CE 100 - Final Exam

December 12, 2006

Name ____

Student I.D. _____________________________________

This exam is closed book. You are allowed three sheets of paper (8.5" x 11", both sides) of your own notes.

You will be given three hours to complete four problems. Write out your solution with symbols before plugging in any numbers and clearly state any assumptions you make, and please box your answer! Read through the whole exam first and skip ahead to the easy parts when you get stuck.

Good Luck!

On all problems, you may assume that the fluid is water, unless otherwise noted. For your reference:

Density of water = ρ_w = 1000 kg/m^3
Dynamic viscosity of water = μ = 1.12 x 10^{-3} N·s/m^2
Density of air = ρ = 1.2 kg/m^3
Kinematic viscosity of air = ν = 1.5 x 10^{-5} m^2/s
Atmospheric Pressure = p_{atm} = 100 kPa
Gravitational Acceleration = g = 9.81 m/s^2
1 Gallon = 3.79 Liters = 0.00379 m^3

The Moody chart can be found on the last page of the exam.

1) Water supply design (20 points)

Suppose you build a house out in the "boonies" where you need to run a pipe to the nearest water supply, which is fortunately at an elevation of about 1000 m above that of your house. The pipe will be 6 km long and the gage pressure just inside the pipe entrance is 1000 kPa. You require a minimum of 3.0 gal/min (0.189 m^3/s) of water when the end of your pipe is open to the atmosphere. To minimize cost, you want to buy the smallest diameter pipe possible. The pipe you will use is smooth.

a) Find the total head loss from the pipe inlet to its exit. (8 points)

b) Find the minimum required pipe diameter. Neglect any minor losses due to valves, elbows, entrance lengths, etc., since the length is so long and major losses dominate. (12 points)

2) Pizza store delivery vehicle drag (25 points)

A new pizza store is planning to open and needs a small delivery car with a large sign attached. The sign (a flat plate) is 0.5 m high and 1.5 m long. The boss mounts the sign bluntly facing the wind (see diagram A). One of the drivers is taking fluid mechanics and tells her boss she can save lots of money by mounting the sign parallel to the wind (see diagram B).

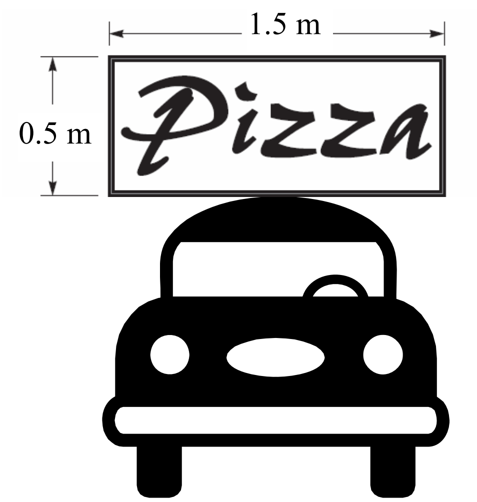


Diagram A

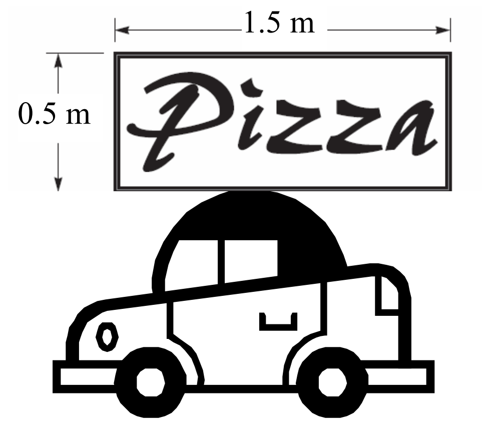
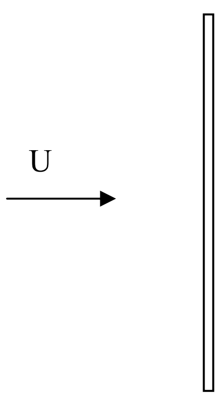


Diagram B

a) Calculate the drag on the *sign alone* at 70 km/h (19.4 m/s) in both orientations. See figure below for C_D values. (8 points)

