Ö. Savaş NAME: **SOLUTIONS** SID:

8:00-11:00, Thursday, December 18, 2003

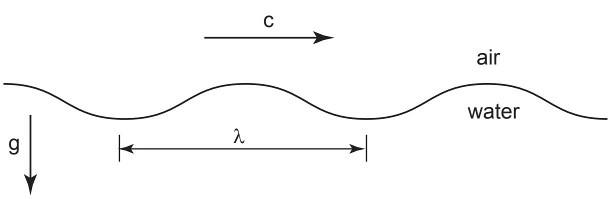
ME 106.2
FLUID MECHANICS
FINAL EXAM – open book

YOU MUST SHOW ALL WORK, AND PRESENT ALL ANSWERS IN DIMENSIONALLY CORRECT FROM. FAILURE TO COMPLY WILL REDUCE YOUR GRADE BY HALF.

1.(10%) The *mean free path* λ of a gas is defined as the average distance that a molecule travels between successive collisions. It is postulated that λ depends on the mass m and the diameter d of the gas molecules and the density ρ of the gas. Determine the dependence of λ on these gas parameters using dimensional analysis. Estimate λ for air at standard conditions for which $d = 3.8 \times 10^{-10}$m and $m = 4.8 \times 10^{-23}$g.

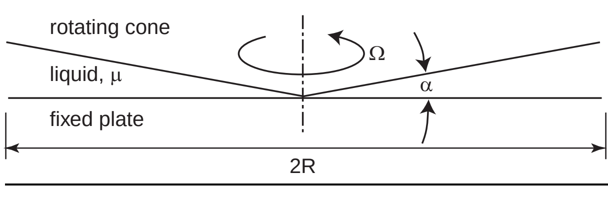
$$\lambda = \frac{m}{\sqrt{2}\,\pi d^2 \rho} = \frac{4.8 \cdot 10^{-26}}{\sqrt{2}\,\pi \times (3.8 \cdot 10^{-10})^2 \times 1.2} = 6.2 \cdot 10^{-8} m$$

2.(10%) The speed c of a large (gravity) wave on the deep ocean surface seems to depend on its wavelength λ. Since these waves are driven by the gravity g, estimate the speed of a 1000m long surface gravity wave.



$$c = \sqrt{\lambda g / 2\pi} = \sqrt{1000 \times 9.81/2\pi} = 40 m/s$$

3.(20%) A cone viscometer which is used to measure the viscosity μ of liquids consists of a flat plate and a *shallow* cone, where the gap angle $\alpha \ll 1$. The plate is fixed and the cone rotates at a constant angular velocity of Ω. The flow in the cavity can be locally approximated as that between two parallel plates. Show that the shear stress on the surfaces is uniform. Determine the torque required to maintain the constant rotation rate. (10+10)



$$\tau \approx \mu U/h = \mu \Omega r / \alpha r = \mu \Omega / \alpha \qquad T = \int_o^R r \times dF = \int_o^R r \times \tau \times dA = \int_o^R r \times \tau \times 2\pi r dr = \frac{2\pi}{3} \frac{\mu \Omega R^3}{\alpha}$$

4.(20%) Consider the flow of water through a vinyl garden hose. The hose is 15 m long, 2.0 cm in diameter, with roughness hight of about 0.2 mm. Assume that a pressure drop of 1 atmosphere is maintained between the ends of the hose. What is the theoretically maximum possible flow rate through it? What is the practically maximum flow rate through it? (10+10)

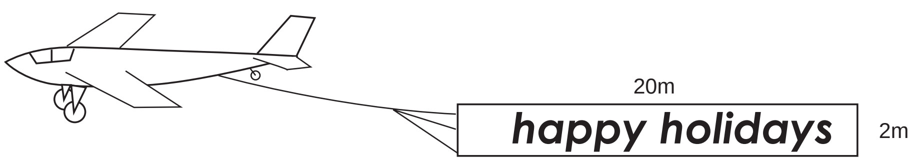
$$Laminar\ flow:\ Q = \frac{\pi d^4 \Delta p}{128 \mu L} = \frac{\pi \times 0.02^4 \times 1.01325 \cdot 10^5}{128 \times 1.0 \cdot 10^{-3} \times 15} = 0.0265 m^3/s$$

$$Turbulent\ flow:\ \epsilon/d = 0.2/20 = 0.01 \rightarrow f = 0.038 \rightarrow U = \sqrt{2d\Delta p/\rho f L},\ Q = \pi D^2 U/4$$

$$U = \sqrt{2 \times 0.02 \times 1.01325 \cdot 10^5 / 1000 \times 0.038 \times 15} = 2.66 m/s,\ Q = \pi \times 0.02^2 \times 2.66/4 = 0.00084 m^3/s$$

$$Re = dU/\nu = 2 \times 266/0.01 = 53,000 \rightarrow f = 0.038 \ \text{ confirmed}$$

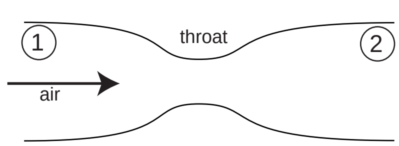
5.(20%) Consider advertisement banners carried by low speed aircraft at large public gatherings. The speed of the aircraft is about 70 km/h. The ad it tows is a thin fabric and measures 2m × 20m. Estimate the drag force and the engine power needed to tow the sign. Justify your assumptions. (10+5+5)



Turbulent boundary layers on both sides of the sign:
$Re = UL/\nu = 1944 \times 2000/0.15 = 2.59 \cdot 10^7$

	C_d	$D = 2 \times C_d \rho U^2 A/2$ (N)	$P = UD$ (kW)	$P = UD$ (hp)
laminar flow	$1.328 Re^{-0.5}$=0.00026	2.4	0.046	0.06
smooth rigid plate	0.003	54	1.06	1.4
rough rigid plate	0.01	180	3.5	4.7
fluttering fabric	0.2	3600	70	95

6.(20%) Consider the frictionless compressible flow of air in the convergent-divergent flow duct shown in the figure. The inlet and the exit areas are the same, A. The conditions at the inlet are $p_1 = 1$ atm, $T_1 = 277$K, and $u_1 = 100$ m/s. The minimum throat area is $0.5A$. (a) Describe the possible isentropic flow scenarios. Determine the flow speed, Mach number, and pressure at the throat and at the exit plane for (b) subsonic discharge and (c) supersonic discharge. (6+7+7)



You may use either formulas 11-56-11.60,11.71 or Figure D.1.

(a) subsonic discharge or supersonic discharge

(b) same as inlet: sonic at throat, $u_2 = 100$ m/s, $M_2 = 0.3$, and $p_2 = 1$ atm

(c) Using Figure D.1: sonic at throat, $u_2 = 520$ m/s, $M_2 = 2.2$, and $p_2 = 0.1$ atm

---