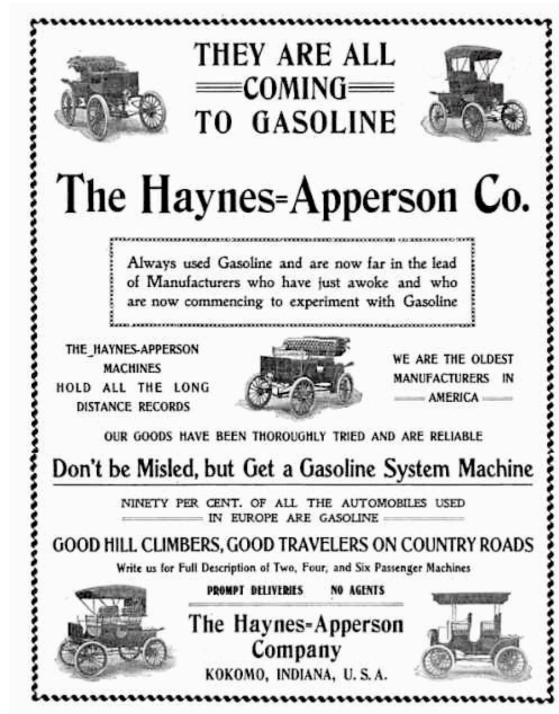
GEOS 24705 / ENST 24705
Problem set #18
Due: Tues. May 29th

Problem 1: Automobile history virtual tour

Take a virtual tour through the early history of the automobile in the U.S.

A. Look through the history of autos here:
http://earlyamericanautomobiles.com/1900.htm

(Be warned, the site has some broken links.) Pick two different time periods and read the relevant pages, and describe some features of the auto's evolution. Consider factors such as: how do you steer, where is the engine, how are the wheels suspended, etc. Note the larger diversity in the early years, both the number of companies and range of technologies, which include external-combustion steam and electric. The early years are full of relatively short-lived companies you've never heard of.



B. Read the story of two early (1895) automobile races in the U.S. Start from where it reads "Automobile Racing"
http://www.earlyamericanautomobiles.com/timesrace1.htm

These races were like technology trials, coming only three years after the first U.S.-built car and only 10 years after Bertha Benz' demonstration test drive. The second race started just outside U. Chicago, and students left their football games to watch:

The streetcar lines from the west and north and south brought all the "rooters" to the route of the motocycles. The colors of Michigan and the University of Chicago, of Boston and the Chicago Athletic Association lent brightness, if that were possible, to one of the brightest Thanksgiving mornings Chicago has ever seen. People did not mind standing in the yielding snow…Passing through the groups gathered here and there it was surprising to hear the scientific discussion going on as the merits of motorcycles and the eventual good they were to work in urging forward the "good roads" problem of America.

C. Watch this episode of Jay Leno's Garage about the steam (but gasoline-powered) 1925 Doble, an extremely modern and high-powered example of this technology. Watch through 5:00, then it's OK to skip around. For extra credit compare to a video of a 1906 Stanley Steamer at
https://www.youtube.com/watch?v=5Me8b0ed59s

D. *(Optional)* For extra credit, read and discuss the posted article wishing for a resurgence of steam.

E. *(Optional)* For extra credit, watch a 1906 film shot in San Francisco days before the earthquake, (note: the sound is 'fake' and added later) https://www.youtube.com/watch?v=8Q5Nur642BU and read a Chicago Tribune article describing the 1895 race and the early history of automobiles in Chicago. Discuss and comment on the integration of automobiles and other street users.
http://www.chicagotribune.com/news/ct-chicago-auto-show-early-cars-flashback-0208-jm-20150207-story.html

Problem 2: Automobile tour

Find an automobile and take a look under the hood. Take photographs and identify and label as many parts as you can. Also state the make and model of the car, the year if possible, and how you got access to it.

Everyone should muster the resourcefulness to find a car to inspect, even if you don't own one. Googling is fine – encouraged – to understand what you are seeing or what you should expect to see. (There are some good diagrams of systems in the automobile at http://www.sundevilauto.com/auto-diagrams). However, do not submit digital photographs taken by someone else, not to mention stock advertising photos from the web. You have to go look with your own eyes.

Note that old cars are generally easier to understand than newer cars (though often dirtier). For extra credit, find a newish car and an old car and compare them. Hybrids are very complicated – you can do a hybrid if it's the only thing you have access to, or for extra credit, but it's best to start by looking at a conventional car.

