SMS-204: Integrative marine sciences.

Homework 5, Reynolds #, flows and swimming.

1. (60/100) 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 doing the following:
   Be careful to convert to consistent units!

Bead Diameter [mm]	Sinking velocity [cm s^{-1}]	Velocity x Diameter [m^2 s^{-1}]	Reynolds Number (unitless)	Drag Force (newtons)
3.03	3.20	0.00010	0.087	0.00093
4.69	6.93	0.00033	0.293	0.00347
6.29	11.64	0.00073	0.659	0.00836
9.44	23.08	0.00218	1.961	0.02826
12.58	34.48	0.00434	3.904	0.06688

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 above

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 above

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)?

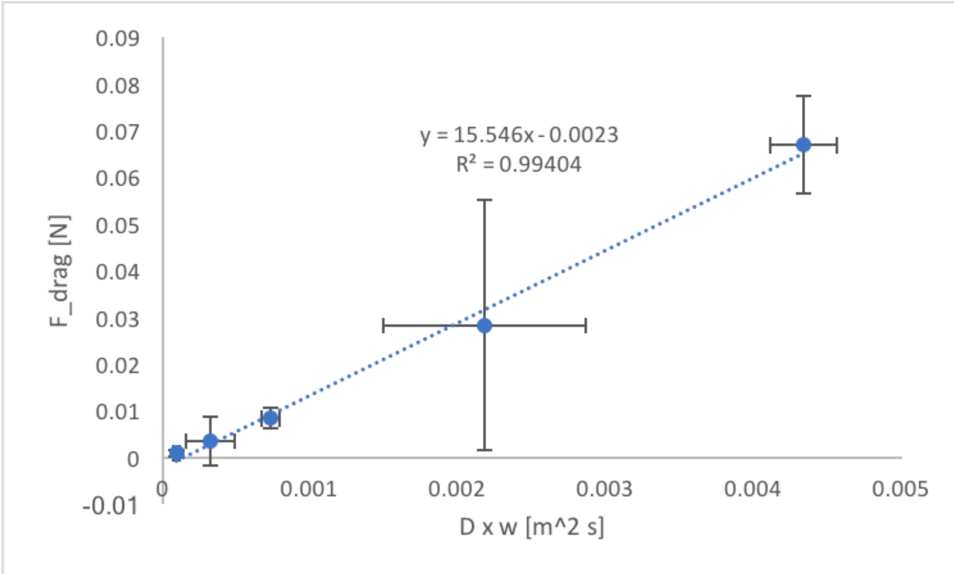

Figure 1. Drag force (=$gV_{sphere}(\rho_{sphere}-\rho_{glycerin})$ as function of sinking velocity times the bead's diameter. X-Error bars are +/-Δ(W×D), y-Error bars are +/- Δ F_{drag}

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 Fig. 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)

We find $3\pi\mu=15.55$ (based on the slope of the graph) →
$\mu=15.55/3\pi=1.65$Kg/s/m.
This is close to values of about 1.42 Kg/s/m reported for glycerin at 20°C (http://physics.info/viscosity/). The agreement is good and a little surprising 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 size, 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 it the jelly fish moves forward. Fluid motion is 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

350um 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 ~200um 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 spore 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

Sized ~1mm, 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 pray.

Antartica 'butterfles' 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.

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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