HOT TOPICS IN MARINE BIOLOGY 5.1

Flow Is a Drag, but It Sure Can Smell Good

The first thing that we usually learn about organisms is that they are rarely controlled by only one factor in nature. Not only are several different effects usually at work (e.g., temperature, salinity, and water flow), but also the organism has numerous needs (e.g., to find food, mates, and a proper substratum). This complexity is readily illustrated by a study of the effects of flow on marine epifaunal invertebrates such as predatory crabs and prey bivalves.

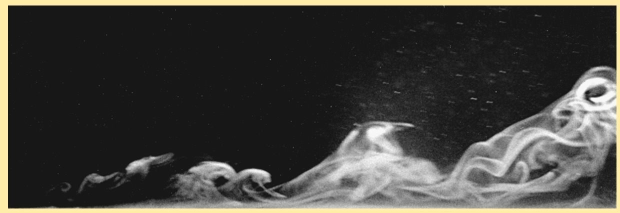
Consider the carnivorous blue crab *Callinectes sapidus* (see Figure 13.20c), which is a common coastal crab on the east and Gulf coasts of North America. Its favored prey is the infaunal eastern hard clam *Mercenaria mercenaria*, which is found in soft intertidal and shallow subtidal bottoms. The crab walks actively about and can locate its prey by means of chemosensory hairs on the antennules that recognize molecules carried to it in bottom currents. Where do these molecules come from? They are propelled through the hard clam's exhalant siphon and become entrained in the flow, creating an odor plume that eventually reaches the crab (Box Figure 5.1).

The crab's problem is as follows: How can it locate the origin of the detected molecules (even clams have a scent, which must be explained by various excretory products such as peptides and urea)? It can walk randomly until the scent (or, more properly, rate of stimulus of the chemosensory hairs) becomes stronger, but this would be rather inefficient. It helps that the sensory hairs are on both the right and left antennules. As the crab moves, it is able to judge whether to move left or right, depending on the relative strength of the signal that reaches the sensory hairs. (The sensory hairs are quite small, and a viscous boundary layer of water develops around them. That's why crabs and lobsters often flick their antennules to reduce the boundary layer and to allow flowing water and the entrained molecules to impact upon the chemosensory hairs.)

The crab also derives information directly from the flow. The molecules are moving downstream, and so it makes sense to use water flow information to aid in locating higher concentrations of those molecules. That is why crabs also have mechanoreceptor hairs on the antennules.

Armed with both chemosensory and mechanosensory hairs, the crab's prey location problem appears to be solved, and it might seem that any nearby clams are doomed. Or are they? The odor plume emitted by a clam can provide useful information only if there is a regular decline of concentration with distance of the material in the plume responsible for the strength of the odor. That occurs if there is a well-developed boundary layer. Then water is propelled through the clam's exhalant siphon and moves regularly up into the mainstream. From an initial position downstream, the crab walks upstream toward the source of the odor and eventually finds its way to the exhalant siphon by successively encountering increasing odor intensity, much as a heat-seeking missile might find its way down a warm chimney. Work by Richard Zimmer demonstrated that the flux of material (molecules per unit time) flowing past an odor-detecting animal is what matters: a low-velocity current with high concentration of odor has the same effect as a high-velocity current with low concentration of odor.


(a)


(b)

BOX FIGURE 5.1 Dye traces of odor plumes. The blue crab *Callinectes sapidus* must locate the odor plume emanating from the exhalant siphon of the clam *Mercenaria mercenaria.* (a) If the current is relatively weak, the flow is laminar and the odor plume maintains its integrity. (b) If the current is strong, or if the bottom is rough, the boundary layer becomes turbulent and the crab will have trouble following the odor to its source. (Courtesy of Marc Weissburg.)

If, on the other hand, the bottom is irregular or the near-bottom water current is very fast, the water flow near the bottom will be turbulent and there will be a poorly developed boundary layer. Under these conditions, crabs often fail to locate the odor plumes generated by the clams.* In the natural estuarine habitats of the crabs, such as Chesapeake Bay, the current velocities are often in the range at which a boundary layer is well developed, and recent research shows that the plumes are regular enough to permit the crabs to follow them to the source.

How do the crabs detect the odor? Detection is chemical, and it is done by receptors on the claws, legs, and antennules. Leg sensors help control steering as the crab moves toward the odor plume's source and antennule sensors help control upstream movement. The claw, leg, and antennule sensors are located on the right and left sides of the crab, so the crab gets its best information by facing directly upstream to get orientation information from both left and right sides. But there is a major problem: with an odor source often comes a water flow, which is sometimes a challenge to the crab. Imagine yourself standing in the surf facing directly into an oncoming wave: you will be knocked down! If you turn 90 degrees you will be a bit more streamlined; this is a natural response of people facing the surf. The same goes for a blue crab. Its drag is much less if

* See Weissburg and Zimmer-Faust, 1993, in Further Reading, Hot Topics in Marine Biology.

