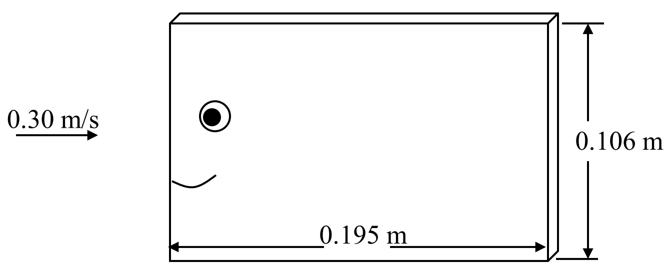
An engineer studies swimming fish in order to develop bio-inspired designs for boat and submarine hulls. These studies focus on a fish known as a "scup" (Stenotomus chrysops), shown in the following photo. The speed of the swimming fish, the body area on one side of the fish, and the length of fish from head to tail are given in the table adjacent to the photograph.

swimming speed =	0.3 m/s
body area on one side =	0.0207 m^2
body length =	0.195 m
salt water density =	1026 kg/m^3
salt water kinematic viscosity =	$1.19*10^{-6}$ m^2/s

a. For the given conditions, determine if the flow over the entire length of the fish is laminar, turbulent, or a combination of the two. Show your work supporting your answer.

b. Estimate the total drag acting on the fish, assuming skin friction drag dominates (a good assumption based on experiments) and that the fish shape may be modeled as a thin, flat rectangular plate as shown below.



c. Calculate the power required for the fish to swim at the given conditions.

SOLUTION:

The Reynolds number based on the fish's length is:

$$\text{Re}_L = \frac{UL}{\nu} = \frac{(0.30\ \text{m/s})(0.195\ \text{m})}{(1.19*10^{-6}\ \text{m}^2/\text{s})} = 49{,}200. \quad (1)$$

Since the Reynolds number is less than 500,000, the boundary layer over the entire fish is laminar.

The total drag acting on the (rectangular) fish may be found using the drag coefficient for a laminar boundary layer flow over a flat plate (the Blasius solution),

$$D_{2\text{ sides}} = 2D_{1\text{ side}} = 2c_D \tfrac{1}{2}\rho U^2 LW, \quad (2)$$

where L is the length of the fish (L = 0.195 m) and H is the height of the fish (H = 0.106 m), and c_D for a laminar flat plate flow is,

$$c_D = \frac{1.328}{\text{Re}_L^{1/2}}, \quad (3)$$

where the Reynolds number based on the fish's length was found in Eq. (1).

Using the given data,

Re_L = 49,200

$\Rightarrow c_D = 5.99*10^{-3}$

Note that experimental measurements provided by Anderson *et al*. (2001) found that the drag coefficient for these conditions is $4.4*10^{-3}$. Hence, the prediction from our simplified model has a relative error of about 36%.

ρ = 1026 kg/m^3

U = 0.30 m/s

L = 0.195 m

H = 0.106 m

$\Rightarrow D_{1\text{ side}} = 5.72*10^{-3}$ N

$\Rightarrow D_{2\text{ sides}} = 1.14*10^{-2}$ N (4)

The power required for the fish to swim at a speed of U = 0.30 m/s given the drag found in Eq. (4) is,

$$P = D_{2\text{ sides}}U \Rightarrow P = 3.43*10^{-3}\ \text{W} = 3.43\ \text{mW} \quad (5)$$

A good resource on boundary layer characteristics over swimming fish is:

Anderson, E.J., McGillis, W.R., and Grosenbaugh, M.A., 2001, "The boundary layer of swimming fish," *The Journal of Experimental Biology*, Vol. 204, pp. 81 – 102.