12/14/2008 Final exam Review problem
057:020 Fall 2008

1. Head loss

Oil ($S = 0.85$) with a kinematic viscosity of 6×10^{-4} m^2/s flows in a 15-cm pipe at a rate of 0.020 m^3/s. What is the head loss per 100 m of length of pipe?

2. Minor loss

If oil ($\nu = 4 \times 10^{-5}$ m^2/s, $S = 0.9$) flows from the upper to the lower reservoir at a rate of 0.028 m^3/s in the 15-cm smooth pipe, what is the elevation of the oil surface in the upper reservoir?

Make use of Moody chart (Fig. 8-20 in Text. Pp434).

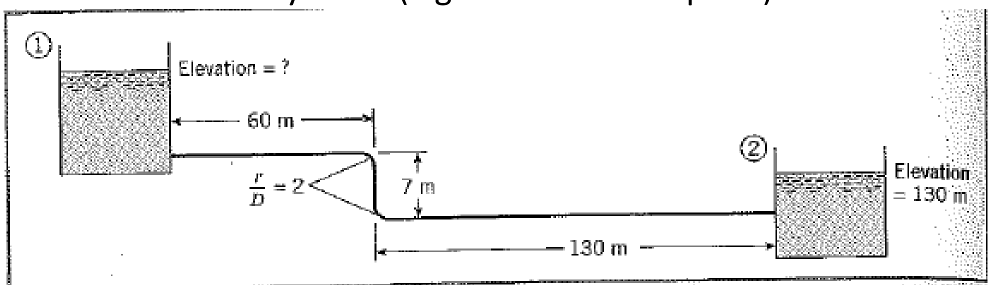
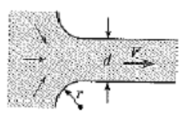
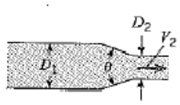
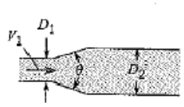
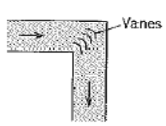
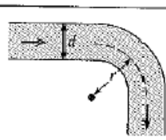


TABLE 10.3 LOSS COEFFICIENTS FOR VARIOUS TRANSITIONS AND FITTINGS

Description	Sketch	Additional Data		K	Source
Pipe entrance		r/d		K_e	(2)*
		0.0		0.50	
		0.1		0.12	
$h_L = K_e V^2/2g$		>0.2		0.03	
Contraction		D_2/D_1	K_C $\theta = 60°$	K_C $\theta = 180°$	(2)
		0.0	0.08	0.50	
		0.20	0.08	0.49	
		0.40	0.07	0.42	
		0.60	0.06	0.27	
		0.80	0.06	0.20	
$h_L = K_C V_2^2/2g$		0.90	0.06	0.10	
Expansion		D_1/D_2	K_E $\theta = 20°$	K_E $\theta = 180°$	(2)
		0.0		1.00	
		0.20	0.30	0.87	
		0.40	0.25	0.70	
		0.60	0.15	0.41	
$h_L = K_E V_1^2/2g$		0.80	0.10	0.15	
90° miter bend		Without vanes		$K_b = 1.1$	(39)
		With vanes		$K_b = 0.2$	(39)
90° smooth bend		r/d			(5) and (15)
		1	$K_b = 0.35$		
		2	0.19		
		4	0.16		
		6	0.21		
		8	0.28		
		10	0.32		

12/14/2008 Final exam Review problem
057:020 Fall 2008

3. Lift and drag coefficient

A commercial airplane has a total mass of 70,000 kg and a wing planform area of 150 m^2 (Fig. 11–54). The plane has a cruising speed of 558 km/h and a cruising altitude of 12,000 m, where the air density is 0.312 kg/m^3. The plane has double-slotted flaps for use during takeoff and landing, but it cruises with all flaps retracted. Assuming the lift and the drag characteristics of the wings can be approximated by NACA 23012 (Fig. 11–45), determine (*a*) the minimum safe speed for takeoff and landing with and without extending the flaps, (*b*) the angle of attack to cruise steadily at the cruising altitude, and (*c*) the power that needs to be supplied to provide enough thrust to overcome wing drag.

