Homework #5

Due: Friday 10/4/2013
(4 problems worth 20 points)

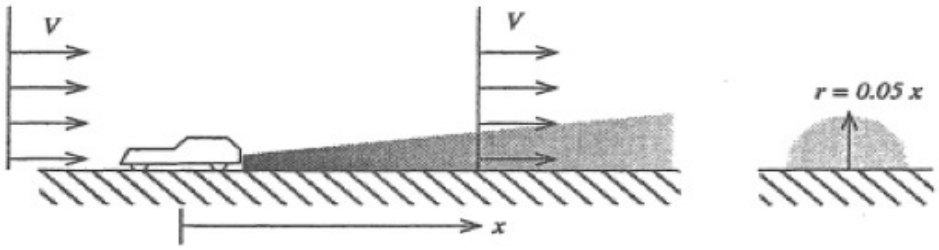
1. [5 points] *An automobile moves along a highway at a speed V=60 mph while emitting carbon monoxide (CO) in its exhaust at a rate of 10 g per kilometer of travel. In a reference frame attached to the automobile, a wake region extends behind the car as shown in the figure below. Within this region the fluid speed equals the vehicle speed V and the emitted CO is uniformly mixed within the semicircular cross-section of the wake, whose radius r equals 0.05 x, where x is the distance behind the vehicle.

a) Calculate the mass rate of emission of CO (in g/h)

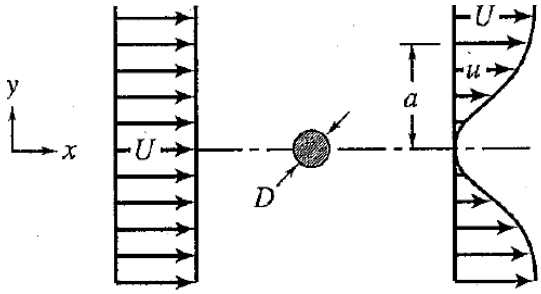
b) Mass density of CO (in g/m3) in the vehicle wake at a distance x=100 m behind the vehicle.

c) The vehicle is preceded by a long line of vehicles spaced 100 m apart, moving at the same speed and emitting CO at the same rate. At any location, each of these vehicles makes an additive contribution to the total value of CO density, depending upon its distance away. Calculate the mass density of CO at x=100 m behind the car shown in the sketch, due to the cumulative effect of all the preceding vehicles.

(Note: The sum $\sum_{n=1}^{\infty} \frac{1}{n^2} = \frac{\pi^2}{6} = 1.645$)



2. [5 points] Experimental measurements are made in a low-speed air jet to determine the drag force on a circular cylinder. Velocity measure-ments at two sections, where the pressure is uniform and equal, give the results shown below. Evaluate the drag force on the cylinder, per unit width.

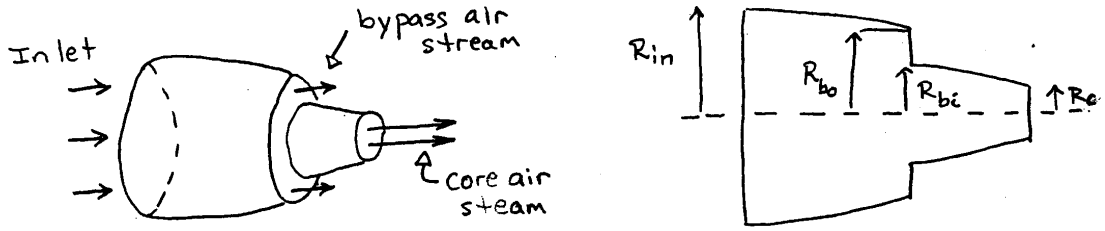


$U = 50$ m/s
$\rho = 1.2$ kg/m^3
$D = 30$ mm
$a = 2.2D$
$u = U \sin\left(\frac{\pi y}{2a}\right)$; $0 \le y \le a$
$U = U$; $y > a$

3.[5 points] In a turbofan engine some of the inlet air goes through a set of compressor blades and then exits the engine, thus "bypassing" the core of the engine (the combustion chamber and the turbine). The ratio of the mass flow rate of air going around the core to that going through the core is called bypass ratio. You are working on the design of a new engine. The inlet of the engine is circular with a radius of 2.1m. The exit of the

* This problem is from "Introduction to Fluid Mechanics" by James A. Fay, MIT Press, 1994.

bypass air is an annulus with an inner radius of 1.25m and an outer radius of 1.7m. The velocity and density at the inlet and exit may be assumed to be uniform over each surface. The velocity of the bypass air at the exit is 290 m/s and the density is 0.85 times the density of the inner air. The exit velocity of the air from the engine core is 420m/s and the density is 0.55 times that of the inlet air. The exit of the core flow is circular.
a) Find the radius of the core flow nozzle exit in order to have a bypass ratio of 8.
b) If the engine is operating in steady state conditions, what is velocity of the inlet flow?
c) What is the trust generated by the engine (i.e. what force is generated by the engine on an airplane or test stand)?
Neglect the aerodynamic forces (due to pressure and viscous stress) acting on the outside of the engine. Also neglect the weight of the engine, so that we are only interested in the horizontal component of the force. Assume the engine is operating at sea level in a standard atmosphere.



4. [5 points] The video below shows droplet formation in a microfluidic junction. Assume that the flow is steady. Using only the information in the snapshot below, apply the mass conservation to estimate the ratio of droplet speed to the average velocity of the fluid in the inlet channel. http://media.efluids.com/galleries/all?medium=461

Quote of the week:
"The strength of the United States is not the gold at Fort Knox or the weapons of mass destruction that we have, but the sum total of the education and the character of our people." - Clairborne Pell, 1918 – 2009, former US Senator from Rhode Island best known as the sponsor of the Pell Grant.