16.682: Technology in Transportation - Pset #2

Issued: Wednesday, February 16th, 2011
Due: Thursday, February 24th, 2011

Topics Covered: Thermodynamics
Internal Combustion Engines
Road Vehicle Engineering

1: Engine Tuning

As shown in class, the ideal Otto cycle is depicted in this diagram:

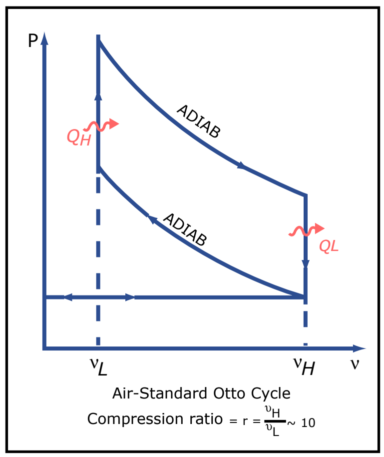


Image by MIT OpenCourseWare.

The actual 4-stroke Otto cycle (if you were to put a pressure sensor in the cylinder) looks more like this:

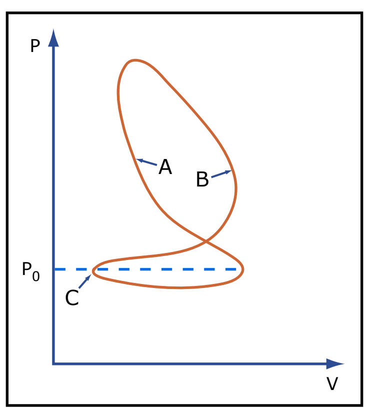


Image by MIT OpenCourseWare.

Label the actions that are occurring in the engine at points

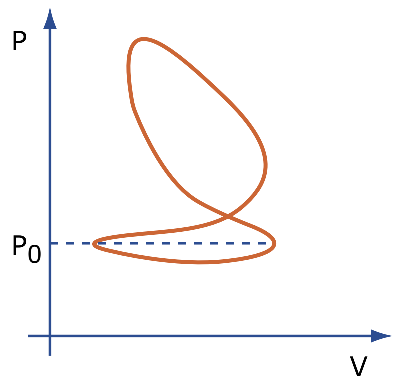
A)

B)

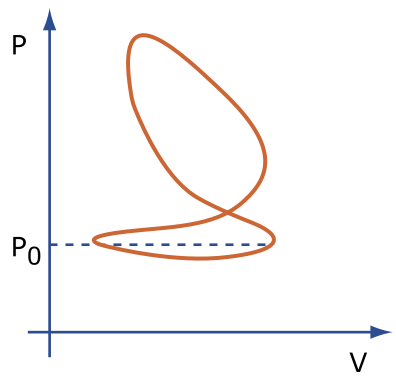
C)

The amount of energy that an engine outputs is proportional to the area of this "box" in the ideal engine cycle. Given what you know about engine cycles, draw the modified PV diagrams (sketch which way each part of the graph would move) for how each of these features impact the cycle:

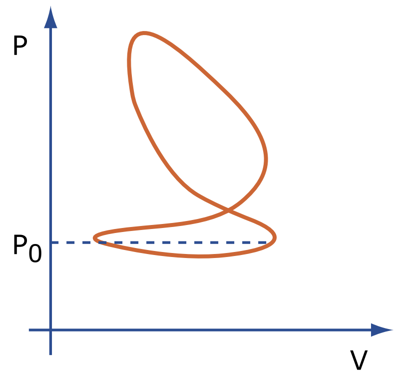
1. Supercharging (forced induction)