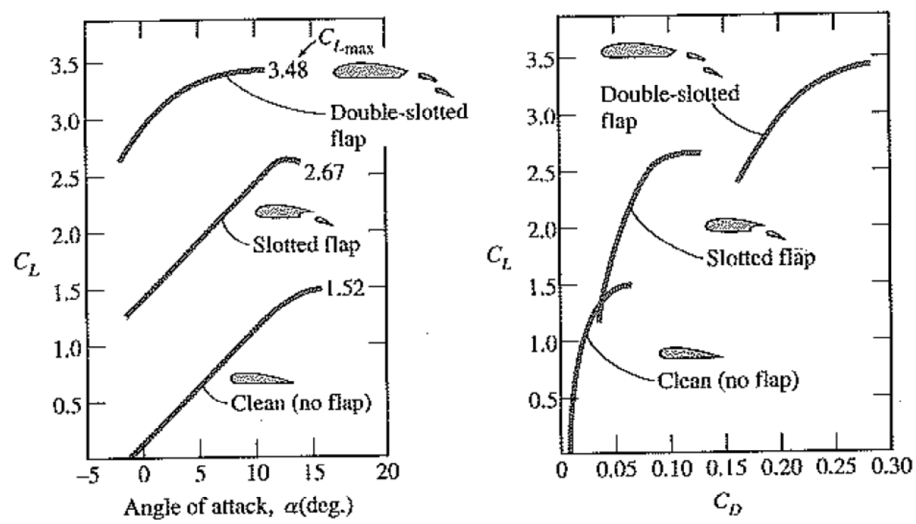
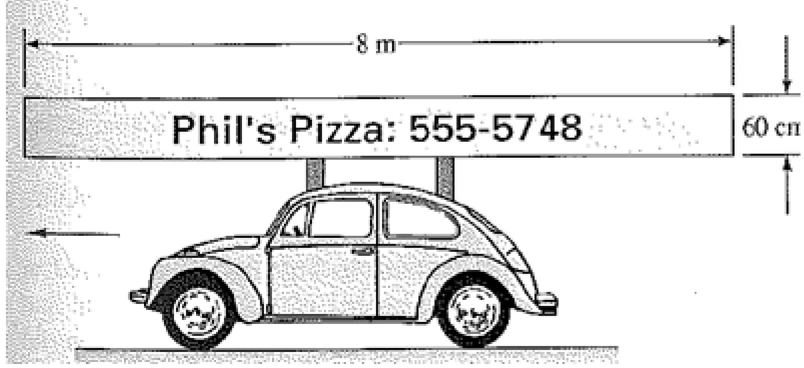


FIGURE 11–45
Effect of flaps on the lift and drag coefficients of an airfoil.
From Abbott and von Doenhoff, for NACA 23012 (1959).

4. Boundary layer

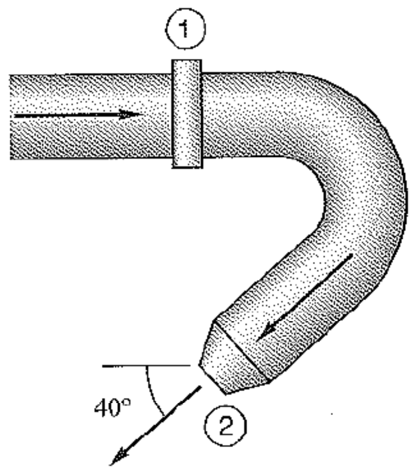
A delivery vehicle carries a long sign on top, as in Fig. P7.56. If the sign is very thin and the vehicle moves at 65 mi/h, (*a*) estimate the force on the sign with no crosswind



12/14/2008 Final exam Review problem
057:020 Fall 2008

5. RTT: Momentum conservation

Water at 20°C flows through the elbow in Fig. P3.60 and exits to the atmosphere. The pipe diameter is $D_1 = 10$ cm, while $D_2 = 3$ cm. At a weight flow rate of 150 N/s, the pressure $p_1 = 2.3$ atm (gage). Neglecting the weight of water and elbow, estimate the force on the flange bolts at section 1.



