**Cwave and n as trainable parameters**

**Overview of Propulsion Power Calculation**

The **required propulsion power** ( P\_{\text{total}} ) for a ship is determined by overcoming the total hydrodynamic resistance ( R\_{\text{total}} ) acting against its motion through water. The total resistance comprises several components:

1. **Frictional Resistance (** R\_{\text{friction}} **)**: Caused by the friction between the ship’s hull and water.

2. **Residuary Resistance (** R\_{\text{resid}} **)**: Arising from hull form-related factors like wave-making and viscous effects not captured by simple frictional models.

3. **Wave-Induced Resistance (** R\_{\text{waves}} **)**: Due to the interaction between the ship and external wave fields.

The sum of these resistances gives the **Total Resistance (** R\_{\text{total}} **)**, which must be counteracted by the ship’s propulsion system to maintain a certain speed.

**Detailed Calculation Steps and Relations**

**1. Convert Speed from Knots to Meters per Second**

The ship’s speed ( V ) is often given in knots. Convert it to meters per second (m/s) for consistency in SI units.

V (\text{m/s}) = V (\text{knots}) \times 0.514444 \, \frac{\text{m}}{\text{s} \cdot \text{knots}}

**Example:**

V = 10 \, \text{knots} \times 0.514444 \, \frac{\text{m}}{\text{s} \cdot \text{knots}} = 5.14444 \, \text{m/s}

**2. Calculate the Reynolds Number (** \text{Re} **)**

The **Reynolds Number** is a dimensionless quantity that helps predict flow patterns in different fluid flow situations. It characterizes the ratio of inertial forces to viscous forces and is given by:

\text{Re} = \frac{V \times L}{\nu}

Where:

• V  = Speed of the ship (m/s)

• L  = Characteristic length (m) (typically the ship’s length)

• \nu  = Kinematic viscosity of water (m²/s)

**Example:**

\text{Re} = \frac{5.14444 \, \text{m/s} \times 229 \, \text{m}}{1.19 \times 10^{-6} \, \text{m}²/\text{s}} \approx 9.8995 \times 10^{8}

**3. Determine the Frictional Resistance Coefficient (** C\_f **)**

The **Frictional Resistance Coefficient** ( C\_f ) quantifies the frictional resistance per unit area and is estimated using empirical relations. A common approximation for turbulent flow over a flat plate is:

C\_f = \frac{0.075}{(\log\_{10} \text{Re} - 2)^2}

Where:

• \log\_{10} \text{Re}  = Base-10 logarithm of the Reynolds Number

**Example:**

\log\_{10} 9.8995 \times 10^{8} \approx 8.996

C\_f = \frac{0.075}{(8.996 - 2)^2} = \frac{0.075}{6.996^2} \approx 0.001531

**4. Calculate Frictional Resistance (** R\_{\text{friction}} **)**

**Frictional Resistance** is the resistance due to the friction between the ship’s hull and water. It is calculated as:

R\_{\text{friction}} = \frac{1}{2} \rho C\_f S V^2

Where:

• \rho  = Water density (kg/m³)

• C\_f  = Frictional resistance coefficient

• S  = Wetted surface area (m²)

• V  = Speed (m/s)

**Example:**

Given:

• \rho = 1025 \, \text{kg/m}³

• C\_f = 0.001531

• S = 9,950 \, \text{m}²  (as per your latest input)

• V = 6.687 \, \text{m/s}  (converted from 13 knots)

R\_{\text{friction}} = 0.5 \times 1025 \times 0.001531 \times 9950 \times (6.687)^2

R\_{\text{friction}} \approx 0.5 \times 1025 = 512.5

512.5 \times 0.001531 \approx 0.7824

0.7824 \times 9950 \approx 7,788.28

7,788.28 \times 44.75 \approx 3.386 \times 10^{5} \, \text{N}

R\_{\text{friction}} \approx 3.386 \times 10^{5} \, \text{N}

**5. Estimate Residuary Resistance (** R\_{\text{resid}} **)**

**Residuary Resistance** accounts for resistance not captured by frictional models, such as wave-making and viscous effects related to hull form. It is estimated using:

R\_{\text{resid}} = C\_{\text{resid}} \times R\_{\text{friction}}

Where:

• C\_{\text{resid}}  = Residuary resistance coefficient (dimensionless)

**Example:**

Given:

• C\_{\text{resid}} = 0.03

R\_{\text{resid}} = 0.03 \times 3.386 \times 10^{5} \approx 1.016 \times 10^{4} \, \text{N}

**7. Estimate Wave-Induced Resistance (** R\_{\text{waves}} **)**

**Wave-Induced Resistance** arises from the interaction between the ship and external wave fields. It is influenced by factors such as wave height, wave direction relative to the ship’s heading, and hull form.