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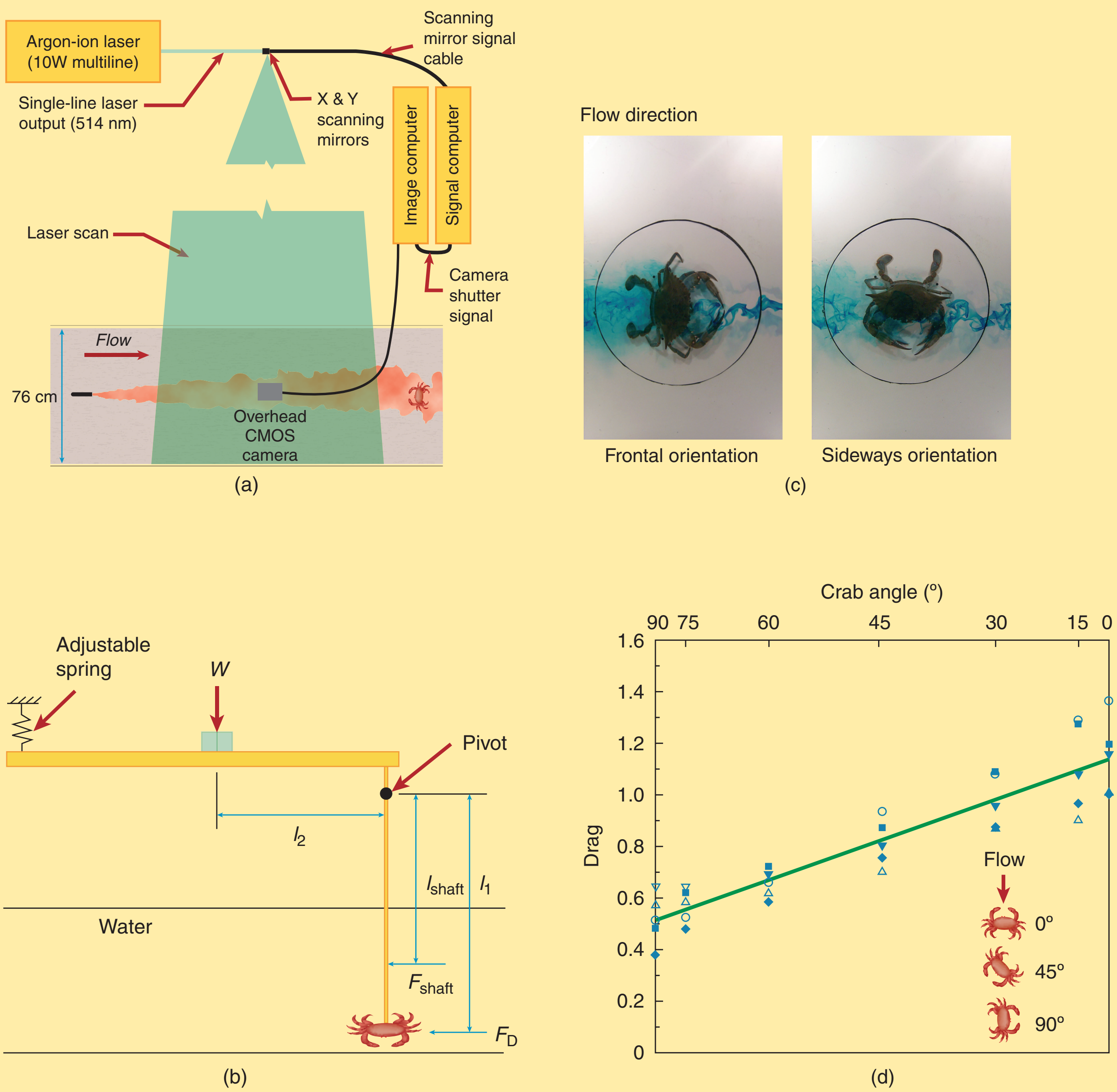

BOX FIGURE 5.2 (a) Experimental design to study the spread of odor plumes. Dye and odor chemical are both released at the same location in a flume. Water currents carry both downstream, and flow is characterized by a laser-light source that induces fluorescence and is detected by high-speed video. (b) Drag on crabs is measured by attaching crab in flume to a strain-detecting device; (c) blue crabs have maximum sensory detection but also maximum drag when facing current, as shown by larger downstream wake in left crab photo, where crab faces current frontally. (d) Drag caused by crabs placed at different angles to the flow. They rotate to minimize drag when current strength increases. (Courtesy of Marc Weissburg.)

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it does not directly face the flow. So, a conflict arises: If the current speed is fast, maximal information needed for moving upstream and steering in the direction of the odor plume is in conflict with minimizing drag.