P3.60

12/14/2008 Final exam Review problem
057:020 Fall 2008

Answer

1. Head loss

Solution First we determine whether the flow is laminar or turbulent by checking to see if the Reynolds number is below 2000 or above 3000.

$$V = \frac{Q}{A} = \frac{0.020 \text{ m}^3/\text{s}}{(\pi/4)D^2 \text{m}^2} = \frac{0.020 \text{ m}^3/\text{s}}{0.785(0.15^2 \text{ m}^2)} = 1.13 \text{ m/s}$$

Then
$$\text{Re} = \frac{VD}{\nu} = \frac{(1.13 \text{ m/s})(0.15 \text{ m})}{6 \times 10^{-4} \text{ m}^2/\text{s}} = 283$$

Since the Reynolds number is less than 2000, the flow is laminar. The head loss per 100 m is obtained from

$$h_f = \frac{32\mu LV}{\gamma D^2}$$

Here $\mu/\gamma = \nu/g$; hence

$$h_f = \frac{32\nu LV}{gD^2}$$

Then
$$h_f = \frac{32(6)(10^{-4} \text{ m}^2/\text{s})(100 \text{ m})(1.13 \text{ m/s})}{(9.81 \text{ m/s}^2)(0.15^2 \text{ m}^2)} = 9.83 \text{ m}$$

The head loss is 9.83 m/100 m of length. ◁

12/14/2008 Final exam Review problem
057:020 Fall 2008

2. Minor loss

Solution Apply the energy equation between the surfaces of the upper and lower reservoirs:

$$\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + \sum h_L$$

$$0 + 0 + z_1 = 0 + 0 + 130 \text{ m} + \frac{fL}{D}\frac{V^2}{2g} + 2K_b\frac{V^2}{2g} + K_e\frac{V^2}{2g} + K_E\frac{V^2}{2g}$$

Here K_b, K_e, and K_E are loss coefficients for bend, entrance, and outlet, respectively. These have values of 0.19, 0.5, and 1.0 (Table 10.3). To determine f, we get Re in order to enter Fig. 10.8:

$$\text{Re} = \frac{VD}{\nu}$$

But

$$V = \frac{Q}{A} = \frac{(0.028 \text{ m}^3/\text{s})}{0.785(0.15 \text{ m})^2} = 1.58 \text{ m/s}$$

Then

$$\text{Re} = \frac{1.58 \text{ m/s}(0.15 \text{ m})}{4 \times 10^{-5} \text{ m}^2/\text{s}} = 5.93 \times 10^3$$

Now we read f from Fig. 10.8 (smooth pipe curve): $f = 0.035$. Then

$$z_1 = 130 \text{ m} + \frac{V^2}{2g}\left[\frac{0.035(197 \text{ m})}{0.15 \text{ m}} + 2(0.19) + 0.5 + 1\right]$$

$$= 130 \text{ m} + \left[\frac{(1.58 \text{ m/s})^2}{2(9.81 \text{ m/s}^2)}\right](46 + 0.38 + 0.5 + 1)$$

$$= 130 \text{ m} + 6.1 \text{ m} = 136.1 \text{ m}$$ ◁

12/14/2008 Final exam Review problem
057:020 Fall 2008

3. Lift and drag coefficients

SOLUTION The cruising conditions of a passenger plane and its wing characteristics are given. The minimum safe landing and takeoff speeds, the angle of attack during cruising, and the power required are to be determined.

Assumptions **1** The drag and lift produced by parts of the plane other than the wings, such as the fuselage drag, are not considered. **2** The wings are assumed to be two-dimensional airfoil sections, and the tip effects of the wings are not considered. **3** The lift and the drag characteristics of the wings can be approximated by NACA 23012 so that Fig. 11–45 is applicable. **4** The average density of air on the ground is 1.20 kg/m³.

Properties The densities of air are 1.20 kg/m³ on the ground and 0.312 kg/m³ at cruising altitude. The maximum lift coefficients $C_{L,\,max}$ of the wings are 3.48 and 1.52 with and without flaps, respectively (Fig. 11–45).

