1. Total ship resistance can be broken down into sub components. The two main components are pressure resistance and viscous resistance. List the sub-components of these two main components and give definitions for each.

**Answer**

1. We can show the sub-components schematically as below.

Another way to show a breakdown into components is with a sketch like the one shown below, which you have in your notes.
2. Calculate Reynolds number, $R_n$, for a ship with $LWL=170\text{m}$ at $V=14.5$ knots in salt water at 10°C. For a 4m model of this ship, what would the $R_n$ be in a tow tank with fresh water at 15°C when the ship speed of 14.5 knots is scaled according to Froude number, $F_n$?

**Answer**

2. Reynolds number, $R_n$ is defined as:

$$R_n = \frac{VL}{\nu}$$

So by substituting the values given in the problem we get

$$R_{ns} = \left(14.5 \text{ knots}\right) \times \left(0.5144 \frac{\text{m} \cdot \text{s}^{-1}}{\text{knots}}\right) \times (170\text{m}) \over 1.358 \times 10^{-6} \frac{\text{m}^2 \cdot \text{s}^{-1}}{} = 937 \times 10^6$$

Since we scale according to Froude number, $F_n$ we start with:

$$F_{nm} = F_{ns}$$

Expanding and rearranging gives:

$$V_m = V_s \sqrt{\frac{L_m}{L_s}}$$

By substituting the values in the above expression we get

$$V_m = (14.5 \text{ knots}) \times \left(0.5144 \frac{\text{m} \cdot \text{s}^{-1}}{\text{knots}}\right) \times \sqrt{4\text{m}} \over 170\text{m} = 1.144 \text{ m} \cdot \text{s}^{-1}$$

Then we can calculate the Reynolds number of the model, $R_{nm}$ as:

$$R_{nm} = \frac{VL}{\nu}$$

By substituting the values in the above expression we get

$$R_{nm} = \left(1.144 \text{ m} \cdot \text{s}^{-1}\right) \times (4\text{m}) \over 1.1390 \times 10^{-6} \frac{\text{m}^2 \cdot \text{s}^{-1}}{} = 4.018 \times 10^6$$
3. Do a dimensional analysis for ship resistance in an inviscid fluid (assume we are concerned with geometrically similar ships so that a single characteristic dimension describes the vessel geometry). Show that the wave resistance is a function of Froude number.

Answer

3. For a ship at the free surface of an inviscid fluid…

Step 1: Write a functional expression

\[ R_w = \phi[\rho, g, V, L] \]

Step 2: Then write an equation as

\[ R_w = k\rho^a g^b V^c L^d \]

Step 3: Next we look at the dimensions of the expression

\[ \frac{ML}{T^2} = k \left( \frac{M}{L^2} \right)^a \left( \frac{L}{T^2} \right)^b \left( \frac{L}{T} \right)^c (L)^d \]

Step 4: By inspection we equate the exponents of each side of the equation for like terms and get a system of equations

\[ M : 1 = a \]
\[ L : 1 = -3a + b + c + d \]
\[ T : -2 = -2b - c \]

Step 5: From this we can solve

\[ a = 1 \]
\[ c = 2 - 2b \]
\[ d = 2 + b \]

Step 6: Then we can rewrite the equation above as

\[ R_w = k\rho^1 g^b V^{2-2b} L^{2+b} \]
\[ = k\rho^1 V^2 L^2 \left( \frac{gL}{V^2} \right)^b \]

Rearranging the equation yields

\[ \frac{R_w}{\rho V^2 L^2} = \phi \left[ \frac{V}{\sqrt{gL}} \right] \]

This shows that the resistance is a function of Froude number, \( F_n \)

4. Using simple, brief, qualitative arguments, explain the difference between the relative importance of viscous and pressure resistance components for these two ships: a 240m bulk carrier with a design speed of 16 knots and a 160m container ship with a design speed of 22 knots.

Qualitatively, you might expect that the relatively slow moving bulker will have a high proportion of its total resistance contributed by viscous effects. Rather than rely simply on the speed, we can base our qualitative assessment on the vessel’s Froude number, which at 0.17 is relatively low (but quite typical of a bulk carrier). As wave resistance is relatively low at low speeds and increases markedly with speed, we can expect the bulker to have relatively low wave making resistance.

The same reasoning applies to the container ship. 22 knots is actually very fast for a ship of this size and its corresponding Froude number (0.28) is high compared to the bulker and is at the high end of the range for ships of this type (container ships). As the speed is high, we should expect the wave making resistance to be of greater relative importance to the container ship than it is for the bulker.