How marine organisms use fluids: exchanges of momentum and heat

Write-up due 1/12/04, 1:30 PM

The purpose of this lab is to think in detail about how marine organisms interact with their fluid environments. Specifically, which aspects of these interactions are determined by the organisms' morphological and behavioral traits, and which aspects are determined by the physical properties of fluids? This distinction is important because organisms' traits are potentially subject to evolutionary change over time, whereas physical properties are not.

In this lab, you will look at organism-fluid interactions in three contexts:

1) Swimming mechanics of small planktonic organisms
2) Scaling of forces on model organisms moving in fluids
3) Transport of mass from model organisms in stationary and moving fluids

Each of these exercises has its own experimental station. You will work in three groups of 3-5, one at each station. You will have roughly 25 minutes at each station. At each station, you should first play around with it, to get a feel for the experimental system. Then, you and your team should agree on an experimental protocol, assign tasks; and finally perform and record your observations. Each exercise has a short set of questions, which you can begin during the lab (if you have time) and complete afterwards.

Station 1: Swimming mechanics of small planktonic organisms

Materials: *Artemia* nauplii and/or copepods, dishes of water and karo syrup, particles or dyes for flow visualization, plastic forks, video and microscopy equipment, pipettes.

In this experiment, you will study the morphology and swimming movements of a small zooplankter, a newly hatched brine shrimp larva. The organisms are good study organisms, in that they are easy to culture and have a simple morphology – only one pair of swimming arms. As they develop and grow, they acquire more and more pairs of swimming arms. The first stages (which we will look at) do not yet feed. Older individuals acquire the ability to suspension feed on particles such as phytoplankton cells. Alternatively, look at copepods or other zooplankton from a net tow.

Use a pipette to extract a few nauplii from the culture vessel, and place them on a microscope slide under the compound scope. You may need to do this several times – some specimens and preparations may be better than others for obtaining different information. For example, for observing morphology you might want very little water in your slide, but for watching how appendages move in swimming you might want to create a gap under your cover slip with modeling clay and use extra water, so they have room to move.

For one or more of your specimens:

1) Sketch the nauplius (or copepod) morphology under compound scope
2) Observe the organism's swimming movements in a small aquarium using the high-speed video.
3) Move the plastic forks back and forth at various speeds in the dishes of different fluids, to mimic the movement of the swimming appendages. Which combinations of fluids and speeds most closely correspond to the flow patterns you observe in the high-speed video?

Lab question #1.1: Summarize your observations from 1-3 above. What can you say about how *Artemia* nauplii or copepods swim? In particular, how do the appendages move during a swimming stroke and recovery? How does the organism as a whole move while the appendage performs its stroke and recovery?

In general, how important does viscosity appear to be in the swimming of these animals (and which observations lead you to this conclusion)? Did you see any special behaviors, such as escape responses?

Station 2: Scaling of forces on model organisms moving in fluids

Materials: stopwatch, plastic ruler, graduated cylinders with fluids, test objects (modeling clay and/or marbles), spring scale, calculator.

In this experiment, you will determine how the fluid forces on a swimming organism scale with changes in the organism's size, and with changes in the physical properties of the fluid environment. The model "organisms" will be spheres and cylinders of different sizes and weights.

The basic technique is simple: measure the falling speed of objects of known weight in fluids of known viscosity and density. Measure the speed by observing the time taken for each test object to fall a specified distance through the fluid in graduated cylinders. You will use two fluids: water and karo syrup. These fluids differ in viscosity by a factor of about a thousand. You can adjust the model clay to vary mass and shape.

From the raw measurements, you will calculate and plot two indices:

- Reynolds number, $Re = \dfrac{UD\rho}{\mu}$
- Drag Coefficient, $C_{drag} = \dfrac{W}{\pi/8\ \rho U^2\ D^2}$

In these formulas, the variables are:

D	Diameter of test object	(cm)	μ	Fluid viscosity	(gm/cm sec)
W	Weight of test object	(gm)	ρ	Fluid density	(gm/cm^3)
U	Speed of sinking	(cm/sec)			

For each of 5-10 objects, record or calculate all the following information:

Object	D	W	U	μ	ρ	Re	C_{drag}

Lab question #1.2a: How does the speed of a sinking object vary with the viscosity of the fluid through which it moves? What does this imply about the forces on objects in various fluids?

Lab question #1.2b: How does the sinking speed vary with shape? Does a sphere sink faster or slower than a cylinder of equal weight and density? Do the proportions of the cylinder matter?

Lab question #1.2c: Make a graph with Reynolds number on the horizontal axis and drag coefficient (C_{drag}) on the vertical axis. Do you see a pattern in the results? Specifically, do your results for different objects and fluids lie along a single curve?

Station 3: 3) Transport of mass from model organisms in stationary and moving fluids

Materials: model "organism", flume, scales, plastic ruler, dyes.

In this experiment, you will manipulate and visualize the flow around a model organism. You will also investigate how transport of mass away from the organism's surface depends on flow rate around it. By making an analogy with heat transfer, you already have an intuition for the effects of flow – standing outside on a cold day, how much of a difference does the wind make to how cold you feel?

To study the effects of flow, we will use a flume – a water tunnel designed to create a simple and repeatable pattern of flow (this one was built by Chris Jordan, at N.M.F.S.). In your group, you must designate one person to be a "dry hands" person. Only a "dry hands" person may touch the electrical switches on the flume. That person may not do anything involving water while he/she has responsibility for the flume controls. The rest of the group are recorders, who will take measurements and notes on what you as a group observe.

IMPORTANT: To prevent electrical hazards, the "dry hands" person must not touch anything wet at any time during the experiment.

You will quantify mass transfer by placing an object of known weight (a piece of candy) into the flume for a specified amount of time, and then weighing it again. The rate of mass loss is the decrease in weight divided by the time.

Choose a model organism to study. Take a baseline measurement of its weight (remember to wet it first, to account for the water on its surface). You will study three flow settings on the flume, determined by the digital readout:

- No flow
- Slow flow
- Fast flow

For each of these flows, make note of the following:

i. What is the pattern of fluid flow in the vicinity of the organism? What appear to be the fluid forces involved in generating the flow patterns? Is the external flow important? Is convection (flow produced by density differences) important?

ii. What is the internal temperature of the organism? What does this say about the rate of heat loss at each flow setting?

If there is time, try a different organism or a different position in the flume and compare.

Lab question #1.3: Describe how the fluid flow patterns you observed around the organism changed with each flume setting. How did the rate of mass loss vary as a function of the flow patterns? Explain the relationship between the patterns you observed in the flow and the patterns you observed in the heat transport.

Optional: What are the Reynolds numbers of your objects in the flow? How does transport depend on Reynolds number?