MODEL TESTING

* Bluff Body: form drag >> friction drag

\[ C_D \] constant over range of Reynolds #'s
for a fixed regime (laminar or turbulent)

- Measure force on model, calculate \( C_D \) (\[ C_D = \frac{F}{\frac{1}{2} \rho u^2 A_m} \])
- Use this \( C_D \) for full-scale \( F_{\text{fullscale}} = C_D \cdot \frac{1}{2} \rho u^2 A_p \)

if the full-scale body operates in a turbulent regime
so MUST the model you test

* Streamlined Body:

\[ C_{D_{\text{Total}}} = C_f (R\#) + C_{D_0} \]

- frictional drag - profile/form drag
only slightly dependent on Reynolds #
due to separation

\[ \text{dependent} \]

\[ \text{Reynolds} \# \] (smaller) \( \leftrightarrow \) (larger)

as long as similar to flat plate if \( \text{in an regime same wetted area} \)

\[ \text{this is an assumption we make (is ok)} \]
**EXPERIMENT:** \( \text{Re_{model} \& Re_{prototype}} \)

- Measure force on model @ \( \text{Re}_{model} = \frac{Um Lm}{\nu_m} \)
- Determine \( C_{D_{model}} = \frac{F_m}{\frac{1}{2} \rho_m U_m^2 A_m} \)
- Form drag is \( C_{D_{om}} = C_{D_m} - C_f (\text{Re}_m) \)

\( C_{D_{om}} = C_{D_0 \text{prototype full scale ship}} \)

- Can now predict total \( C_D \) on prototype:

\[
C_{D_{proto}} = C_{D_{omodel}} + C_f (\text{Re}_{proto})
\]

\[
= C_{D_{omodel}} + C_f (\text{Re}_{proto})
\]

\[
\therefore \ C_{D_{proto}} = C_{D_m} - C_f (\text{Re}_m) + C_f (\text{Re}_{proto})
\]

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**Aside:**

If roughness on model is high, need to account for this.
For a ship

\[ C_D = C_D \left( \frac{Re}{Fr} \right) \]  function of both Reynolds \# and Froude \#'s

\[ Re = \frac{UL}{\nu} \quad Fr = \frac{U}{\sqrt{gL}} \]

\[ Re \sim l \quad Fr \sim \frac{1}{Fr} \quad \text{so} \]

both cannot be scaled together!

\[ \frac{R}{F^2} = \frac{\sqrt{gL^2}}{2} \]

Froude's Hypothesis

\[ C_D(R, F) = C_F(R) + C_R(F) \]

Residual drag

Equivalent flat plate drag

\[ C_R(F) \text{ is assumed not to be a function of Reynolds \#; accounts for form drag & separation drag.} \]
Predict $C_r$.

Run Experiment with matching Froude #’s

$F_m = F_{proto}$

Then correct for Reynolds # effects.

Use $c_f = \frac{0.075}{(\log_{10} Re - 2)^2}$ ITTC Ship Curve for friction!