

GEOS 24705 / ENST 24705

Problem set #16

Due: Tues. May 25

### **Problem 1: Automobile tour**

Find an automobile (your own, a friend's, a passing stranger's) and take a look under the hood. Take photographs (or make sketches) and identify and label as many of the following parts as you can. If you think the car does not actually have the component mentioned, explain why you think it does not. If you absolutely can't find a car to inspect, do an optional problem instead.

Extra identification of car parts is welcomed beyond those suggested here. For extra credit, find a newish car and an old car and compare them. You will likely find the older car much more understandable. Please do not feel obliged to crawl underneath a car – this problem set is about what you can see from the top – and even if you want to, do not do so unless you have first “chocked” the wheels to prevent inadvertent rolling.

- A. Engine block – how many cylinders does the car have? Are they vertical, horizontal, or in a V?
- 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.
- 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. You almost certainly can't see it.

- 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. The electric starter motor that turns the crankshaft when you are first getting your engine started is likely hard to see.

- E. The cooling system for the engine – something has to remove all that waste heat, if 75% of fuel energy is coming out as 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 the first thing to break if you drive over rocks or other obstacles that are too high, leaving you stuck in whatever rough road you were foolish enough to take). The oil filter is accessible, but from underneath the car; 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 too to move the oil around, either in the oil pan or attached to it; again, generally not visible.
- G. The transmission that connects your engine's rotating crankshaft via gears to the driveshaft or front axle (for front-wheel-drive cars) is typically hard or impossible to see from above.
- H. If you have a hybrid car, identify the electric motor and generator.

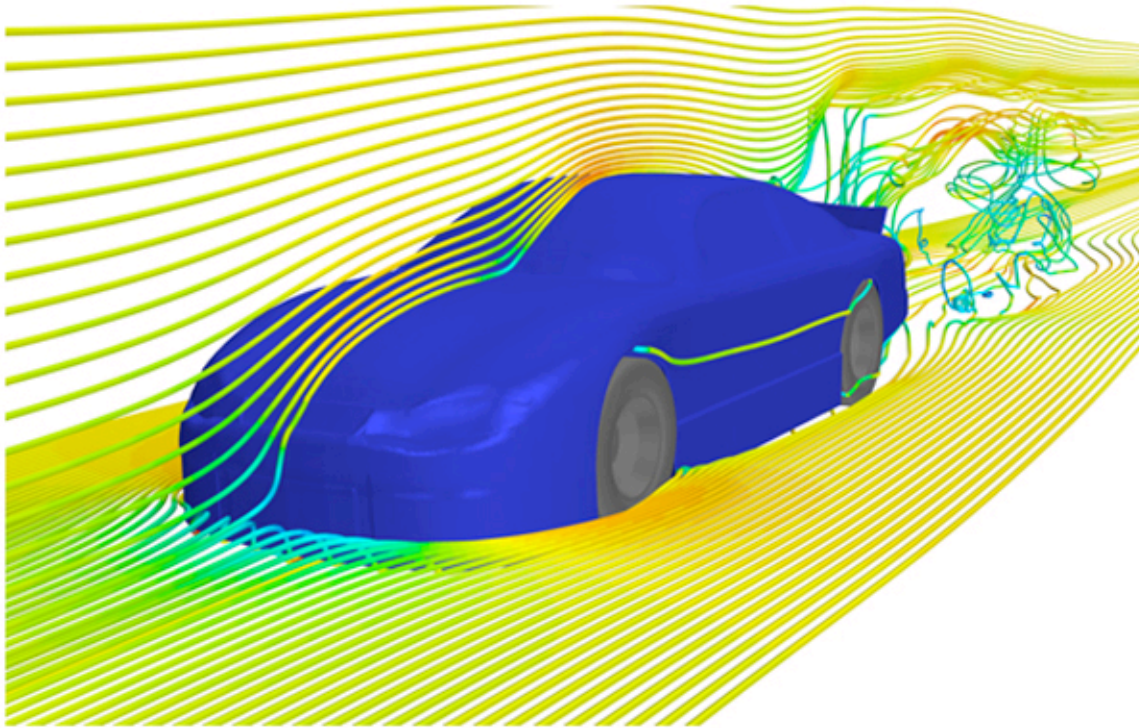
## Problem 2: Air resistance and fuel economy

A wind turbine *extracts* the kinetic energy from a stream of moving air, slowing the air down in the process. A moving car does the exact opposite of a wind turbine – it bumps into stationary air and *gives* it kinetic energy, speeding it up as it is pushed ahead of the car. Because energy is conserved, the car has to give up some of its own energy to the air to get the air moving. "Air resistance" or "aerodynamic drag" is therefore one of the important energy losses involved in driving.

