Name: ______________________________

13.012 Marine Hydrodynamics for Ocean Engineers

FALL 2004 FINAL EXAM
THURSDAY DECEMBER 16, 2004
9:00am-12:00pm

Ocean
ENGINEERING

YOU HAVE THREE HOURS TO COMPLETE THIS EXAM

FOR THIS FINAL EXAM YOU ARE ALLOWED **TWO DOUBLE-SIDED SHEET** (OR 4 SINGLE-SIDED SHEETS) OF NOTES ONLY.

BE SURE TO PUT YOUR NAME ON THIS EXAM SHEET IF YOU WRITE YOUR ANSWERS TO PART A IN THE BLANKS PROVIDED, AND ON YOUR BOOKLET!

BE SURE TO SKETCH THE PROBLEMS IN PART B, STATE YOUR ASSUMPTIONS AND SHOW YOUR WORK!

USE THE PROVIDED EXAM BOOKLET:

Grades will be available after break or as soon as they are posted by MIT on WebSIS.

Use the following constants unless otherwise specified:

Gravity: $g = 10\ m/s^2$

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

Assume the fluid is incompressible unless otherwise defined.

1 KNOT = 0.5144 m/s
1 FOOT = 0.3048 m

Give all answers in SI units (kg, m, s). All numerical answers MUST have the proper units attached.

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Part A (40%):

1) A military submarine typically operates around 30 Knots when fully submerged. The full scale submarine is approximately 250 feet long, 20 feet in diameter. You are asked to perform resistance tests on a model submarine in a recirculating water tunnel. The facility is 0.5 meters x 0.5 meters in cross section with a 1.5 meter long test section. The tunnel has a maximum operating speed of 9 m/s. The most relevant non-dimensional parameter to ensure proper scaling is ______________. Based on this scaling parameter you design an experiment to fit into the water tunnel, the model sub diameter is ____________ and length is __________ and testing speed is ______________.

2) Deep water waves propagate from left to right past a cylindrical structure that protrudes up from the bottom through the free surface. The cylinder has diameter of 0.5 meters, and the waves in that area have a predominate wavelength of 10 meters. Wave diffraction [can] [cannot] be neglected. If the height of the waves is less than one diameter, ______________ forces dominate.

3) Medical experts want to design a better heart valve. In order to do so they want to first perform scale model tests to determine the force needed to close the valve against the flow in the artery, and thus they need to know the relevant non-dimensional parameters. Consider the valve can be modeled as a round orifice that opens and closes at some frequency. Blood flows through the valve at some velocity and has material properties, ρ and μ. Assume that the blood is incompressible and Newtonian. Determine the relevant non-dimensional groups involved (not all the blanks need to be filled):

______________ ______________ ______________ ______________

______________ ______________ ______________ ______________

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4) A plane crashes off an apparently deserted island in the South Pacific Ocean. Survivors are "Lost" and need to create a constant source of water at their base camp. There are 45 survivors, each requiring about 1.5 liters (0.0015 m^3) of water each per day. The survivors are camped at the beach, but a water supply exists up a hill some distance away. They decide that they can use gravity to their advantage to supply water to their location. Assuming there are 12 hours of daylight during which all this water must be provided, the water must originate from at least __________ meters above Sea Level from to ensure the appropriate volume flow rate (neglect friction losses through the piping system) such that enough water arrives at the beach each day.

5) The advance ratio of a propeller is defined as J = ___________ and is the ratio of ___________ to ____________.

6) An overhead power line is 0.05 meters in diameter in a wind of 4 m/s, the vortex shedding frequency of the power line is ____________ Hz.

7) The initial acceleration of a cylinder of density, ρ_C, diameter, d, and length, l, dropped from rest in a horizontal orientation is equal to ________________.