The general formula used is:

R\_{\text{waves}} = \frac{1}{2} \rho g A S\_{\text{wave}} C\_{\text{wave}}

Where:

• g  = Acceleration due to gravity (m/s²)

• A  = Wave amplitude (typically half the significant wave height,  \frac{\text{SWH}}{2} ) (m)

• S\_{\text{wave}}  = Wetted surface area affected by waves (m²)

• C\_{\text{wave}}  = Wave resistance coefficient (dimensionless)

**Determining** S\_{\text{wave}} **:**

A simplified estimation assumes that the wave interaction area scales with the ship’s length and beam:

S\_{\text{wave}} = L \times \text{Beam}

**Example:**

Given:

• L = 229 \, \text{m}

• \text{Beam} = 32 \, \text{m}

• \text{SWH} = 2.19 \, \text{m}

• C\_{\text{wave}} = 0.0178  (as per adjusted value to align with instrument reading)

A = \frac{2.19}{2} = 1.095 \, \text{m}

S\_{\text{wave}} = 229 \times 32 = 7,328 \, \text{m}²

R\_{\text{waves}} = 0.5 \times 1025 \times 9.81 \times 1.095 \times 7,328 \times 0.0178

R\_{\text{waves}} \approx 0.5 \times 1025 = 512.5

512.5 \times 9.81 \approx 5,027.625

5,027.625 \times 1.095 \approx 5,504.06

5,504.06 \times 7,328 \approx 40,258,956.8 \, \text{N}

40,258,956.8 \times 0.0178 \approx 716,658 \, \text{N}

R\_{\text{waves}} \approx 7.167 \times 10^{5} \, \text{N}

**Note:** The **Wave Resistance Coefficient (** C\_{\text{wave}} **)** is typically determined empirically or through detailed computational models, as it accounts for complex interactions between the hull and wave dynamics.

**8. Determine Total Resistance (** R\_{\text{total}} **)**

The **Total Resistance** is the sum of calm water resistance and wave-induced resistance.

R\_{\text{total}} = R\_{\text{calm}} + R\_{\text{waves}}

**Example:**

R\_{\text{total}} = 3.4876 \times 10^{5} + 7.167 \times 10^{5} \approx 1.0663 \times 10^{6} \, \text{N}

**9. Calculate Required Propulsion Power (** P\_{\text{total}} **)**

The **Required Propulsion Power** is the power needed to overcome the total resistance at the desired speed, adjusted for the propulsion system’s efficiency.

P\_{\text{total}} = \frac{R\_{\text{total}} \times V}{\eta}

Where:

• \eta  = Propulsion system efficiency (dimensionless)

**Example:**

Given:

• R\_{\text{total}} = 1.0663 \times 10^{6} \, \text{N}

• V = 6.687 \, \text{m/s}  (converted from 13 knots)

• \eta = 0.7

P\_{\text{total}} = \frac{1.0663 \times 10^{6} \times 6.687}{0.7} \approx \frac{7,136,570}{0.7} \approx 10,195,100 \, \text{W}

P\_{\text{total}} \approx 10.195 \, \text{MW}

**Summary of Equations Used**

1. **Speed Conversion:**

V (\text{m/s}) = V (\text{knots}) \times 0.514444

2. **Reynolds Number:**

\text{Re} = \frac{V \times L}{\nu}

3. **Frictional Resistance Coefficient:**

C\_f = \frac{0.075}{(\log\_{10} \text{Re} - 2)^2}

4. **Frictional Resistance:**

R\_{\text{friction}} = \frac{1}{2} \rho C\_f S V^2

5. **Residuary Resistance:**

R\_{\text{resid}} = C\_{\text{resid}} \times R\_{\text{friction}}

6. **Calm Water Resistance:**

R\_{\text{calm}} = R\_{\text{friction}} + R\_{\text{resid}}

7. **Wave-Induced Resistance:**

R\_{\text{waves}} = \frac{1}{2} \rho g A S\_{\text{wave}} C\_{\text{wave}}

• A = \frac{\text{SWH}}{2}

8. **Total Resistance:**

R\_{\text{total}} = R\_{\text{calm}} + R\_{\text{waves}}

9. **Required Propulsion Power:**

P\_{\text{total}} = \frac{R\_{\text{total}} \times V}{\eta}