1. Total ship resistance can be broken down into sub components. What are the two main components? Use a sketch to show how the sub-components relate to each other.

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.

![Diagram of total resistance and sub-components](image_url)
2. Calculate Reynolds number, \( R_n \), for a ship with \( L_{WL} = 165\text{m} \) at \( V = 14.3 \text{knots} \) in salt water at 10°C. For a 4.3 m 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 14.3 knots is scaled according to Froude number, \( F_n \)? What are the consequences of not obeying the law of similitude dictated by \( R_{nM} = R_{nS} \)?

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

\[
R_n = \left( \frac{(14.3\text{knots}) \times \left( 0.5144 \text{ m/s} \times 165\text{m} \right)}{1.3538 \times 10^{-6} \text{ m}^2 \cdot \text{s}^{-1}} \right) = 896 \times 10^6
\]

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

\[
V_m = \left( 14.3\text{knots} \times \left( 0.5144 \text{ m/s} \times \frac{4.3\text{m}}{165\text{m}} \right) \right) = 1.187 \text{ m/s}
\]

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

\[
R_{nM} = \left( 1.187 \text{ m/s} \right) \times \left( 4.3\text{m} \right) = 4.483 \times 10^6
\]

Reynolds law of similitude is not obeyed, the fundamental consequence of which is that the viscous effects at model and full scale are not similar.
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 a real fluid…

Step 1: Write a functional expression

\[ R = f(\rho, \mu, g, V, L) \]

Step 2: Then write an equation as

\[ R = k\rho a \mu b g^c V^d L^e \]

where \( k \) is a constant.

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

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

Step 4: By inspection we equate the exponents of each side of the equation for like terms and get a system of 3 equations and 5 unknowns

\[
\begin{align*}
M : 1 &= a + b \\
L : 1 &= -3a - b + c + d + e \\
T : -2 &= -b - 2c - d
\end{align*}
\]

Step 5: From this we can solve the equations in terms of any two unknowns (\( a \) and \( c \) are used here)

\[
\begin{align*}
a &= 1 - b \\
d &= 2 - b - 2c \\
e &= 1 + 3a + b - c - d \\
&= 1 + 3(1 - b) + b - c - (2 - b - 2c) \\
&= 2 + c - b
\end{align*}
\]

Step 6: Then we can rewrite the equation above as

\[
R = k\rho^{(1-b)} \mu^b g^c V^{(2-b-2c)} L^{(2+c-b)}
\]

\[
= k\rho V^2 L^2 \left( \frac{\mu}{\rho VL} \right)^b \left( \frac{gL}{V^2} \right)^c
\]

Rearranging the equation yields

\[
\frac{R}{\rho V^2 L^2} = f \left( \frac{VL}{V}, \frac{V}{\sqrt{gL}} \right)
\]

This shows that the non-dimensionalized resistance is a function of Reynolds and Froude numbers, \( R_n \) and \( F_n \).

The viscous component of total resistance is a function of Reynolds number; the wave making component is a function of Froude number. This an be demonstrated formally by considering dimensional analyses of (i) ship resistance in an inviscid fluid (no viscous component), and (ii) submarine resistance in a real fluid (no wave making).

In the case of an inviscid fluid, we can ignore the viscosity term, which leaves the resistance as a function solely of the Froude number.
5. 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.

We can use the Froude number as a helpful indicator of the relative importance of viscous and wave making resistance.

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 small at low speeds and increases markedly with speed, we can expect the bulker to have relatively low wave making resistance. Indeed, the coefficient of wave making resistance, $C_w$, increases with the fourth power of speed.

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.