Weissburg and colleagues† used a complex apparatus (Box Figure 5.2a) to characterize the odor plume in moving water in a flume. Both an odor and a fluorescing dye were released upstream of a crab under different conditions of flow. A laser light source produced planes of light that could be integrated to characterize the flow. Crabs were placed in the moving water and, when they were impacted by moving water, their motion rotated a device that could estimate the drag on the crab (Box Figure 5.2b). By this mechanism they could show that drag was maximal when the crabs faced directly into the current and minimal when the crab rotated 90 degrees (Box Figure 5.2d). When flow was very low, crabs faced into the current but rotated when the current increased. The researchers used dye to visualize the flow around crabs in different orientation, and crabs facing the current head-on had a dead spot of water eddies downstream of the body, showing how a localized low spot of pressure downstream would greatly increase drag in this orientation (Box Figure 5.2c). ■

† See Weissburg and others, 2003, in Further Reading, Hot Topics in Marine Biology.

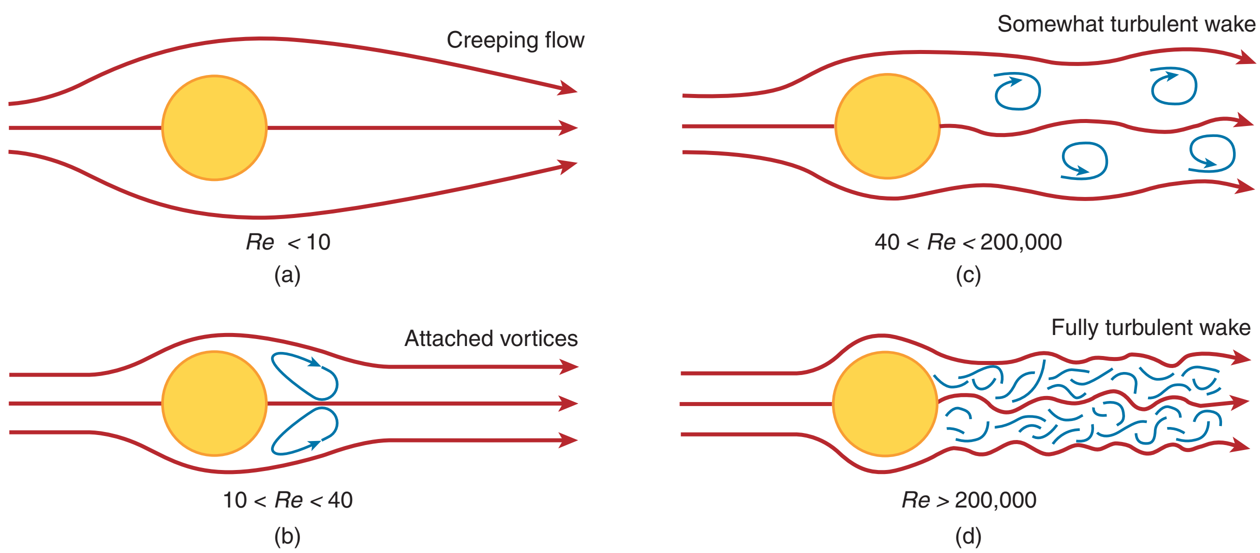

FIG. 5.11 **Different types of wake downcurrent of a cylinder, at different Reynolds numbers. (After Vogel, 1994.)**

of moving water, a working area where the organism and flow field are characterized, and a drain–return system (Figure 5.12).

Most flume designers seek two objectives: maintenance of laminar flow and maintenance of scaling by *Re* (and there are also other parameters beyond the scope of this text). A long flume is desirable because it takes awhile for the flow over the bottom surface to stabilize and produce a predictable boundary layer and velocity profile above the bottom. A wide flume, relative to water column height, prevents effects of the walls on flow. Scaling by *Re* is also essential to keep the proper ratio of inertial to viscous forces.[6] This refinement has an advantage, however, in that you can study a very small object, such as a copepod, by making a larger model and placing it in a more viscous medium.

[6] See Hot Topics in Marine Biology 5.1 to see a flume application.

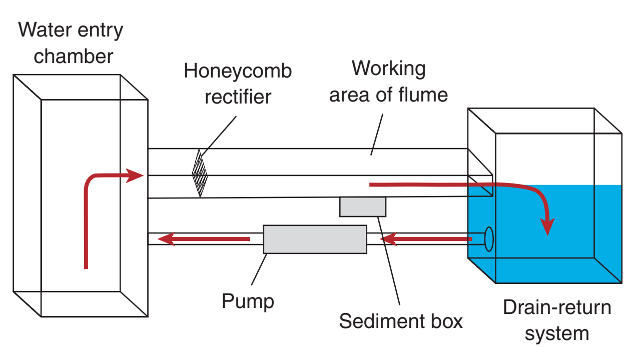

FIG. 5.12 **A flume designed to study the effects of flow on small epibenthic animals. In this design, water is recirculated by means of a pump. Water enters a honeycomb-like material to rectify the flow and then flows into the working area of the flume, where organisms are placed. Water leaves the working area and drains into a sump, from which it is pumped to the water entry chamber.**