SMS-204: Integrative marine sciences.

Homework 5, Reynolds #, flows and swimming.

1. Fill in the first two columns in the table below with data from Lab 1 (can be found on the lab website or in the answers to Homework 1). Provide units.
   Fill out the rest of the table by computing as described below:
   Be careful to convert to consistent units!

Bead Diameter [mm]	Sinking velocity [cm/s]	Sinking velocity x Diameter [cm^2/s]	Reynolds Number (unitless)	Drag Force (newtons)
3.1	2.62	0.81	0.07	0.001
4.7	5.45	2.56	0.23	0.003
6.3	9.30	5.86	0.53	0.008
9.5	19.00	18.05	1.62	0.029
12.6	29.40	37.04	3.33	0.067

Table 1. Data from lab. I chose the median values from all groups.

a. (10pts) Compute the Reynolds number (*Re*) for all different settling spheres (assume that for glycerin μ=1.4Kg/s/m (Pa s) and ρ~1.26g/ml.

See Table 1.

b. (10pts) Determine the drag force on sinking spheres, assuming that when the spheres reach constant settling speed and no net force is acting on the bead:

$$F_{drag}=F_{gravity}-F_{buoyancy}=gV_{sphere}(\rho_{sphere}-\rho_{glycerin})$$

Where g is the gravitational acceleration, V_{sphere} the sphere volume and ρ the density of the metal spheres, ρ_{sphere}=7800Kg/m^3, and glycerin $\rho_{glycerin}$=1260Kg/m^3.
See Table 1.

c. (15pts) Plot F_{drag} (based on the equation above) as function of sinking velocity times diameter. Is the relationship linear (don't forget to add error bars based on the different estimates for velocity obtained by the different groups)?

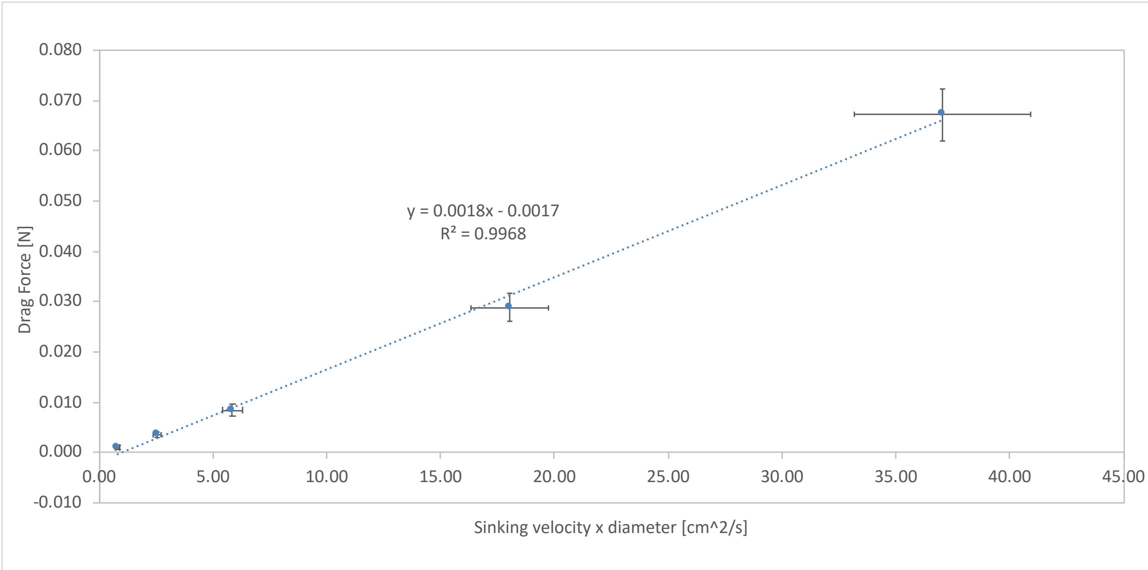

Figure 1. Drag force (=$gV_{sphere}(\rho_{sphere}-\rho_{glycerin})$ as function of sinking velocity times the bead's diameter. X-Error bars are +/-$\Delta(W\times D)$, y-Error bars are +/- ΔF_{drag}

x-error bars: $\Delta(W\times D)/(W\times D)=\{(\Delta W/W)^2+(\Delta D/D)^2\}^{0.5}$
y-error bars: $\Delta F/F=3(\Delta D/D)$ {Assuming the only uncertainty is due to the volume uncertainty which is driven by the uncertainty in diameter}. I used half the difference between the 84th and 16th percentile as the measure of uncertainties.

d. (15pts) Obtain the regression line for the plot, that is an expression of the type: F_{drag}= slope x sinking velocity x diameter + constant, and provide the display of the fit on the graph.
See Figure 1.