2. Optimal valve timing, intake and free-flow exhaust (reducing engine "breathing")



3. Boring out an engine (increasing its displacement)



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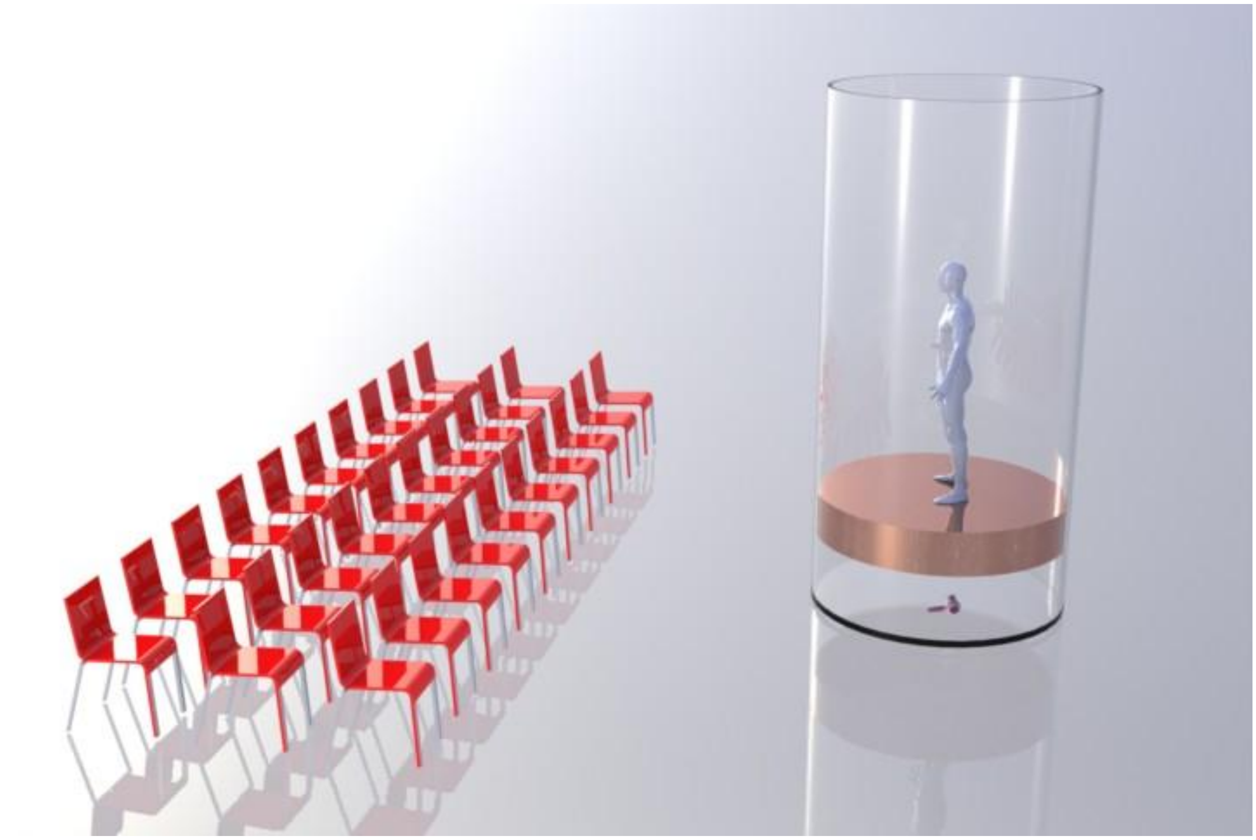
2. A New Elevator:



After Thursday's (2/3/2011) lecture, you left the classroom in an entrepreneurial mood, thinking "man, that simple piston engine example was spectacular – why don't all elevators work that way? They'd be smooth, safe (no cables to break) and Carnot says it has the potential to be really efficient. I could patent it, license it to an elevator company and collect millions while I'm sunbathing on my yacht". So you decide to pursue the concept further . . .

You model the elevator as a cylinder with a 2m internal diameter, where the 200-lb elevator passenger stands on a 50-lb, frictionless, perfectly sealed piston. The gas (Nitrogen) underneath it is heated by a 1,500 watt hair dryer, and the platform comes to rest in the lower position leaving a 0.5m air gap. The platform displaces a total of 4m to bring the passenger to the next floor (before getting more complicated with multi-floor elevators, you test out the concept with a single floor).

Initially, the pressure and temperature of the nitrogen are 101.679kPa and 298K. Assume that the piston is adiabatic and that the cylinder is perfectly insulated on all sides. The individual gas constant for nitrogen is 297 J/kgK and its specific heat capacity at constant pressure is 1.04 kJ/kg K. Assume that ambient pressure is 101.325kPa absolute outside of the cylinder.

a) What is the mass of the contained nitrogen gas?

b) What is the total heat capacity of this gas?

c) At what temperature must the gas be to support the elevator in its top position?List a few materials that the cylinder and piston could be made from, which could support this temperature.

d) How much energy was required to move the elevator one floor up? How does this compare to the gravitational potential energy gained by the passenger and piston?

e) How long did the hairdryer have to be on to do this? (assuming the heating element can reach the temperature in part c and nothing melts).

f) Is this an efficient way of moving people?

g) Has the entropy of the system changed during this transition? If yes, what is the change in entropy? (See constitutive relations for ideal gases)

h) If we could complete the heat cycle of this "simple engine" by cooling the nitrogen in order to bring the passenger back down, what would the P-V diagram look like? Draw it and make sure to label where the passenger is at each corner of the graph, as well as where heat is transferred into the system and rejected.

i) Aside from the concerns noted above, list 3 more practical problems for effectively implementing such an elevator system.