You have already computed the kinetic energy / time carried by a flow as  $\frac{1}{2} \rho A v^3$ . It would be reasonable to guess that a car with cross-section  $A$  had to exert this much energy/time to push air ahead of it. But the shape of the car matters – the more streamlined the car shape, the more easily the car can slice through air without disrupting it. The drag losses of a car are then given by

$$L = \frac{1}{2} \rho A v^3 C_d$$

where  $C_d$  is some coefficient that depends on the car shape, that can range between 1 (maximum possible energy loss) and zero (the car does not disturb the air at all). A boxy car will have higher  $C_d$ , a sleek car lower  $C_d$ . (A Hummer is  $C_d \sim 0.59$ , for example, while a Porsche Boxster is 0.29). The Porsche has low  $C_d$  not because its designers wanted to be super-green – in fact, sports cars aren't very fuel efficient – but because the  $v^3$  dependence means that aerodynamic drag matters much more at high speed. Porsche's 1900 car could be upright and square because it went slowly, but the fast Boxster has to be sleek not to have unacceptable energy losses. Electric cars, which are fuel-limited since batteries are so heavy, also try to keep  $C_d$  low so that their fuel economy is as good as possible.



Regardless of your car shape, you obviously reduce your aerodynamic losses if you drive more slowly. (That  $v^3$  dependence means that fast is bad for gas mileage). The 55 mile-an-hour speed limit common across much of the U.S. was imposed in 1974 via the Emergency Highway Energy Conservation Act specifically to reduce gasoline usage – it was a response to the 1973 oil crisis when OPEC imposed an oil embargo on the U.S., prices spiked (as you saw in lecture), shortages led to empty gas pumps, and the U.S. suddenly realized we were dependent on foreign oil.

In this problem, you'll decide whether the 55 mph speed limit was a practical way of reducing our dependence on foreign oil.

*Assumptions: you can assume you have a normal, middle-of-the-road car, with  $C_d \sim 0.35$  and an overall fuel economy of  $\sim 22$  miles per gallon.*

- A. Compute your total rate of energy consumption (J/s, or W) if you are driving at 55 mph. *Hint: You know the energy content per gallon of gasoline (PS1), and you know how fast you're going.*
- B. Compute your rate of energy loss to aerodynamic drag at 55 mph.
- C. What fraction of your gasoline consumption goes to aerodynamic drag?
- D. Compute what the rate of loss to aerodynamic drag would be at 70 mph.
- E. What fractional change in gasoline consumption per mile results from driving 70 mph instead of 55 mph?
- F. Was the Emergency Highway Energy Conservation Act effective? (This is something of a judgment call, of course, because every bit of conservation matters, and regardless of energy conservation, going slower was a benefit in terms of reducing highway deaths).

- G. (*Optional*) How fast can a Boxster drive before it exceeds the aerodynamic losses of a Hummer driving at 55 mph?
- H. (*Optional*) From aerodynamics alone, how much worse is the gas mileage of a Hummer than that of a Boxster, if both are driven at 55 mph? Assume all else about the cars is equal. (In practice other factors also make the Hummer less efficient).
- I. (*Optional*) Formula One racing cars are intended to go very fast, in races where fuel consumption matters, but have drag coefficients close to 1 – that is, they seem more “blocky” even than Hummers. Presumably this is a deliberate design choice (and the engineers are good). Why was it chosen?
- J. (*Optional*). Aerodynamic losses are only one of the many factors that cause cars to burn fuel. In class we discussed four factors downstream of the engine: frictional losses in gearing and bearings, braking (so that you need to replace that lost kinetic energy when you later accelerate back up to speed), aerodynamic drag, and rolling resistance. The last factor is the loss that occurs as the wheel contacts the road. You have probably experienced rolling resistance losses in a visceral way if you’ve ever ridden a knobby-tired mountain bike and tried to keep up with someone on a racing bike with skinny tires – life feels very unfair then, because you have to do much more work to maintain the same speed.

Think about energy loss to rolling resistance. Write down all the factors it’s likely to depend on. (Does it depend on speed, for instance?). Decide if those factors should be raised to some power or not (e.g., speed or speed squared or cubed?). Throw in a coefficient (call it  $C_{rr}$ ), and combine everything together to write your made-up equation for energy/time lost to rolling resistance. (You will probably get it right, just from thinking from your gut). Does a Hummer have greater rolling resistance than a Boxster?