GEOS 24705 / ENST 24705
Problem set #5
All optional. Due: Tues. Apr. 17

Problem 1: Virtual field trips
We could visit non-working steam locomotives in the Museum of Science and Industry but have no opportunity to see in person a working steam engine. Take any or all of the virtual field trips below, though, by scanning through online videos, finding good examples, and describing what you see. Don't look at models – only working full-size engines. Give the URL of each video with your answer.

A. Compare and contrast **stationary engines**: an early stationary engine (1700s – very early 1800s) and a later one (late 1800s-early 1900s). (Stationary engines power mills and pumps and don't move). Describe similarities and differences. What was each engine used for? Estimate cylinder size. Look for things we discussed in class, including the speed regulator (a spinning device with two spheres). Does the engine have a flywheel, a large rotating wheel whose momentum smooths out the power delivery to the system being driven? With a flywheel, the engine dumps power jerkily on each stroke to the wheel, but the wheel then smoothly delivers power to the load. Describe the system that couples the pistons to whatever is being driven.

B. **Steam locomotives**: definitely an early steam locomotive (early 1800s – 1890s) since their moving parts are generally more visible, and (additional extra credit) compare to a later one (up to 1950s). The categories are easy to identify: the very earliest locomotives are very primitive looking, and the late-1800s ones have a characteristic V-shaped flared smokestack. The 20th century locomotives look more "modern" and more similar to modern trains.

   Look for the cylinders and pistons, the rods controlling the valves that let steam into the cylinders. Count how many wheels power is being delivered to. Estimate the size of the boiler. Identify (if you can) whether the locomotive is powered by wood or by coal. Identify emissions of smoke from the burning fuel vs. releases of steam. Identify and describe other features of interest (better description = more credit)

C. **Ship engines**. Unlike a locomotive engine, a ship engine was 'closed cycle' – steam was not vented but instead condensed and re-used, which both increased efficiency and saved on freshwater (no transatlantic ship could afford to carry the amount of water that would be vented as steam if powered by a locomotive-like engine). Ships also had to carry their own fuel for an entire voyage, so maximizing efficiency was a premium. Typically steam in a ship engine would pass through three successive cylinders, expanding and cooling slightly more in each one, wringing the maximum power out of the steam before it was recondensed. Google under "marine steam engine" or "ship steam engine" or "triple expansion engine". These are more compact, so it can be difficult to get a good view, but look for the three different cylinders (each with its piston), describe other features of interest.

Problem 2: Fundamental issues with steam engines

A heat engine operates by extracting mechanical work (W) while moving heat down a temperature gradient, from something hot (at a temperature T_h) to something cold (at T_c). Carnot derived the limiting efficiency (work out / heat in) for a heat engine as

$$\varepsilon = 1 - T_c/T_h$$

so the hotter an engine can be run, the larger its efficiency. By the early1900s, as you saw in the last problem set, steam engine efficiencies were reaching 25%, and therefore were running at very high temperatures. If steam is produced by heating liquid water, then the steam temperature is tied to steam pressure by the Clausius-Clapeyron equation (see steam handout).

A In practice, steam engines never actually achieved their Carnot limits. Assume that each engine's efficiency (at 25%) was only 1/2 its own Carnot limit. What temperature would the early 1900s engines then have to run at to achieve 25% efficiency?

B What is the boiler pressure in those engines? (Use the Clausius-Clapeyron equation). Give the result in atmospheres as well as in SI units. Remember that Newcomen and Watt could only hold 1 atmosphere of pressure differential in their boilers!

C If you somehow converted those engines to use an ideal gas as the working fluid rather than steam, and hold the same temperature (so that you have the same efficiency)… what would the pressure be in this case?

D Someone comes to you and offers to show you a new steam engine whose steam supply system line has a valve that shuts off contact with the liquid water in the boiler at 100 C and then continues heating the steam (so that it's superheated). What are the advantages to this design? What pressure does your engine have to be rated at now to achieve the efficiency above?

E Why didn't people design steam engines like this? (In practice steam engines were superheated a little, and steam turbines have a superheated stage now, but superheating is done only over short temperature range, not from 100 C onwards).

F The big question of this section: Why did the steam engine disappear relatively quickly after the invention of the internal combustion engine? The above questions should suggest one of the factors that led to their demise.