Please do not feel obliged to crawl underneath a car; what you can see from the top is fine for this problem set. If you do want to crawl underneath, make sure that you have first set the parking brake AND also "chocked" the wheels to prevent inadvertent rolling.

Try to identify something from each of the areas below. If you think the car does not actually have some component, explain why you think it does not. If you can't find something in a category, explain where you looked for it. Extra credit for extra systems or for going over and above in identifications.

A. **Engine block** – how many cylinders does the car have? Are they vertical, horizontal, or in a V? Remember that for a four-stroke engine, each cylinder will have two valves.

B. **Ignition system**. Identify the spark plugs that ignite each cylinder, and find the distributor cap that sends electrical signals to the spark plugs. (Recent cars may not have this). The distributor cap should in turn be connected (eventually) to the battery that is providing power for the spark plugs.

C. **Air/fuel system**. The air that gets mixed with the fuel comes from outside the car. It is piped in through large tubes, passes through an air filter, and is distributed evenly to each cylinder via an "intake manifold". The air filter enclosure should be accessible and readily visible as you have to change filters frequently. Fuel is added before the air enters the cylinder. In a pre-1990 gasoline car, air and fuel are mixed in a flying-saucer-shaped carburetor sitting on top of the engine. Modern cars all operate by fuel injection; you should be able to identify the fuel injectors and the fuel lines that feed them. If you have a turbocharged car, you'll also see a compressor that pre-compresses air before it enters the cylinders. The rest of the fuel system is typically quite difficult to see, but trace the fuel lines as far as you can.

   Somewhere buried way down there is an (electric) fuel pump that moves fuel from your gas tank to the engine; this will be underneath your car at best and possibly actually inside the gas tank.

D. The **electrical system** of the car, which includes a battery and an alternator (a generator) turned by the engine's rotation that makes electrical power to charge the battery. (There is a picture of an alternator in the first electricity reading – car alternators are usually simple AC generators, with their output rectified to produce DC for the battery). The belt connecting the alternator to the engine should be visible from above, and you should be able to find and identify the alternator. There is an electric starter motor that turns the crankshaft when you are first getting your engine started, but this is likely impossible to see.

E. The **cooling system** for the engine – if 75% of fuel energy is coming out as waste heat, then something has to remove all that waste heat! The cooling system consists of tubes and hoses that circulate water (or other coolant fluid) around the engine cylinders, a radiator that lets the hot fluid cool off, a fan to blow air around the radiator, and the fan belt that uses the rotation of the engine to turn the fan. There is a water pump that circulates cooling fluid but that is usually difficult to see from above.

F. The **lubrication system**. At minimum you'll be able to find the "dipstick" that goes into your oil reservoir and lets you check the oil. The oil pan containing the oil might be hard to see. The oil pan is often the lowest part of the car's engine assembly (and therefore the first thing to break if you drive over rocks or other obstacles that are too high). The oil filter is accessible, since you have to change it periodically, but it is likely only visible if you crawl under the car. (Read caution above if you want to try this). There's an electric pump to move the oil around, either in the oil pan or attached to it; again, generally not visible.

G. *(Optional)* The **transmission** that connects your engine's rotating crankshaft via gears to the front axle (for front-wheel-drive cars) or to the driveshaft and rear axle (for rear-wheel-drive cars) is typically hard or impossible to see from above. You may be able to identify if your car is front-wheel or rear-wheel or all-wheel drive, though.

H. *(Optional)* If you are looking at a hybrid car, identify the electric motor/s and the generator that charges the battery (which will be much bigger than the little alternator on conventional cars).

I. *(Optional)* Measure the mismatch between engine speed and wheel speed, and the necessary gear ratio of your transmission for its various gears. You can measure this by taking a test drive and noting the linear speed you are driving in a certain gear along with the engine rotational speed (in revolutions per minute or rpm) on your odometer. You can convert the car's linear speed to the rpm of the wheels if you measure the wheel diameter. The ratio of those rotational velocities is your "gear ratio". Determining your gear is easy if you have a manual transmission; if you have an automatic transmission, try listening for the gear changes as it shifts and count which gear you are in. Some modern automatics have "continuously variable transmissions" that does not have a mechanical system that produces a fixed set of gear ratios.

Note: while you are doing your auto tour you may want to measure the cross-sectional area of the vehicle (if it's not a big truck) for Problem #3. Just take a tape measure and measure the width of the vehicle and its height from bottom of bumper to roof.