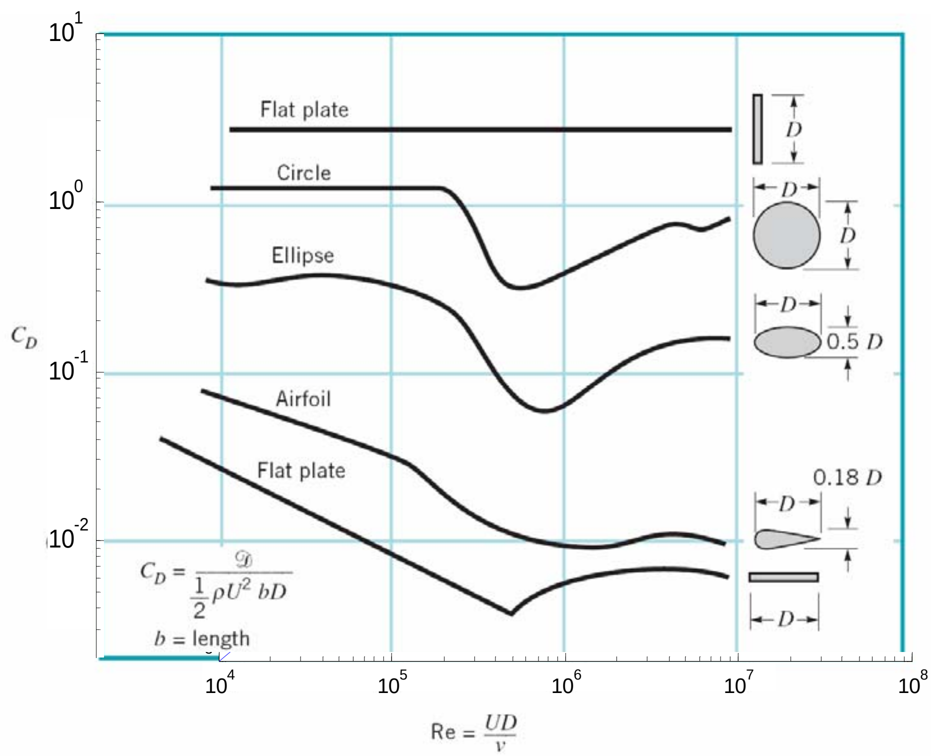
b) Which of the two types of drag dominates for each case? (3 points)

c) Make a rough sketch of the flow pattern for each orientation using the diagram below. (3 points)



d) Suppose the car without any sign has a drag coefficient of 0.4 and a frontal area of 3.7 m^2. For V = 70 km/h calculate the *total drag* of the car-sign combination for both orientations. (5 points)

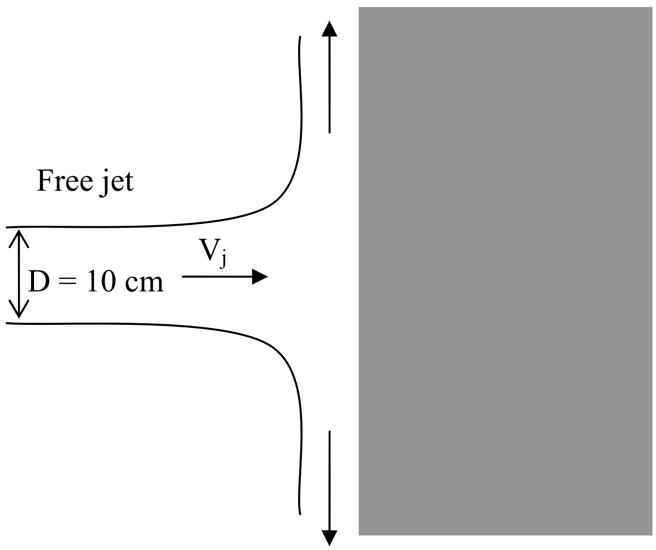
e) Assuming perfect engine efficiency, calculate the power required by the engine to drive the car at 70 km/h in both orientations. (Hint: power = force * velocity) If engine power use is proportional to fuel efficiency, find the cost of using orientation B as a fraction of the cost of using orientation A. (6 points)



NOTE the LOG AXES! Character of the drag coefficient as a function of Reynolds number for objects with various degrees of streamlining, from a flat plate normal to the upstream flow to a flat plate parallel to the flow (two-dimensional flow).

