Student name: _____

This is a closed book examination. You are allowed 1 sheet of 8.5" x 11" paper with notes.

For the problems in Section A, fill in the answers where indicated by _____, or in the provided space. When a list of options is presented ([…],[…],[….] etc), circle all the options (all, none, one or more) that apply.

Use the following constants unless otherwise specified:

Gravity: $g = 10$ m/s^2 water density: $\rho_w = 1000$ kg/m^3 kinematic viscosity: $\nu_w = 1\times10^{-6}$ m^2/s
Seawater density: $\rho_w = 1025$ kg/m^3 kinematic viscosity: $\nu_{sw} = 1\times10^{-6}$ m^2/s
Air density: $\rho_a = 1$ kg/m^3 kinematic viscosity: $\nu_a = 1\times10^{-5}$ m^2/s

Assume the fluid is incompressible unless otherwise defined.
Give all answers in SI units (kg, m, s). All numerical answers MUST have the proper units attached.

Part A (25%): (each question carries equal weight: 5 points)

1) A sphere of volume V in a fluid of density ρ is located at a point $(0, L, 0)$ with respect to a certain coordinate system. *In terms of this coordinate system*, identify whether each of the 6x6 added mass coefficients are zero (0), or non-zero (x) (do not work out any values).
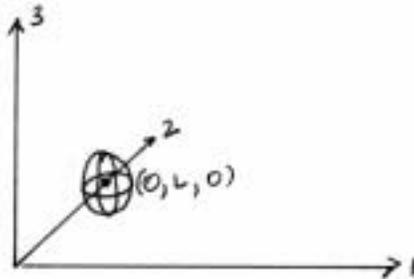

2) For a circular cylinder of mass $m = 5$ kg with diameter $d = 0.15$m in a uniform current with velocity $U = 2.0$ m/s, the frequency of vortex shedding is $\omega_s =$ _____. If the cylinder is mounted such that the system has a restoring coefficient, k, and damping coefficient, b, the vortex shedding frequency for lock-in to occur would have to equal $\omega_s =$ _____.

3) An engineer was asked to evaluate the added mass matrix of a structure composed by two cylinders, a thin rod of negligible volume and a sphere, as seen in Figure 5. To help the engineer, note in the added mass matrix of the structure the non-zero terms with "x" and the zero terms with "0" and with "n/a" if you can't tell. Use a (+) or (-) in front of the x's to indicate whether the non-zero added mass force or moment would be positive or negative by right hand rule convention given the coordinate system.
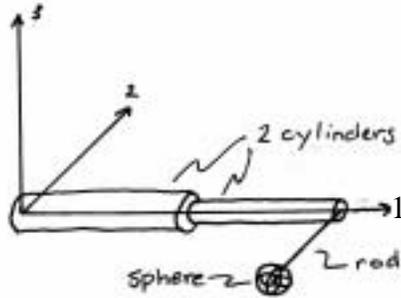
4) Sketch the vortex shedding pattern behind a cylinder at Reynolds number 20 and 200.
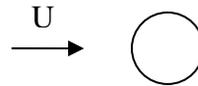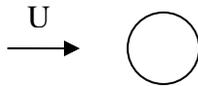
5) An upside down umbrella washed overboard from a ship that had been attacked by the Black Pearl, a vicious pirate ship, is heaving up and down in the eerily calm water. (partial credit possible here, model umbrella as a hemisphere)

a) Sketch the wave pattern that is generated by this motion (radiated waves).

<u>SIDE VIEW</u>   <u>TOP VIEW</u>

b) Sketch the wave pattern that is generated by this motion (radiated waves) if the umbrella is moving forward at a constant speed U. Consider both cases when the forward speed is greater or less than the radiated wave group/phase speed. (use back of page if necessary)

FOR PART B PROBLEMS: BE SURE TO SKETCH THE PROBLEM, STATE YOUR ASSUMPTIONS AND SHOW YOUR WORK! USE THE PROVIDED EXAM BOOKLET. DON'T FORGET TO CHECK UNITS!
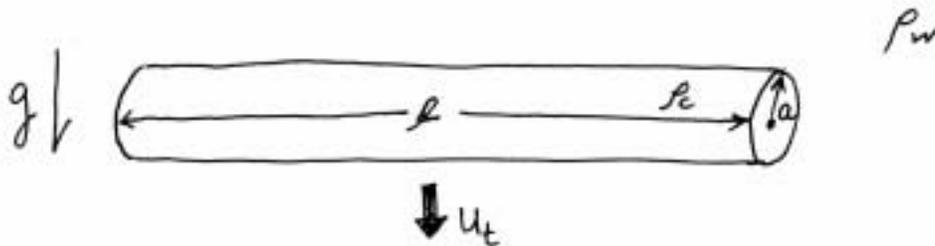
PROBLEM B.1: (15%)

A slender cylinder of density $\rho_c = 1.5\rho_w$ is released from a submarine in water of density ρ, as shown in the figure below. The cylinder has length l and radius a.

a) Some time after the cylinder is dropped, as the descending velocity increases, viscous effects become significant. Eventually the cylinder ceases to accelerate and reaches a "terminal velocity". Given $l = 1m$, $a = 0.1m$, $\rho_w = 10^3 \, kg/m^3$, evaluate the terminal velocity of the cylinder.

