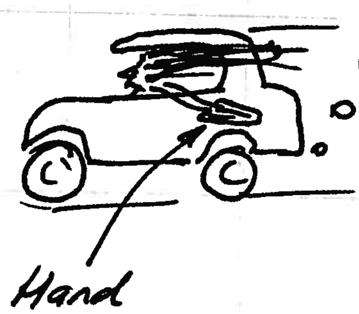
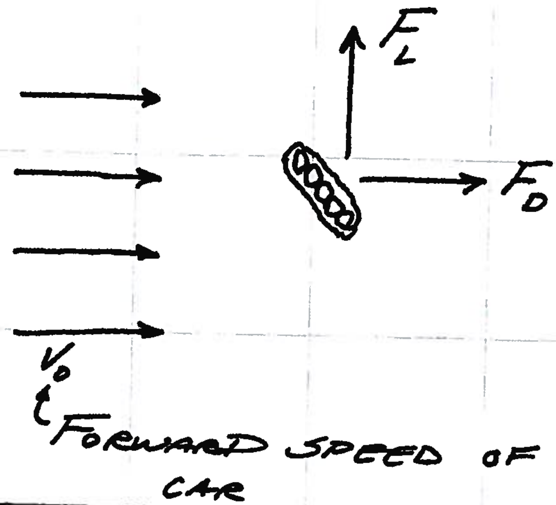
Drag & Lift

pg 407
Ch 11

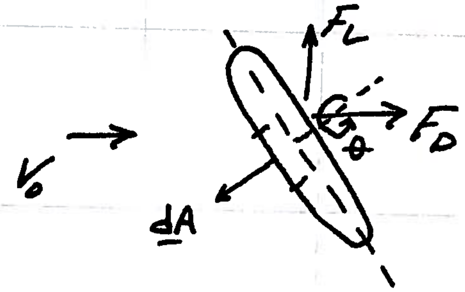
- An object moving in a fluid (or fluid moving past an object) creates two related forces
  - Drag
  - Lift

① Driving in fast car window down





Treat the hand as an airfoil (pg 408)



$$dF_L = \underbrace{-p\,dA\sin\theta}_{\text{Pressure Force}} - \underbrace{\tau\,dA\cos\theta}_{\text{Friction Force}}$$

$$dF_D = \underbrace{-p\,dA\cos\theta}_{\text{Form Drag}} + \underbrace{\tau\,dA\sin\theta}_{\text{Friction Drag}}$$

Integrate to recover forces

$$F_L = \int (-p\sin\theta - \tau\cos\theta)\,dA$$

$$F_D = \int (-p\cos\theta + \tau\sin\theta)\,dA$$

Drag force is related to a dimensionless group

$$\frac{F_D}{A\left(\frac{\rho V_0^2}{2}\right)}$$

$$C_D = \frac{F_D}{A\left(\frac{\rho V_0^2}{2}\right)}$$ is found by experiment.

$C_D \propto Re$ (Figure 11.5)

Figure 11.5 or 11.9 used to estimate C_D for various cases

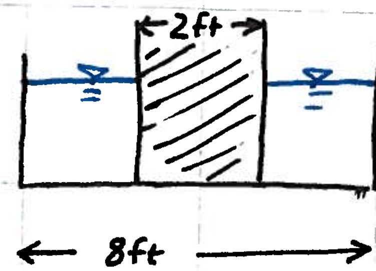
Table 11.1 Also lists some useful C_D values.

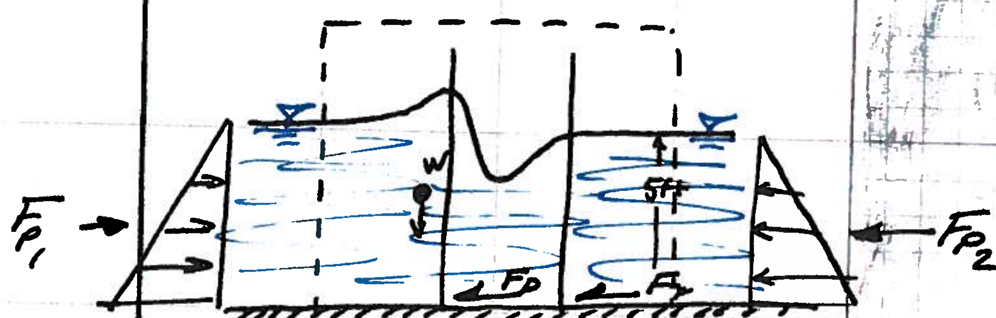
Observe sphere, streamline have $C_D \propto Re$

Flat plate, square rod are not Re dependent

Application

Consider a rectangular bridge pier





At $Q = 240$ cfs; Downstream normal depth is 5 ft.

What is upstream depth?

$C_D = 2.0$ (Table 11.1)

$\therefore$

$F_D = (2.0)(2y_1)(\rho \frac{V_1^2}{2})$

$F_{P_1} = \rho g \frac{W y_1^2}{2}$

$F_{P_2} = \rho g \frac{W y_2^2}{2}$ y_2 is known!

$\Sigma F = \rho g W y_1^2/2 - \rho g \frac{W y_2^2}{2} - \frac{4 y_1 V_1^2 \rho}{2}$

$= \rho V_2 Q - \rho V_1 Q$

Momentum

$$\Sigma F_x = -\rho V_1 Q + \rho V_2 Q$$ (Took some liberties to get here)

$$F_{P_1} - F_{P_2} - F_D - F_\tau = \rho V_2 Q - \rho V_1 Q$$

NEGLECT FRICTIONAL SHEAR; THIS BEHAVIOR; LIKE HYDRAULIC JUMP IS OVER SHORT DISTANCE

$$F_D = C_D A \left(\frac{\rho V_1^2}{2}\right)$$

A IS PROJECTED AREA SO IS PRODUCT OF PIER WIDTH AND APPROACH DEPTH (y_1)

$$A = 2y_1$$

$$V_1 = \frac{Q}{Wy_1} \qquad V_2 = \frac{Q}{Wy_2} \quad y_2 \text{ KNOWN}$$

$$\frac{gWy_1^2}{2} - \frac{gWy_2^2}{2} - \frac{4y_1}{2}\left(\frac{Q}{Wy_1}\right)^2 = \frac{Q^2}{Wy_2} - \frac{Q^2}{Wy_1}$$

ONLY UNKNOWN IS y_1

PUT IN NUMBERS AND SOLVE

	①	②	③	④	⑤	①+②+③-④+⑤
y_1	$\frac{gWy_1^2}{2}$	$-\frac{gWy_2^2}{2}$	$-\frac{4y_1}{2}\left(\frac{Q}{Wy_1}\right)^2$	$\frac{Q^2}{Wy_2}$	$-\frac{Q^2}{Wy_1}$	#
5	3220	-3220	-360	1440	1440	360 ← WANT "0"
6	4636	-3220	-300	1440	1200	-876
5.5	3896	-3220	-327	1440	1309	-218
5.25	3550	-3220	-342	1440	1371	81.4
5.35	3686	-3220	-336	1440	1345	-35
→ 5.32	3645	-3220	-338	1440	1353	-0.38 CLOSE ENOUGH