8) An object is free to float on the free surface. When this object heaves up and down it generates waves with amplitude comparable to the heave amplitude and frequency of the heave motion. These waves radiate out from the body and can be represented by a potential function, ϕ_R. The fluid motion is governed by ________________ (equation). The boundary condition for these waves at the body is given by ________________. Far from the heaving body the boundary conditions for this potential is ________________.

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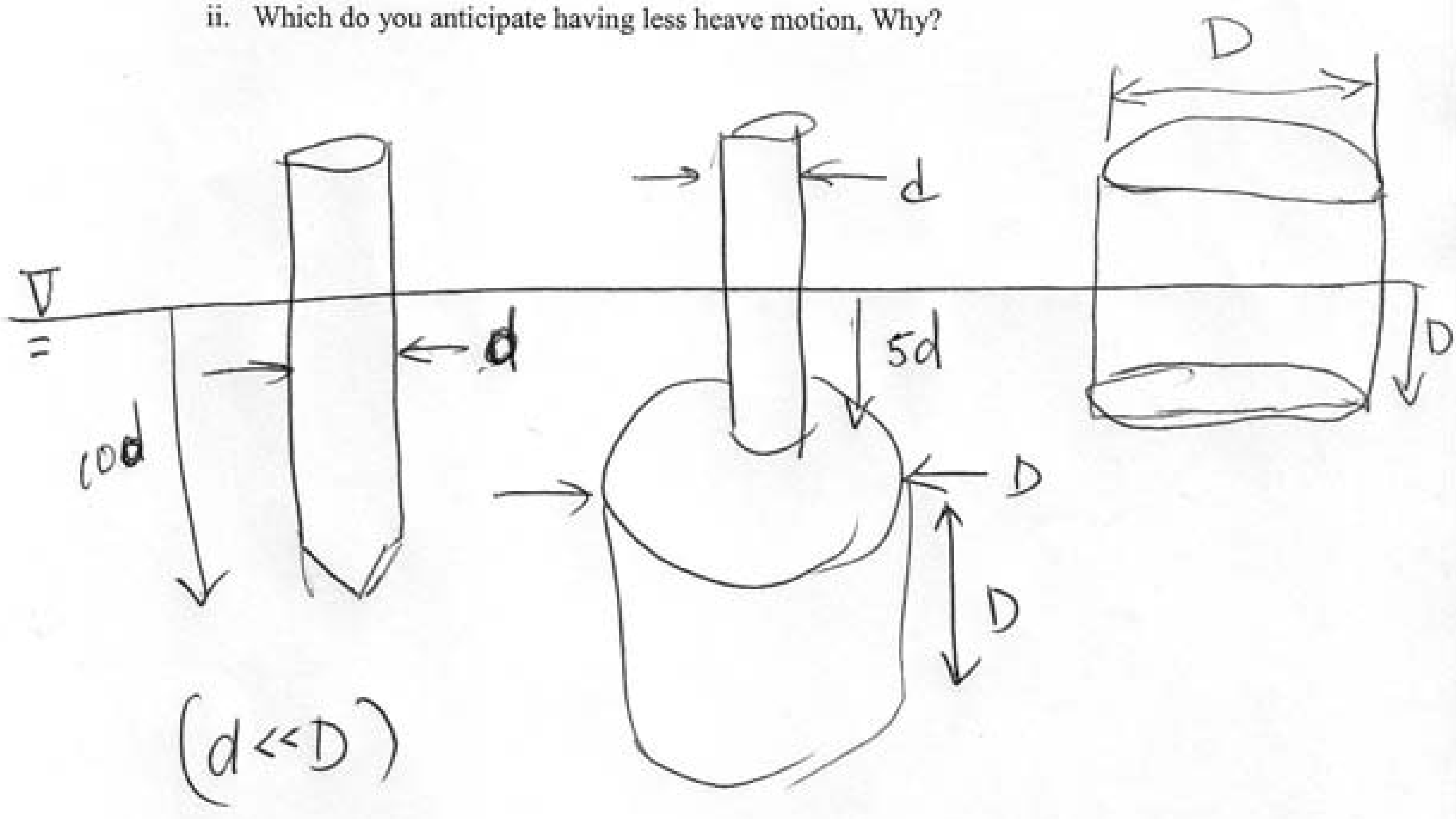
9) A sphere is tethered such that its highest point is one half a sphere diameter below the free surface. The density of the sphere is comparable to air. The equation of motion of the sphere is given by ______________________________, where m = __________, m_a = ________________, C_{33} = ________________, B_{33} is damping and $F_3(t)$ is the forcing as a function of time.