The average drag coefficient for a cylinder can be approximated by: $C_D = 1.2$ for $Re < 3x10^5$, $C_D = 0.6$ for $Re > 3x10^5$.

b) Determine the frequency of vortex shedding around the cylinder at this velocity in terms of the dimensions given above.
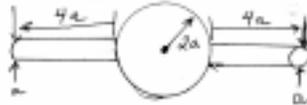
PROBLEM B.2: (40%)

Housing for certain underwater sensor equipment has a geometry shown below. The sphere has radius $2a$, and the cylinders have radius $r_c = a/2$ and length $l_c=4a$. The density of the device can be assumed to be uniform and have a value of twice that of water.


        Vertical   Horizontal

(a) To get it to the sea floor, the device is lowered into the water and then is released, find its *initial* acceleration for (i) a vertical orientation; and (ii) a horizontal orientation.

(b) Assuming deep water, calculate the terminal drop velocity for the device falling in a *horizontal* orientation for (i) very small a; and (ii) large a.

(c) If the instrument is dropped *horizontally* with initial generalized velocity (0, -U_2, U_3, 0, 0, 0). Find the moments (M_1, M_2, M_3) on the cylinder at the instant the cylinder is dropped in terms of a, ρ, U_2, U_3.

(d) An engineer is concerned that if dropped in a *vertical* orientation, the device may become "unstable" and reach the bottom in an unpredictable manner. If the equipment is falling with steady downward velocity U, at a small angle α from its vertical position, estimate, based on potential (non-viscous) flow effects only, the overturning moment M_2 on the device as a function of U and θ_5.

<u>**PROBLEM B.3: (20%)**</u>

A long rigid cylinder is mounted vertically from a floating platform and extends to the sea floor. In this region there is often a strong shear current but luckily no waves on a regular basis. This current has a maximum value $U_{max} = 1.0$ m/s from the free surface down 5meters into the water. Below 5m the velocity profile tapers linearly to $U_{min} = 0.1$ m/s @ z = -10m. Below z = -10m the flow is constant at U_{min}. The cylinder is has a constant diameter of d = 0.5 m. The sea floor is 200 meters below the free surface.

a) Determine the vortex shedding frequency at (i) the top of the structure (0m > z > -5m) and (ii) the lower portion of the structure (z < -10m).

b) Consider the forces acting on the structure: $F_{in\text{-}line}$, $F_{transverse}$. At the top of the structure what is the frequency of drag force per unit length? Frequency of lift force per unit length? How is this different at the bottom section of the structure (z < -10m)?

c) What do you think will be the effect of this velocity profile on the structure? Consider the change in vortex shedding along the length and how that might affect forces, vibrations, etc.

d) If the cylinder was flexible but experienced a uniform current how would you expect it to behave (consider the motion of a flexible cylinder in the first mode of oscillation). Use sketches and text to explain.
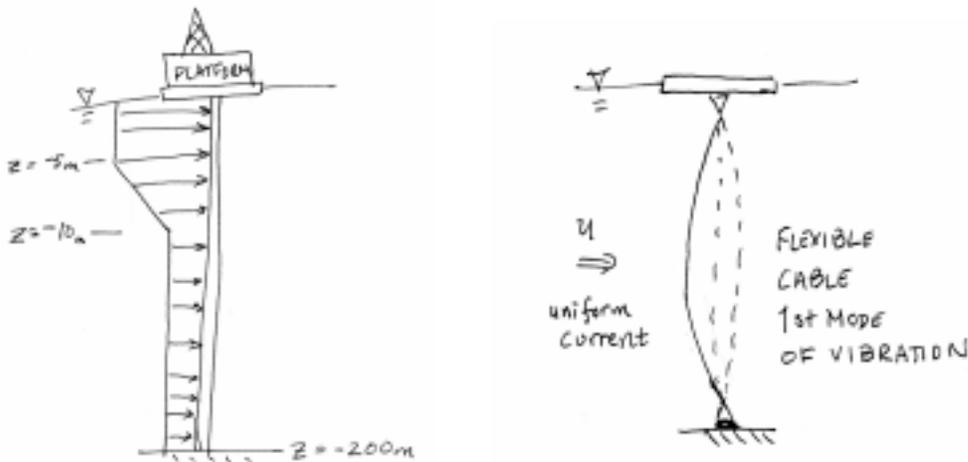
(Bonus +5 points)

e) During hurricane season, large storms generated some distance away generate waves that affect this structure. If the waves are incident in the direction of the current, and the current is uniform explain how the forces per unit length on the structure can be determined. State the variables/constants that are needed and a general formula (or explain what terms should be considered).