Problem 3: Energy losses in automobiles / predicting fuel economy

Background: Where does the chemical energy of the fuel you burn in your automobile go? When you think about it, it's not immediately obvious that you'd need to keep the engine on once you get a car up to speed. Of course you need to apply power to the car to accelerate it up to speed -- you're adding kinetic energy. Or if you go up a hill, you're adding potential energy. But once the car is at cruising speed on flat grown, its kinetic and potential energy are constant. Why do you then need to keep burning fuel to apply mechanical work to the engine? In the absence of losses of energy, that would seem to force your car to continue accelerating.

The answer is, your car is constantly experiencing losses of energy. Moving metal parts scrape against each other, losing energy to friction. (You lubricate parts with oil to minimize this, but you cannot make frictional losses zero.) As the car moves, it must push air ahead of it, giving some of its kinetic energy to the air ("air resistance" or "aerodynamic drag"). And the wheels deform on contact with the ground and so scrape along it and lose energy as they roll. (We call this "rolling resistance"; you could avoid it only if you had perfectly round, perfectly stiff wheels that made perfect contact with the ground at a single point.) Of course in city driving you would also be losing power every time you brake and then accelerate back up to speed again. You need to continue drawing power from your engine to compensate for all these ongoing losses.

There is also an amplifying factor: your actual power draw is significantly more than the losses of kinetic energy. The thermodynamic efficiency of a car engine is typically only around 25%. Since you throw ¾ of the chemical energy in fuel away as waste heat, you need to burn fuel equivalent to 4 times as much power as the car is losing to friction.

Side note: we use the terms 'fuel economy' or 'fuel efficiency' to describe the amount of energy a car uses in driving, but the term 'efficiency' is deceptive. Fuel usage differences aren't mostly due to differences in the thermodynamic efficiency of engines. It's just that heavier, blockier, and bigger cars necessarily require more work to keep in motion. Similarly, driving any car uses more energy than a motorcycle. Calling this 'waste' is a statement of values as much as physics.

In typical average driving for a small car, the energy losses in driving are split fairly equally between braking, rolling resistance, air resistance, and frictional losses. The slides posted online help walk you through the formulas for air resistance and rolling resistance. You may want to read also the posted document "Air_and_rolling_resistance.pdf" for the physics.

Despite improved engineering of automobiles, fuel economy – the amount of energy needed to drive some distance – remained almost flat for decades. You can see this in slides & in this table (https://www.bts.gov/content/average-fuel-efficiency-us-light-duty-vehicles) from the Dept. of Transportation. Cars became more streamlined in profile, reducing their air resistance, but they also became heavier, and both rolling resistance and the power needed to accelerate scale with the car's mass. Similarly, though engine technology has improved, reducing engine losses, we also demand that cars deliver higher performance, so cars are no longer optimized for the kind of driving they actually do. Most technological improvements since the 1970s were thus counteracted by driving heavier and more powerful vehicles. Only in recent years, since new fuel economy standards were imposed, have fuel economy numbers begun to creep up.

In this problem you'll first estimate the energy losses in driving, and compare them to the real fuel economy. The point is to understand that you can predict fuel usage from first principles.

Problems:

Assume that you have a middle-of-the-road new car for some reasonable year (state it). Pick its fuel economy from the DOT table. Pick a coefficient for drag C_d and rolling resistance C_{rr} from the figures in the handout on air and rolling resistance. (Note: the drag coefficient is called Cw here, not $C_{d.}$.) Use a C_{rr} is consistent with estimates on the slides, assuming that a highway surface is closer to concrete than asphalt. Make reasonable estimates of car weight and size.

A. State your assumptions, but increase the fuel economy a bit to reflect highway driving.

B. As a reality check, compute your gasoline consumption in gallons per hour if you are driving at 55 mph. Is this consistent with your experience driving, i.e. how many hours you can drive before you have to stop to refill your tank?

C. Now use your knowledge of the energy density of gasoline and convert units to state the car's total power consumption in W (or kW).

D. Divide the power by ~4 to get the mechanical work that the engine puts out, in W, assuming a 25% efficiency. This value should account for your losses to friction, drag, and rolling resistance.