Analysis (*a*) The weight and cruising speed of the airplane are

$$W = mg = (70{,}000\ \text{kg})(9.81\ \text{m/s}^2)\left(\frac{1\ \text{N}}{1\ \text{kg}\cdot\text{m/s}^2}\right) = 686{,}700\ \text{N}$$

$$V = (558\ \text{km/h})\left(\frac{1\ \text{m/s}}{3.6\ \text{km/h}}\right) = 155\ \text{m/s}$$

The minimum velocities corresponding to the stall conditions without and with flaps, respectively, are obtained from

$$V_{min\,1} = \sqrt{\frac{2W}{\rho C_{L,\,max\,1}A}} = \sqrt{\frac{2(686{,}700\ \text{N})}{(1.2\ \text{kg/m}^3)(1.52)(150\ \text{m}^2)}\left(\frac{1\ \text{kg}\cdot\text{m/s}^2}{1\ \text{N}}\right)} = 70.9\ \text{m/s}$$

$$V_{min\,2} = \sqrt{\frac{2W}{\rho C_{L,\,max\,2}A}} = \sqrt{\frac{2(686{,}700\ \text{N})}{(1.2\ \text{kg/m}^3)(3.48)(150\ \text{m}^2)}\left(\frac{1\ \text{kg}\cdot\text{m/s}^2}{1\ \text{N}}\right)} = 46.8\ \text{m/s}$$

Then the "safe" minimum velocities to avoid the stall region are obtained by multiplying the values above by 1.2:

Without flaps: $V_{min\,1,\,safe} = 1.2V_{min\,1} = 1.2(70.9\ \text{m/s}) = 85.1\ \text{m/s} = 306\ \text{km/h}$

With flaps: $V_{min\,2,\,safe} = 1.2V_{min\,2} = 1.2(46.8\ \text{m/s}) = 56.2\ \text{m/s} = 202\ \text{km/h}$

12/14/2008 Final exam Review problem
057:020 Fall 2008

4. Boundary layer

Solution: For air at 20°C, take $\rho = 1.2$ kg/m³ and $\mu = 1.8E{-}5$ kg/m·s. Convert 65 mi/h = 29.06 m/s. (a) If there is no crosswind, we may estimate the drag force by flat-plate theory:

$$Re_L = \frac{1.2(29.06)(8)}{1.8E{-}5} = 1.55E7 \ (turbulent), \quad C_D = \frac{0.031}{Re_L^{1/7}} = \frac{0.031}{(1.55E7)^{1/7}} \approx 0.00291$$

$$F_{drag} = C_D\left(\frac{\rho}{2}\right)V^2 bL(2\ sides) = 0.00291\left(\frac{1.2}{2}\right)(29.06)^2(0.6)(8)(2\ sides) = 14\ \text{N} \quad \textit{Ans.}\ (a)$$

5. RTT: Momentum conservation

Solution: First, from the weight flow, compute Q = (150 N/s)/(9790 N/m³) = 0.0153 m³/s. Then the velocities at (1) and (2) follow from the known areas:

$$V_1 = \frac{Q}{A_1} = \frac{0.0153}{(\pi/4)(0.1)^2} = 1.95\ \frac{m}{s}; \qquad V_2 = \frac{Q}{A_2} = \frac{0.0153}{(\pi/4)(0.03)^2} = 21.7\ \frac{m}{s}$$

The mass flow is $\rho A_1 V_1 = (998)(\pi/4)(0.1)^2(1.95) \approx 15.25$ kg/s. Then the balance of forces in the x-direction is:

$$\sum F_x = -F_{bolts} + p_1 A_1 = \dot{m}u_2 - \dot{m}u_1 = \dot{m}(-V_2\cos 40° - V_1)$$

$$\text{solve for} \quad F_{bolts} = (2.3\times 101350)\frac{\pi}{4}(0.1)^2 + 15.25(21.7\cos 40° + 1.95) \approx \mathbf{2100\ N} \quad \textit{Ans.}$$