GEOS 24705 / ENST 24705
Problem set #3
Due: Th. April 8

Problem 1: The person-engine

Some of the greatest power outputs of any humans are put out by professional cyclists. Lance Armstrong was capable of doing 400 W of mechanical work steadily for the course of an entire bike race. And biking is mechanically easy on the body – your joints don't wear out from pounding, so you can bike for many more hours than you can run. The length of bike races is limited in fact not by the legs' tolerance for the exercise but by the stomach's ability to take in fuel. It's hard for people to digest more than 10,000 Calories / day.

A. A Tour de France race averages around 5 hours (note that this is 5 hours hurtling along at 40 km/hour – you would take far, far longer). Assume that Lance puts out 400 W that whole time, and that as a person-engine his mechanical efficiency is 20% (i.e. the power he puts out as work is only 20% of the total power he needs to be taking in).

   What are his energy requirements for a race day (in J, or Calories)?

   Don't forget to add the amount a sedentary person would eat/day – he needs to keep his basal metabolism going too. And be precise with this calculation – don't do an OOM estimate.

B. If Lance can eat only 10,000 Calories per day, how much weight would he lose (kg of fat) each race day? Remember fat is ~ 9 kcal/g. Convert to pounds as well if you don't have a good sense for what a kg is.

C. If there were no rest days during an ~20-day Tour de France, how much mass of fat would Lance lose (in kg or pounds)?

D. If Lance is 165 pounds to begin with, and has 3% body fat, is this a safe amount of fat to lose?

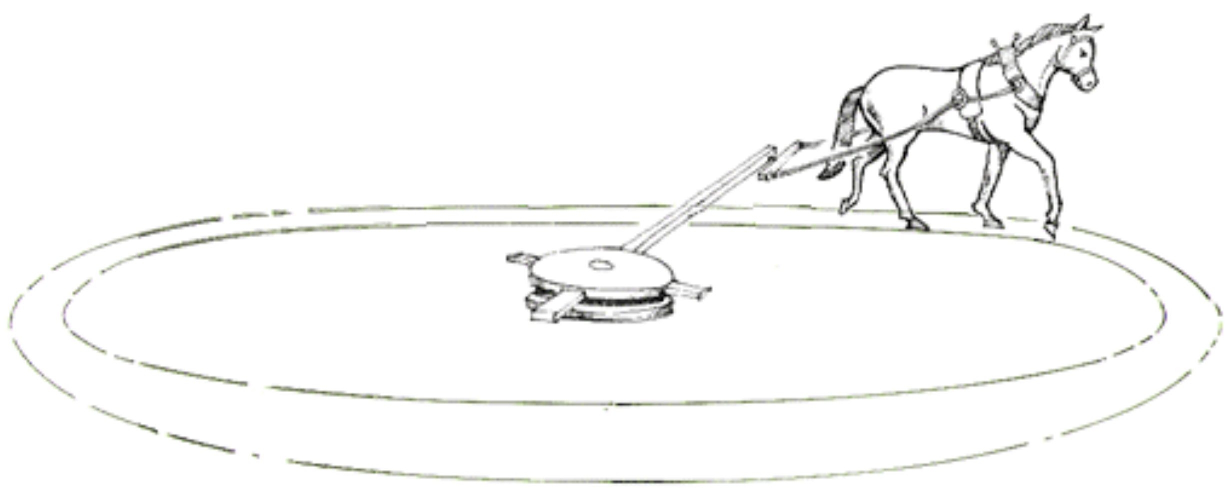
E. As race director you might conclude this is not safe. If so you need to assign some rest days. Assume that on rest days the riders can still eat 10,000 Calories/day and that they sit still or ride gently and recuperate. How many rest days must you schedule to ensure that everyone maintains a safe weight during the Tour?

F. Google – how many rest days are there on the Tour? Did you make the right choice?

Problem 2: The horse-engine and steam-engine

After James Watt invented the first really practical steam engine (patented in 1769, first functional production model in 1774), he was faced with the difficulty of marketing it to skeptical potential consumers who needed convincing why they should buy his product. Watt initially tried advertising his engines as improvements over older and less efficient Newcomen steam engines: he offered to sell an engine for 1/3 the savings in coal that the purchaser would realize over a Newcomen engine. Watt realized eventually though that the majority of his potential customers had never previously purchased any sort of steam engine. To reach these buyers he needed to compare his product with what they were currently using: the horse-engine.

Watt decided he needed a metric relating the mechanical work done by his new engine with that done by a horse. After some careful observations of horses in action turning gristmills and lifting coal up out of a mine, he codified a unit of "horsepower" in 1783. That definition allowed him to demonstrate to potential buyers how many horses his engine could replace. For example, the first rotative steam engine he made, sold to a brewer in 1785 as a replacement for a horse wheel, was billed as "10 horsepower".



In this problem you'll come up with your own estimate of the "horsepower", in our now-standard units of Watts (J/s). This class doesn't have a horse to observe, but we can start from an estimate of your own capability as an engine. Don't look up what a horsepower is til you've finished your estimate.

A. Estimate the mechanical work you could put out steadily during a workday, in the units we're comfortable with, Watts. (Don't average over 24 hours; just consider the time you're working). Think of the several demos in which you've measured your output power in W. Assume that you're in good shape and used to working. You do know that no matter how much you train you cannot match the output of Lance Armstrong, so your number will definitely be less than 400 W.

   (Optional, extra credit: You can check your answer by estimating the additional food you'd eat per day if you were physically active during whole workday, and assume 20% mechanical efficiency. Don't forget to correct for the fact that a "workday" is not 24 hours.)

B. Assume that since you're mechanically not so different from a horse, your power output per kg of muscle is probably equal to that of a horse. That is, both you and the horse have power proportional to mass. Estimate the mass of a horse. Then use that (and your own mass) to estimate the power output of a horse, in W.

C. Look at Braudel p. 337, at the quote from Forest de Belidor about the relative power output of man and horse. Is that estimate consistent with your answer in B?

D. Compare your definition of a horsepower with Watt's definition of horsepower. You can Google the answer. If you were off, explain what went wrong.

E. How many Lances would it take to replace one horse?

Note: Since Watt defined horsepower in 1783, some people have argued that he was overoptimistic about the capacity of a horse and that the average horse can't actually put out 1 horsepower of work, but instead can do only about 0.7 hp. Interestingly, Watt couldn't have been deliberately fudging his numbers – it would have been in his economic interest to undersell the capacity of a horse, not oversell it.