Midterm 1

1. A rider on a bike with a combined mass of 100 kg attains a terminal speed of 15 m/s on a %12 slope (12 vertical/100 horizontal). Assume that the engine is turned off, Calculate the drag coefficient. The frontal area is 0.9 m^2. Speculate whether the rider is in upright or racing position.

2. A The average pressure and shear stress acting on the surface of the 1-m-square flat plate are as indicated in Fig. 1. Determine the lift and drag generated. Determine the lift and drag if the shear stress is neglected. Compare these two sets of results.

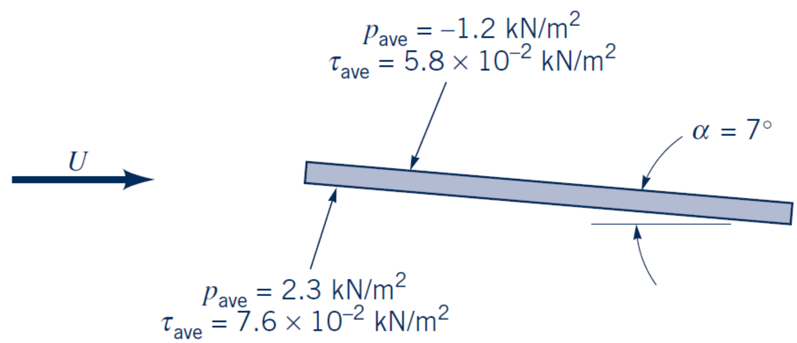


Fig. 1.

3. Velocity profiles are measured at the upstream end (surface 1) and at the downstream end (surface 2) of a rectangular control volume, as shown in Fig. 2. If the flow is incompressible, two dimensional, and steady, what is the drag coefficient? The vertical dimension H = 0.025c. The pressure is p_∞ (a constant) over the entire surface of the control volume. At the upstream end (surface 1), $\vec{V} = U_\infty\, i$. At the downstream end of the control volume (surface 2),

$$0 \le y \le H \qquad \vec{V} = \frac{U_\infty y}{H}\hat{i} + v\hat{j}$$

$$H \le y \le 2H \qquad \vec{V} = U_\infty \hat{i} + v_0\hat{j}$$

$$-H \le y \le 0 \qquad \vec{V} = -\frac{U_\infty y}{H}\hat{i} - v\hat{j}$$

$$-2H \le y \le -H \qquad \vec{V} = U_\infty \hat{i} - v_0\hat{j}$$

where $v(x, y)$ and $v_0(x)$ are y components of the velocity, which are not measured.

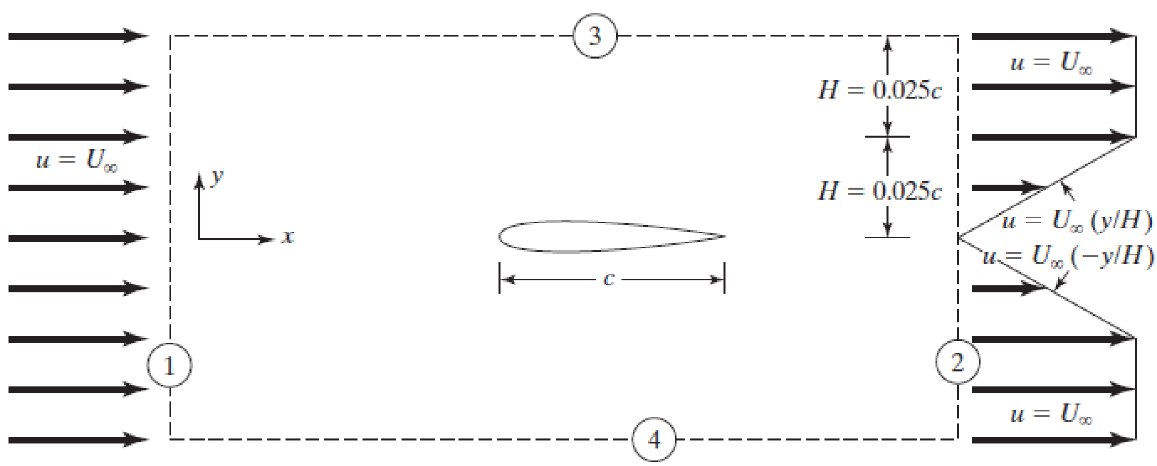
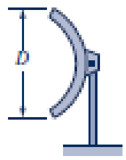
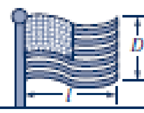
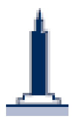
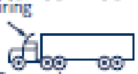
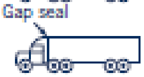
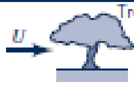


Fig. 2.