E. Compute your power loss to rolling resistance at 55 mph, in W or kW.

F. Compute your power loss to aerodynamic drag at 55 mph, in W or kW.

G. Assume that internal friction is comparable to air and rolling resistance. Add up your values in E, F, and G to get your total losses. Then compare to your prediction of mechanical work in D. Are they similar? Now either 1) compare to your total power consumption in C and estimate the actual thermodynamic efficiency of the engine, or 2) compute the fuel economy for your hypothetical car in mpg. Is your comparison reasonable?

Optional problems for #3

H. *(Optional)* Convert the mean power consumption in W to horsepower. Compare to the stated "engine horsepower" of an automobile, the power that the engine can provide. (See slides). Are they the same? Discuss.

I. *(Optional)* By how much is your power consumption increased if your speed is 80 mph instead of 55 mph? (This difference is why you're advised to drive as slowly as possible if you are low on gasoline – aerodynamic losses scale as v^3.) While driving slowly reduces mainly your drag losses, remember that your rolling resistance losses also depend on v.

J. *(Optional)* The U.S. 55 mph speed limit was set in 1974 by Congress as part of the Emergency Highway Energy Conservation Act, intended to reduce gasoline use after the OPEC oil embargo. Based on your answer in J, this a plausible way to reduce our dependence on foreign oil? Repeat your calculation of J but using a drag coefficient more appropriate for 1974. Does the 55 mph speed limit make more sense now?

K. *(Optional)*. As you reduce speed, aerodynamic losses become sharply less important. At what speed do they become smaller than rolling resistance losses?

L. *(Optional)* How fast can a Boxster drive before it exceeds the aerodynamic losses of a Hummer driving at 55 mph? (See slides for drag coefficients.)

M. *(Optional)* Formula One racing cars are intended to go very fast, in races where fuel consumption matters, but they don't act like Boxsters – instead, they have ***high*** drag coefficients between 0.7 and 1. Aerodynamically they seem more "blocky" even than Hummers. Presumably this is a deliberate design choice (and the engineers are good). Why was it chosen?

N. *(Optional)* Formula One cars not only have a high C_d but also have high rolling resistance (see figures below). Tires for racing bikes, on the other hand, are designed for low rolling resistance. These must be rational choices, but why? Discuss the factors that led to these opposite choices for bike racing vs. auto racing.

Michelin Pro3 Race tire, 116 psi

Pirelli PZero Formula 1 race tire: ~15 psi

O. *(Optional)* Go to a Metra station and observe the sanding that provides enough friction to let the train start. Photograph the sanding system in action if you can.

Problem 4: Virtual tours of fossil fuel extraction

The modern "pumpjack" looks somewhat like an early Newcomen or Watt engine:

L. Pumpjack, R. Watt's "Old Bess" engine, both used for pumping liquids

Both actually use similar pumps. But, in the steam engines, the cycle time of the engine was the same as that of the pump – the piston connected directly to the rocker beam. The pumpjack is driven by a high-speed diesel engine, so it needs complicated gearing to allow the beam to rock much more slowly than the engine pistons are oscillating.

A. Read the oil and gas chapter of the Hayes book, which covers not only drilling but also distribution (pipelines), storage, and refining. Comment on something interesting about each of these aspects. Estimate (and explain your estimation): when you pump gasoline into your car engine, how long ago were those hydrocarbons oil in the ground? Also read through the slides on the history of natural gas, that we did not finish in class.

B. Watch the video here on the "sucker rod pump" used in oil wells. What reminds you of the older lift pump? http://www.youtube.com/watch?v=SFJFiyXTOa0

C. Watch the video here on the pumpjack's gearing system and explain how the 1200 rpm rotation of the engine is downconverted to the speed of the pump. (What is that speed?) http://www.youtube.com/watch?v=FU0dYV3LvAk&feature=related

D. Watch these fracking videos, first on drilling the wells… http://www.youtube.com/watch?v=fBQCQ6HL2Yw

E. ..and then on the fracking process itself, and comment on something interesting. Both videos are by a drilling company so obviously are positive on safety issues. http://www.youtube.com/watch?v=7ned5L04o8w

F. Watch this time-lapse video of the drilling and completion of a fracked well and discuss something interesting: https://www.youtube.com/watch?v=6_j7UkuzJTU

G. For extra credit, watch the Oscar-winning movie "There Will be Blood", about the early oil industry in California. (Trailer here: https://www.youtube.com/watch?v=FeSLPELpMeM). Discuss. This movie is loosely based on the 1927 Sinclair Lewis novel "Oil!"