Feedback on Drag, Thrust and Lift

There was a little confusion on drag. The amount of explicit, discussion of drag forces from shear and pressure varied a lot from paper to paper. Not everyone turned in a discussion of lift (that I requested but informed you that I would not grade). I don't expect a solid understanding of lift until we cover swimming, so I am going to put off any more questions on homework about lift or thrust until that unit. ***I commented on but did not grade the lift portions of your papers***. Lift and thrust will not appear on the first midterm or the second (focused on mass transfer), but at least one question on at least one of the two will appear on the final. You will see lift acting on your suspension feeders, though, so keep thinking about it.

With a couple of exceptions, your answers to the weekly assignments on average are becoming less structured even though they should be becoming more structured as you master fluid dynamic concepts and terms. You should be planning on about two double-spaced or one single-spaced page for your short essay answers (not counting drawings). I helped structure answers early on by walking you through the labs in specific stages. The questions are designed to help you do that walking on your own. Remember to answer each question and then to reorganize your answer into a logical order and a compact whole. It may even be more efficient to re-order the questions in terms of your initial observations, but be sure to address them all. I'm happy to answer questions and make suggestions as you get started, but if you ask by e-mail please use something in your subject line (*e.g.,* "Quick question") to let me know it is not just a submission of the weekly assignment, *i.e,* to make sure I open it promptly.

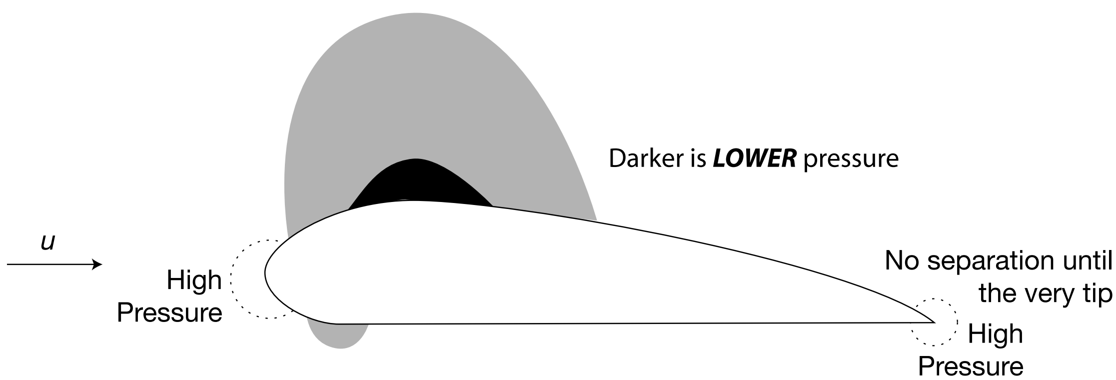
Drag has two components. Skin friction or form drag results from flow parallel to the object's surface. Total drag force from skin friction would be obtained by integrating shear stress over the entire surface, as we did for the sphere at low Reynolds number, carefully keeping track of direction as well as magnitude. Streamlining will usually increase skin friction by making more surface area parallel to the flow. Moving the detachment point forward on the body will actually *decrease* the skin friction because the circulation downstream of the detachment point by definition is upstream (albeit weak compared to the downstream flow). The fundamental idea of streamlining is to slow down the flow after it has passed the widest point of the body slowly enough that the separation is delayed as far back on the object as possible. That keeps the streamlines flowing smoothly around the body, and from Bernoulli's law you know that pressure along those streamlines therefore is *increasing*.

I was surprised to find no calculation of body *Re* among your papers after you had such extensive experience calculating *Re* in the prior few weeks. With a flow velocity of about 5 cm s^{-1}, a half-width of about 1.25 cm and a kinematic viscosity for seawater (35 salinity) at 10˚C of 1.35 x 10^{-6} m^2 s^{-1}, I get *Re* to be about 5 x 10^2. A bane of fluid dynamics is the need to figure out who uses radius and who uses diameter to calculate *Re*. I prefer the half-width of an object (radius) because it is the greatest distance that a parcel of water must be deflected to move around the object, but diameter of cylinders is more frequently used than is the radius, and the flow transitions I suggested at *Re* ~ 40 and 400 from Panton's (1996) drawings were based on diameter. With that length scale we were working well above the transition at *Re* of nearly 10^3 and in line with many of your comments about turbulence in the wake. For a 3D object the reason that I favor the smaller dimension in the *yz* plane is that the transitions will occur at similar *Re* over a wide diversity of shapes; a fish's wake has much more to do with its half-width or width than with its height or length (with the exception of flatfishes in their normal orientation).

Three of you came very close to articulating a misconception, so let me make drag on a cylinder ***at low Re*** explicit, and consider a long, circular cylinder. For a given flow, the cylinder will experience > 1.5 times as much drag if oriented in cross flow as it would if oriented with its axis parallel to the flow. The "skin" area of the cylinder is the same in both cases, but the pressure drag created in cross flow is much greater because the area of flow blockage is much greater. The swimming mechanism in organisms that swim with cilia and flagella exploit this drag difference. In a very real sense, all objects are streamlined at very low *Re*; at very low *Re* the flow can even turn fairly sharp corners.

For the sphere at low *Re* you saw that 1/3 of total drag was due to pressure and 2/3 to shear. For the bodies you constructed in the flows that we produced, most of the drag was due to pressure. Whether you increase pressure abruptly with a blunt nose or build a much more gradual expansion, you will see a region of high pressure in front of the body's widest part. So the trick to reducing pressure drag is to recover as much pressure as possible as the flow decelerates along the body in the region behind that maximum expansion. How much you don't recover is largely determined by the cross-sectional area of the body at the detachment point relative to the cross-sectional area at the body's widest.

For an infinite, 2D airfoil, here is the approximate geometry of the pressure distribution. Make sure that you see why it has the shape that it does. Recall Bernoulli's law. Streamlines do follow the surfaces of airplane wings pretty well. The net force from this pressure distribution will produce an upward component of force on the wing (lift). In the figure below, high and low pressure are relative to ambient atmospheric pressure. But the real story in 3D comes later...



Reference cited

Panton, R.L. 1996. *Incompressible Flow,* 2nd Ed. John Wiley & Sons, N.Y.

Parthian shot:

Which of the shapes below do you think would have lower drag in the flow tank under the flow conditions of your previous observations and why? I've cut off the front and replaced it with an exact copy of the more streamlined looking back.