GEOS 24705 / ENST 24705 / ENSC 21100
Problem set #7
Due: Th. Apr. 19

Problem 1: Understanding limits on the efficiency of heat engines
Some reading to reinforce the lessons of Lecture 7 and the derivation of the limiting efficiency of a heat engine. This rule - $\varepsilon = 1 - T_c/T_h$ - is one of the great fundamental rules of physics so it is important to really understand it.

A. **"The Refrigerator and the Universe".** Read from 105 to the beginning of 116, up to "The Second Law and its Consequences". Write some comment that shows you have read the material.

B. **Carnot's original 1825 paper.** Read to end of page 4. Try not to be confused by Carnot's talking about "caloric" – make sure to read the part A reading first. When writing this, Carnot did not actually know what heat was – he thought it was some substance that he called "caloric". And yet he still managed to derive a physical law that is a foundation of thermodynamics! (Although his greatness wasn't recognized at the time; the scientific establishment ignored him and dismissed him as a 'mere' engineer.) Again write some comment that shows you have read. If you want to read further, on p. 6 he discusses whether one can construct an engine with a different "working substance" than steam.

C. *(Optional extra credit)* – Do any of the other reading and discuss.

Problem 2: Quick calculations of Carnot efficiency
Plug in numbers for several cases to get a sense for how real efficiencies compare to the limiting efficiency determined by Carnot. Remember that it is always possible to be *less* efficient than the maximum. The Carnot efficiency represents the best that you could possibly do for a given T_h and T_c, given a perfect engine that operated on the Carnot cycle. On any other engine cycle, the efficiency would be less even were the engine perfectly constructed, and of course the actual implementation of the mechanical device can introduce further problems. For example, we discussed how Newcomen's engine wasted heat in repeatedly heating and cooling the metal cylinder. In the questions below, remember that you need to express temperatures in the absolute temperature scale Kelvin. One degree Kelvin is the same increment of temperature as one degree Celsius, but the Kelvin scale starts at absolute zero, so 0 Celsius is ~273 K.

A. **Newcomen's and Watt's atmospheric engines.** Since this engine uses steam at one atmosphere, the temperature of that steam must be just at the boiling point, or 100 C. (Read the handout on steam if this is confusing). How close did Watt get to the ideal efficiency?

B. **An advanced gas turbine.** See article here (http://www.mhi.com/news/story/1105261435.html) on a new turbine intended to withstand higher temperatures, which means it can achieve higher efficiencies. From the article (just skim), what is the temperature of this turbine? What is its claimed efficiency? Calculate: what would the efficiency be if it reached its Carnot ideal? *(Note that the efficiency claim is for use in a "combined cycle", which we'll discuss later in class; for now just realize that this is an appropriate configuration to compare against the Carnot upper limit.)*