e. (10pts) According to Stokes' law, $F_{Drag}=3\pi\mu Dv$ (where D is diameter and v the sinking velocity). Divide the slope you got above (for the regression line) by 3π to obtain an estimate of the viscosity of glycerin (μ). How does it compare with published values? (Feel free to use the WWW, and notice that the viscosity of glycerin varies strongly with temperature).
The slope I got is 0.0018 but my units are mixed (SI and non-SI). Converting the units from cm^2/s to m^2/s for diameter times velocity, this slope will increase by 100^2 to 18 and will equal $3\pi\mu$ (=F_{Drag}/Dv). → $\mu = 18/3\pi = 1.91$Kg/s/m.
This is close (<35% difference) to values of about 1.42 Kg/s/m reported for glycerin at 20ºC (http://physics.info/viscosity/). The agreement is reasonable given that the Reynolds numbers for the beads are not very small for Stokes law to be strictly applicable.

2. Watch two of the following movies and describe how the swimming, feeding or spore release strategy and morphology of each of the two organisms you chose match the flow regimes (in terms of Reynolds number) it operates in (20/100).

Vortices formed around a starfish larvae to enhance feeding:
https://gfm.aps.org/meetings/dfd-2016/57d648ebb8ac3117910005f9
1mm in sized larva, Re number is ~1000. Uses cilia to swim. Not a turbulent regime (flow is well organized). Create vortices to enhance feeding (at the cost of swimming slower). Vortices are formed by cilia beating in opposite direction to swimming. Larvae can change the number of vortices it creates to negotiate the tradeoff between swimming speed and feeding

Bacteria flagella:
https://gfm.aps.org/meetings/dfd-2016/57da1549b8ac3117910009ed
Bacteria swim at a low Re number (~10^{-6}). Viscous forces dominate. Hence need a strategy that is not symmetric (flagella).

Jelly fish:
https://www.youtube.com/watch?v=StCfjFXQy24
Jelly fish swim at a high Re number. Inertial forces dominate. By creating one (stroke A) or a double vortex (Stroke B) within the bell, and expelling the fluid, the jelly fish moves forward. Fluid motion is well organized.

Trout swimming upstream:
https://gfm.aps.org/meetings/dfd-2016/57db4473b8ac311791000b19
Trout swim at a high Re number. Inertial forces dominate. Two forms of swimming: continuous (steady) and burst & coast. Creates a turbulent wake.

Unusual microscopic swimmer (Cercariae):
http://gfm.aps.org/meetings/dfd-2014/5416413369702d585c3f0100
350μm organism. Reynolds number ~ 0.4 . Uses non-reversible swimming by changing the angle puddle and body at each stroke. Can Also propagate in opposite direction by folding tail using a traveling wave swimming. Seems reversible and not efficient. Inertia is a little more important than when Re<<1, and movement forward occurs.

Spore release:
http://gfm.aps.org/meetings/dfd-2014/5416731e69702d585c750100
Spores are ~200μm and the regime is that of low Re number. Using tiny flagellar hair spore rotate producing a large current towards its head and a current between the spore and the walls of the Vauchria, that both disconnect the spores from the wall (as it rotates around itself) and exerts a net force to expel the spore.

Nematod swimming
http://gfm.aps.org/meetings/dfd-2014/54174d3369702d585c040300
1mm in size, a nematode has a Reynolds number of about 10 (swims very slowly). Near boundaries a torque is applied (due to the no-slip conditions) that causes it to migrate to

boundaries. This is found to be consistent with numerical simulations. Behavior is beneficial as it will cause the nematode to increase likelihood it will get to its prey.

Antartica ‘butterflies’ swimming
https://gfm.aps.org/meetings/dfd-2015/55f63e2669702d060df00300
Reynolds number is 5-10. Little inertia but sufficient for the organism to rotate after both power and recovery stroke and maintain upward mobility. Alternating vortices are shed in opposite direction. Stroke are not symmetric due to flexibility of swimming appendages.

Sea butterflies:
https://gfm.aps.org/meetings/dfd-2018/5b9b22abb8ac3105e5ac8eaa
Sea butterflies - small plankton with a negatively buoyant shell. Reynolds numbers 10-1000. Sea angels – no shells - Reynolds number ~300. For both: wings beat several time a second in alternating directions (bending their wings by 180 degrees in each). Result in saw-tooth swimming trajectory. Vortex are shed from wings enhancing lift.

3. Movie analysis (20/100): Watch the movie ‘life at low Reynolds number’ (https://www.youtube.com/watch?v=gZk2bMaqs1E).

a. What are the two swimming motors/appendages used by organisms at low Reynolds numbers?
Flagella and cilia.
b. What is the dominating force at low Reynolds number?
The viscous force.
c. What fluid should we swim in to have a similar Reynolds number as the one of the swimming Rotifer in the movie?
Hot roofing tar.

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