)^{1/3}(C_B)^{-1/3}\end{aligned}$$

Schneekluth and Bertram (2000) $S=\left(3.4\nabla^{1/3}+0.5L_{WL}\right)\nabla^{1/3}$