10) (partial credit possible) A buoy manufacturer is considering new buoy designs aimed to minimize heave motion. Consider the following three buoy designs.

i. Give the equation for the natural frequency of the buoys in terms of the given parameters and fluid properties.

ii. Which do you anticipate having less heave motion, Why?



11) Bonus (+4points): A neutrally buoyant submarine can be modeled as a simple horizontal cylinder. Its natural frequency in heave is ω_n = ________________.

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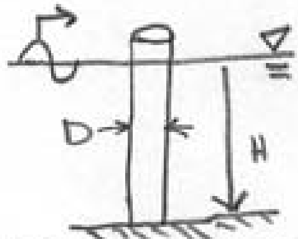

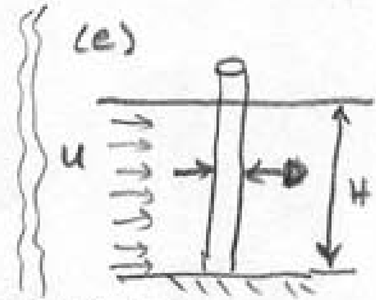

Part B: (60 % total)

Problem B1: (30%)

Offshore platform design company requests that you perform model scale testing of a structure in waves. You are asked to evaluate the wave force on a cylindrical structure with characteristic diameter, *D*. The structure is fixed at the seafloor and pierces through the free surface. The waves can be considered deep water, mono-chromatic waves, incident on the structure in one direction.

a) Using the characteristic parameters of free-surface, gravity waves, the fluid, and the structure, find the non-dimensional parameters that govern this problem.

b) What are the requirements for model testing to ensure appropriate dynamic similitude? Explain your choice of parameters and test conditions.

c) If the model is $1/5^{th}$ scale of a 4.0 meter diameter riser in 100 meters of water, with waves with dominate frequency $\omega = 1$ rad/sec and amplitude 1.0 meters, determine the experimental setup (ie model geometry and wave parameters) necessary for correct model testing.

d) Give the equation that you could use to determine the relative viscous versus inertial forces on the structure.

e) Consider the same $1/5^{th}$ scale model test described above, in the absence of waves but with a current of velocity *V*. Vortices are shed at frequency *f*. It is known that frequency, *f*, is a function of the fluid properties, ρ and μ, and the acceleration due to gravity, *g*.

   i. Express the dependence of frequency on non-dimensional groups.

   ii. A test is performed with the $1/5^{th}$ scale model. If previous tests have shown that viscosity is NOT important, what velocity must be used to obtain the appropriate scaling and what vortex shedding frequency to you expect to see?

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Problem 2: (20%)

An underwater vehicle can be modeled as three cylindrical canisters (L = 1.0 m, diameter, d = 20 cm) with a hemisphere at the leading and trailing edges, the coefficient of drag on each cylinder is 0.8, based on frontal area. The cylinders are arranged in a triangular configuration with equal length and diameter cylinders (l = 0.2 m, diameter, d = 5 cm) connecting them together (Cd = 1.2 for these connection rods) on two places.

a) Determine the thrust requirements necessary to propel the vehicle forward steadily at 1 m/s.

b) You need to determine the power required to drive the AUV propeller. The power is known to depend on the diameter of the propeller, the density of the fluid, N the RPS of the propeller, the viscosity of the propeller, the velocity of the fluid through the propeller (assume this is equivalent to the vehicle speed). Find the non-dimensional groups that govern the power requirements for this vehicle.

c) Given the choice between a single propeller and twin propellers, that produce the same total thrust as the single prop, compare the power required, the size of the propellers (diameters) and the speed of the propeller (rev. per second) for operating a single propeller versus a twin propeller configuration.

