Supplementary material

S1. Calculation procedure for Granville's similarity law scaling

The detailed calculation procedure is presented by Schultz (2007) as follows:

(1) Determine the equivalent sand-grain roughness value (k_s) representing the current ship's hull surface. This value is given as an output from the fouling growth model and hull maintenance activity at a specific point in time, discussed in Section 2.3.4.

(2) To determine the roughness function (ΔU^+) that quantifies the effect of roughness, an initial value for the roughness Reynolds number (k_s^+) is assumed. Here, $k_s^+ = k_s U_\tau / \nu$, U_τ is the friction velocity and ν is the kinematic viscosity. In this study, the assumed k_s^+ value is substituted into a representative roughness function model, such as **Eq. (1)** proposed by Demirel et al. (2017), to determine ΔU^+. Here, κ is the von Kármán constant, for which a value of 0.42 is applied.

$$\Delta U^+ = \begin{cases} 0 & k_s^+ < 3 \\ \frac{1}{\kappa}\ln\left(0.26 k_s^+\right)^{sin\left[\frac{\pi}{2}\frac{\log\left(\frac{k_s^+}{3}\right)}{\log(5)}\right]} & 3 < k_s^+ < 15 \\ \frac{1}{\kappa}\ln\left(0.26 k_s^+\right) & k_s^+ > 15 \end{cases} \quad (1)$$

(3) The frictional resistance line on the rough surface is established using the ΔU^+ value. This is achieved by horizontally shifting the standard frictional resistance line on the smooth surface (Karman-Schoenherr curve from Schoenherr (1932) as represented by **Eq. (2))** along the $\log(Re)$ axis by an amount of $\kappa \Delta U^+ / \ln(10)$. This follows the method proposed by Schultz (2007).

$$\frac{0.242}{\sqrt{C_{F_{smooth}}}} = \log\left(Re \cdot C_{F_{smooth}}\right) \quad (2)$$

4) Concurrently, a line representing the relationship between Re and C_F that must be satisfied by the vessel under the currently assumed k_s^+ condition is defined. This line is derived by first establishing the $Re - C_F$ relationships for a laboratory-scale plate (L_{plate}) using **Eqs. (3)-(4)**, and then scaling this to the ship length (L_{ship}). This scaling can be adjusted by horizontally shifting the baseline in the $\log(Re) - C_F$ plane by an amount of $\log\left(L_{ship}/L_{plate}\right)$.

$$Re = \frac{{L_{plate}}^+}{\sqrt{\frac{C_F}{2}\left(1 - \frac{1}{\kappa}\sqrt{\frac{C_F}{2}}\right)}} \quad (3)$$

$${L_{plate}}^+ = \frac{L_{plate}}{\left(\frac{\nu}{U_\tau}\right)} \quad (4)$$

where ${L_{plate}}^+$ is the non-dimensional plate length, L_{plate} is the length of the laboratory scale plate $[m]$, and C_F is the frictional resistance coefficient of the theoretical plate.

(5) The intersection point of the two reference lines defined in (3) and (4) is found, which yields the corresponding C_F and Re values at that point.

(6) The initially assumed k_s^+ value from step (2) is adjusted, and steps (2)-(5) are iterated until the Re value obtained from the intersection point matches the target ship Reynolds number (Re_s).

(7) Once this iterative calculation converges and the rough surface frictional resistance coefficient (C_{Fs_rough}) corresponding to the target Re_s is determined, the net increase in frictional resistance coefficient due to roughness (ΔC_{Fs}) is calculated using **Eq. (5)**.

$$\Delta C_{Fs} = C_{Fs_{rough}} - C_{Fs_{smooth}} \tag{5}$$

(8) Finally, the added resistance due to the increase in hull roughness caused by fouling is calculated as shown in **Eq. (6)**.

$$\Delta R_{fouling} = \frac{1}{2}\rho V^2 S \Delta C_{Fs} \tag{6}$$

where ρ is the seawater density [kg/m³], and S is the wetted surface area of the ship's hull [m²].

References

Demirel, Y. K., Turan, O., & Incecik, A. (2017). Predicting the effect of biofouling on ship resistance using CFD. *Applied Ocean Research*, *62*, 100–118. https://doi.org/10.1016/j.apor.2016.12.003

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