Equations and Graphs

Shape	Reference area	Drag coefficient C_D
 Parachute	Frontal area $A = \frac{\pi}{4}D^2$	1.4
 Porous parabolic dish	Frontal area $A = \frac{\pi}{4}D^2$	Porosity: 0 / 0.2 / 0.5 →: 1.42 / 1.20 / 0.82 ←: 0.95 / 0.90 / 0.80 Porosity = open area/total area
 Average person	Standing Sitting Crouching	$C_DA = 9$ ft^2 $C_DA = 6$ ft^2 $C_DA = 2.5$ ft^2
 Fluttering flag	$A = \ell D$	ℓ/D = 1: C_D = 0.07 ℓ/D = 2: C_D = 0.12 ℓ/D = 3: C_D = 0.15
 Empire State Building	Frontal area	1.4
 Six-car passenger train	Frontal area	1.8
Bikes		
 Upright commuter	$A = 5.5$ ft^2	1.1
 Racing	$A = 3.9$ ft^2	0.88
 Drafting	$A = 3.9$ ft^2	0.50
 Streamlined	$A = 5.0$ ft^2	0.12
Tractor-trailer trucks		
 Standard	Frontal area	0.96
Fairing  With fairing	Frontal area	0.76
Gap seal  With fairing and gap seal	Frontal area	0.70
 Tree $U = 10$ m/s $U = 20$ m/s $U = 30$ m/s	Frontal area	0.43 0.26 0.20
 Dolphin	Wetted area	0.0036 at Re $= 6 \times 10^6$ (flat plate has $C_{Df} = 0.0031$)
 Large birds	Frontal area	0.40

Typical Drag Coefficient for objects.

Lift and Drag over a flat plate inclined at an angle θ.

$$\mathscr{D} = \int dF_x = \int p \cos\theta \, dA + \int \tau_w \sin\theta \, dA$$

$$\mathscr{L} = \int dF_y = -\int p \sin\theta \, dA + \int \tau_w \cos\theta \, dA$$

Navier-Stokes Equation

$$\boxed{\rho\frac{Du}{Dt} = \rho g_x - \frac{\partial p}{\partial x} + \frac{\partial}{\partial x}[\mu(2\frac{\partial u}{\partial x} - \frac{2}{3}\vec{\nabla}.\vec{V})] + \frac{\partial}{\partial y}[\mu(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y})] + \frac{\partial}{\partial z}[\mu(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z})] \qquad (a)}$$

x-momentum

$$\boxed{\rho\frac{Dv}{Dt} = \rho g_y - \frac{\partial p}{\partial y} + \frac{\partial}{\partial x}[\mu(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y})] + \frac{\partial}{\partial y}[\mu(2\frac{\partial v}{\partial y} - \frac{2}{3}\vec{\nabla}.\vec{V})] + \frac{\partial}{\partial z}[\mu(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y})] \qquad (b)}$$

y-momentum

$$\boxed{\rho\frac{Dw}{Dt} = \rho g_z - \frac{\partial p}{\partial z} + \frac{\partial}{\partial x}[\mu(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z})] + \frac{\partial}{\partial y}[\mu(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y})] + \frac{\partial}{\partial z}[\mu(2\frac{\partial w}{\partial z} - \frac{2}{3}\vec{\nabla}.\vec{V})] \qquad (c)}$$

z-momentum

$$\vec{F}_{\text{body}} + \vec{F}_{\text{surface}} = \frac{\partial}{\partial t}\iiint_{\text{vol}} \rho\vec{V}\, d(\text{vol}) + \oiint_{A} \vec{V}(\rho\vec{V}\cdot\hat{n}\, dA)$$