3. Data Sheet Interpretation:

The following is a torque/speed curve of a motorcycle engine, pulled from a dynamometer run. What happens in these tests is that the throttle is held wide open while the dynamometer roller (a large rotating mass, moved by the force of the rear wheel) accelerates. The moment of inertia of this roller is known and its speed can be measured very accurately (yielding a corresponding acceleration/input torque). Extract as much information from this graph as possible. Reference image: Motorcycle.

a) What is the stoichiometrically correct (book value) ratio for burning fuel in air, by mass?
   a. Gasoline
   b. Diesel
   c. Ethanol
b) The red and blue curves are from two separate runs (tests). Relate the differences in between the two runs to the air/fuel ratio chart below it (this is measured with a sensor in the exhaust stream). This engine burns gasoline.
   a. What happened in the blue run at about 4,500 RPM? Why did the torque dip correspondingly?
c) Why is the torque curve on the blue run more jagged than in the red run?
d) What is the optimum efficiency point of this engine? Use the red run in this calculation and assume that the air/fuel ratio stays constant for the entire run. Why does the engine run most efficiently at this point? Hint: in this scenario, fuel consumption is directly proportional to engine RPM.
e) The motorcycle engine in this problem has a swept volume of 865cc. What is the efficiency of this motorcycle drivetrain, when operating at the RPM in part c?
   a. Consider the air burned by this engine with each revolution. What is its mass?
   b. How much gasoline is burned with this amount of air? What is its energy content?
   c. What is the work done by each revolution of the shaft?
   d. State the efficiency as a percentage of energy in to mechanical energy out.
f) Say you transplanted this drivetrain into a Hummer H2 that requires 45 horsepower to maintain a speed of 60mph.
   a. Would you expect the Hummer to get worse or better gas mileage (at this highway speed) with the new drivetrain?
   b. If different, why so? Name two key differences between the operation of a 393 horsepower V8 (stock engine) and the motorcycle engine at the 45 horsepower output level.

4. Vehicle Traction (Based on Examples in Chapter 1 of *Chassis Engineering* by Herb Adams)

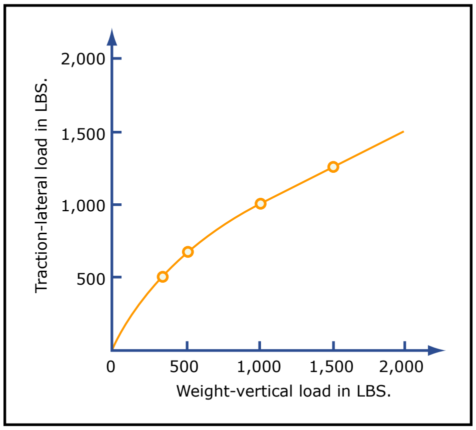


Image by MIT OpenCourseWare.

Chassis Engineering by Herb Adams

In this problem, we will investigate basic vehicle traction principles. The most important vehicle components when it comes to traction are the tires, since they are the only actual interface between the road and the car.

The figure above is a tire performance curve, which illustrates the nonlinear relationship between vertical load on a tire and available traction. As the vertical load on this tire increases, it's cornering efficiency decreases. Assume all vehicles in this problem are using tires that can be represented by the above curve.

a) We are entering a ¼ mile drag race in our small, home built racecar. Assume our vehicle is 1800 lbs and has a single driver who weighs 200 lbs. The vehicle has an even weight distribution between front and the back, and the driver's presence does not change it. What is the max acceleration our vehicle can attain without losing traction (in terms of g's)? What would this translate to in terms of a ¼ mile time (assume traction is limiting factor, not top speed)?

b) We are now racing a heavier, 3000 lb vehicle around a circular race track. As the car turns (going counterclockwise), there will be a lateral weight transfer from the left to the right side of the vehicle. Use the following simplified formula to determine the weight transfer we would expect with a 1 g cornering force, where 'W_{car}' is the weight of the car, 'a' is the cornering acceleration in g's, 'h_{cg}' is the height of the center of gravity in inches (assume 20 inches), 'g' is gravity, and 'l_{track}' is the vehicle track width (assume 60 inches).

$$W_T = \frac{W_{car} * a * h_{cg}}{g * l_{track}}$$

Determine the traction that each wheel is able to maintain after the weight shift. What cornering force (in g's) does this equate to? How does that compare to the traction available to this vehicle on a straight track?

c) Understeer and oversteer are important concepts to understand, and they can be explained by vehicle weight distribution. Assume we have the same vehicle as in part (b), but this time with a

60-40 weight distribution front to back. Assume the vehicle enters a turn and experiences approximately the same weight transfer as in part (b). How much traction is available for the front and rear wheels now? Will the car understeer or oversteer? Why?

d) If you were a racecar driver (circular track) and you had a fixed 60-40 front-rear weight distribution but could add a lateral weight bias of up to 20%, what would you do to maximize the cornering performance of your vehicle? What would your max cornering acceleration be in this case?

16.682 Technology in Transportation
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