Order-of-Magnitude Physics – Problem Set 8

Problem 1. Hummingbirds

Estimate, using order-of-magnitude physics, the mass of the largest bird that can hover. Compare to the mass of the hummingbird.

Problem 2. Active Swimming

The figure on page 189 of McMahon & Bonner's *On Size and Life* (see Course Reader) plots speed v versus length l for "actively swimming" sea creatures (the lower curve; not the upper curve for "burst swimming").

Assume these creatures are isometrically shaped and can generate a power proportional to their mass to swim. Try to reproduce the observed scaling of v with l using order-of-magnitude physics. Consider both the case where the boundary layer is turbulent and the case where the boundary layer is laminar, and comment on which of these cases might hold for the creatures plotted.

Problem 3. Cost-Effective Swimming

According to Figure 2 of Tucker (1975, American Scientist, v63; class hand-out), the minimum cost of transport $\epsilon \equiv P/WV$ for fishes scales with mass as $\epsilon_{\min} \propto m^{-0.3}$. Try to reproduce this scaling by considering two contributions to the power requirement: the basal metabolic rate (BMR) and the power dissipated in drag. Assume that Kleiber's law holds even for cold-blooded fishes so that BMR $\propto m^{3/4}$.

Problem 4. Hurricanes

"The mature hurricane is an almost perfect example of a Carnot heat engine whose working fluid may be taken as a mixture of dry air, water vapor, and suspended condensed water, all in thermodynamic equilibrium. The engine is powered by the heat flow that is possible because the tropical ocean and atmosphere are not in thermal equilibrium. This disequilibrium arises because, thanks to the greenhouse effect, the ocean must lose heat ... to balance the absorption of solar radiation and back radiation from the atmosphere and clouds. The heat transfer is accomplished mostly by evaporation of water ..."—Kerry Emanuel, "Hurricanes: Tempests in a Greenhouse", August 2006 Physics Today

(a) Given an ocean surface temperature T_s and a hurricane air temperature T_o, derive an approximate formula for the wind speed of a hurricane. Clearly define all variables in your formula. (Please don't look up the Emanuel article for the formula—it takes all the fun out of the problem.)

(b) Hurricanes have low pressure cores. For $T_s - T_o \approx 50\,\mathrm{K}$, estimate the pressure in the core. Place your answer on the Saffir-Simpson Hurricane Scale: a Category 1 hurricane has a pressure < 980 millibars, while a Category 5 hurricane has a pressure < 920 millibars.

(c) Estimate a minimum depth of warm ocean water to maintain a typical hurricane.

Problem 5. Ask Your Own Question

Ask an OOM question of your own. You don't have to answer it.