These propellers are fully submerged and can be analyzed in general terms, independently from the vehicle.

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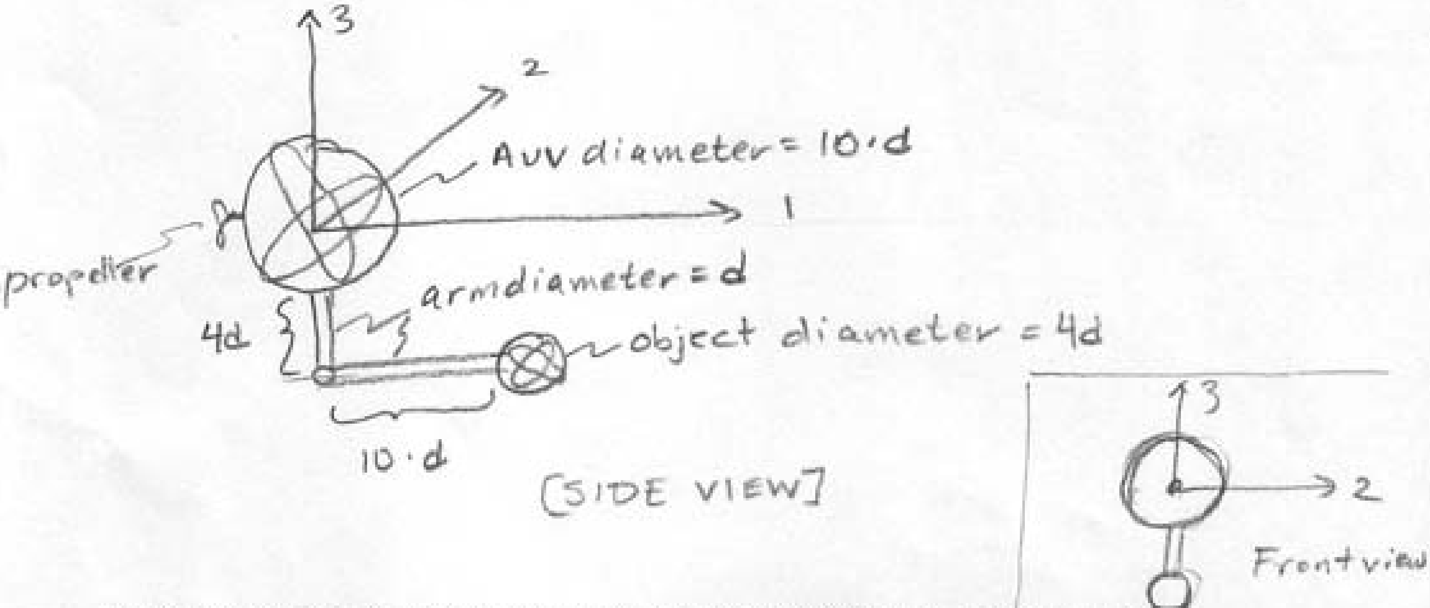
Problem 3: (10%)

A small underwater vehicle is operating over an ancient ship wreck. It can be modeled as a sphere with a remote arm attached. It has already picked up an object that is encrusted with barnacles and is spherical in shape. It must maneuver and bring this object to a central collection station. The vehicle is sketched below.



a) Determine the 6x6 Added mass matrix for the vehicle with the object in terms of the given geometric parameters. (ignore propeller)

b) The acceleration vector is $\dot{U} = (1,0,0,1,1,0)$, $\Omega = 0$, and velocity is $U = (1,-1,0,0,0,0)$. Determine F_1 and M_2.