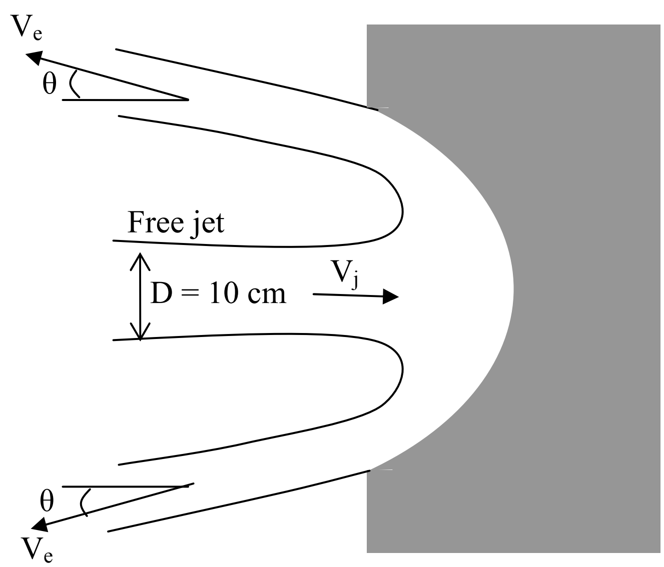
3) Water jets (25 points)

A water jet (average velocity V_j = 8 m/s, D_{jet} = 10 cm) impinges on a flat plate at 90 degrees, as shown below.



a) Compute the force F required to hold the plate in place (neglect gravity). (7 points)

Problem 4 continued. Now suppose the same water jet (V_j = 8 m/s) impinges on a cup cavity as shown below. The water is turned between 90 and 180 degrees from its original flow direction, depending on the cup shape. The water exits at a lower velocity, V_e = 7 m/s, due to friction. (Looking from the left, the exit jet is a circular annulus flowing toward the viewer.)



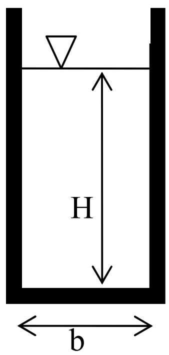
b) Find the force F required to hold the cupped object in place as a function of the return angle θ. Give numeric values for θ = 45° and θ = 0°. (15 points)

c) Compare the results from part (b) to the force from part (a) and give a physical explanation as to why the force has changed. (3 points)

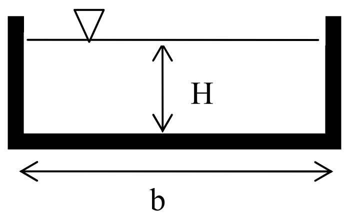
4) Storm channel design (30 points)

You are asked to design an open channel for storm water diversion under uniform flow conditions. The channel is to be of rectangular cross section, it will be laid on a slope of 0.0001, and will be lined with unfinished concrete, so Manning's coefficient is equal to 0.014.

a) Calculate the flow rate for the two channel cross sections shown below to get a feel for the flow behavior in the above situation. For Channel 1, b = 1m and H = 3m; for Channel 2, b = 3m and H = 1m, so they have reversed aspect ratios but the same area. (5 points)



Channel 1



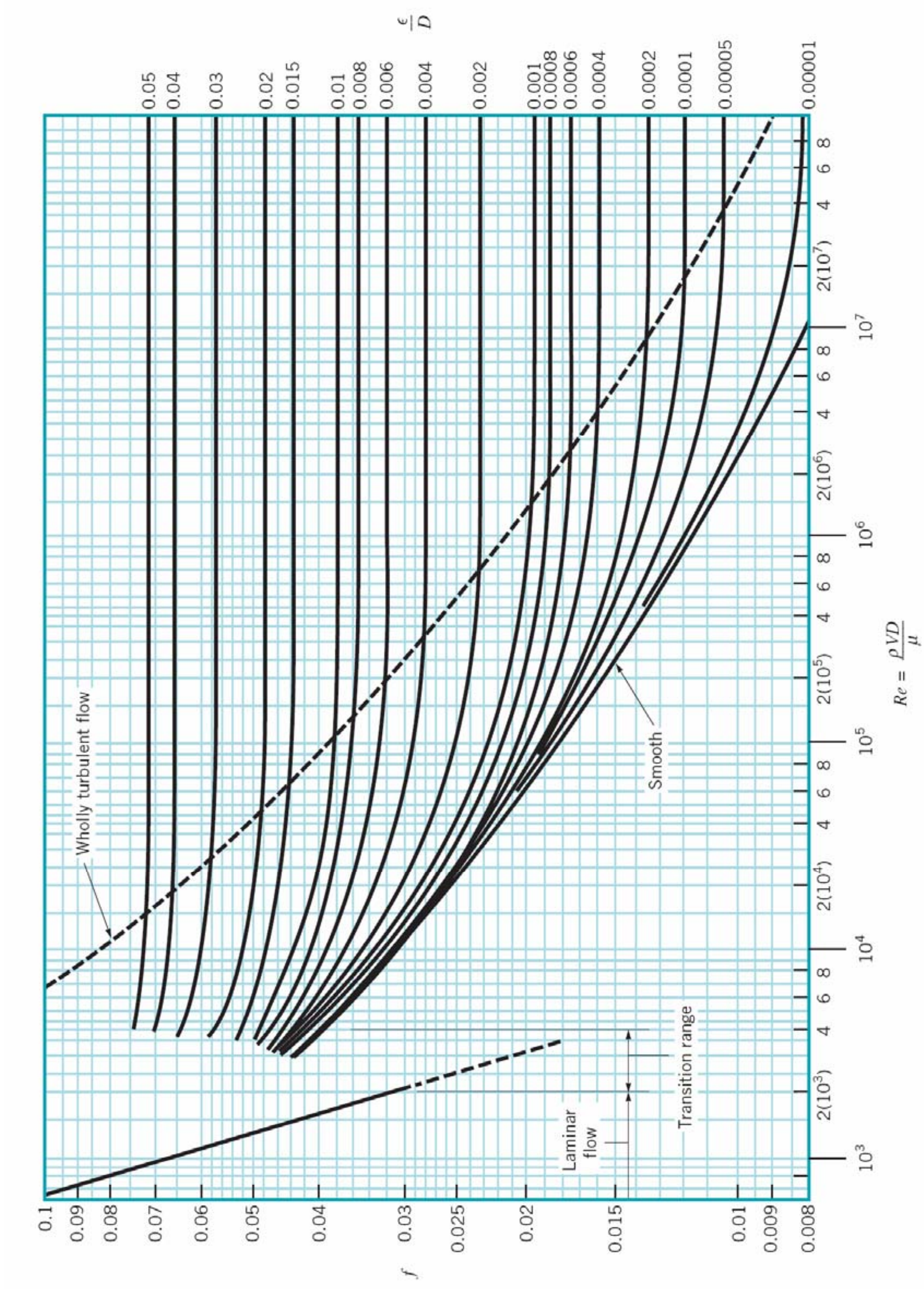
Channel 2

b) Briefly explain why the flow rate is larger for Channel 2 than for Channel 1 (think about the balance of forces involved here). (3 points)

c) For a given cross-sectional area, you want to design your channel such that the flow rate is maximized. For a rectangular channel of *fixed cross-sectional area*, find the optimum depth to width ratio of the channel, so that it can deliver the maximum flow possible. [Hint: think about your answer to (b), and think about how changing b or H will change the flow rate, given that A = bH.] (10 points)

d) For a depth of H = 1 m, verify that the maximum flow rate per unit width that can be delivered by the channel based on your answer to (c) is q = 0.45 m^2/s. (2 points)

e) In the newly laid channel, we place a smooth upward step to control the flow. Using $q = 0.45\ m^2/s$ and $H = 1m$ as the flow depth from part (d), find the maximum allowable step height that will not cause the flow to back up for the given flow rate. Neglect bed slope and friction in the vicinity of the step. (10 points)



Wholly turbulent flow
Smooth
Laminar flow
Transition range
$\frac{\epsilon}{D}$
0.05
0.04
0.03
0.02
0.015
0.01
0.008
0.006
0.004
0.002
0.001
0.0008
0.0006
0.0004
0.0002
0.0001
0.00005
0.00001
f
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.025
0.02
0.015
0.01
0.009
0.008
10^3
$2(10^3)$
10^4
$2(10^4)$
10^5
$2(10^5)$
10^6
$2(10^6)$
10^7
$2(10^7)$
$Re = \frac{\rho VD}{\mu}$