ECE 398GG Prof. George Gross

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Homework 1 Solution

1. **State** the reasons why a typical tractor-trailer combination consumes nearly ten times as much energy per unit distance as a typical passenger car. **Describe** steps that may be implemented to reduce the multiples of energy consumption by the tractor-trailer combination.

Such vehicle combinations are larger in every sense – heavier, with a larger frontal area – and thus entail much higher drag. For instance, with a 4 x larger frontal area and a 3 x higher drag coefficient, the drag force becomes 12 x higher. Many such vehicle combinations spend a larger fraction of driving time in a highway cruising mode, which uses much more energy than in-town driving. The extra mass of the combination intensifies the impacts of roads with small slopes and those of small changes in acceleration.
What can be done? There is a lot of work on fairings and shape changes to give trucks/tractors more streamlined aerodynamical forms. The heavier, longer trucks – with multiple trailers – use less energy in proportion to the length of the combination.

2. To explore the impact of drag on a vehicle, **consider** a passenger car with a frontal area of 2.5 m^2 that cruises at 75 *mph*. **Determine** the ratio of the energy consumed by this car with a drag coefficient of $C_d = 0.32$ to that with $C_d = 0.21$.

Since the question is "how much more energy …" aspects such as vehicle mass and tire resistance may be taken to remain unchanged. Although drag force (and power) rise with the cube of velocity, the force varies linearly with the drag coefficient. This means the drag force will be 0.32/0.21 = 1.52 times higher. To make it easy, put in some numbers (2000 *kg*, $R_t = 0.008$, etc.). The traction force at 75 *mph* is 696 *N* when $C_d = 0.32$ and 511 *N* when Cd = 0.21. The power is 23.4 *kW* at $C_d = 0.32$ and 17.1 *kW* when $C_d = 0.21$. Over one second (same distance travelled), higher drag consumes 23.4 *kJ* and lower drag 17.1 *kJ*. The difference is 6.2 *kJ*. The car with higher drag consumes 6.2 *kJ* more energy every second, 22.4 *MJ* more each hour, and 0.30 *MJ* more each mile, *i.e.,* 83 *Wh* more per mile.

3. Many vehicle designers recommend that the share of the mass of the batteries be, at most, 30 % of the total vehicle mass. Consider a small car with a 2,000 *kg* target maximum mass, a frontal area of 2.3 m^2, $C_d = 0.25$ and tire resistance coefficient of 0.008. **Calculate** the range this car can attain with a cruising speed of 75 *mph* on a level road.

This car needs 545 *N* tracking force and requires energy at the rate of 18.3 *kW*, with hotel and control power requirements ignored. The battery mass is 600 *kg*. Using typical *Li-ion* batteries values, such a battery mass stores about 600 *kJ/kg*. This car stores 360 *MJ*. If we deplete the total stored energy, the car drive lasts 360 *MJ* / 18.3 *kJ/s* = 19.7 x 10^3 *s*, *i.e.*, 5.47 *h* and covers 410 miles.

The real-world situation is not this simple since with a 200 *W* of hotel load and control power added, we realize that the batteries really should not be pushed below the 20 % level, the result is (0.8) x (360 *MJ*)/(18.5 *kW*) = 15.6 x 10^3 *s*, *i.e.*, 4.33 *h* and thus 325 miles.

4. Experts warn that it is easy to leave out critical aspects of vehicle design. For example, roads are not totally level, in general. A drive into a headwind adds to the drag resistance as if the car were moving with the headwind speed added to its actual speed. **Determine** the power required for the small car in problem 3 to cruise at 75 *mph* with no wind on a level road. **Determine** the power required for the same small car to cruise at 75 *mph* with a 10-*mph* headwind on a road with a 2 % slope?

The power without wind on a level road (from problem **3.**) is 18.3 *kW*. The headwind effect is that the car moves at the sum of cruise plus this wind speed. Therefore, we use a speed of 85 *mph* for the drag force computation. We need care in the evaluation of the required power as the product force x speed. The other forces are independent of speed. We compute the force needed at 85 *mph* and multiply it by 75 *mph* = 33.5 *m/s* to obtain the required power. The force at 85 *mph* up a 2 % slope is 1,047 *N*. The power at 75 *mph* is 1,047 *N* x 33.5 *m/s* = 35.1 *kW* – almost double the 18.3 *kW*.

5. If we double the battery mass in an *EV*, can its range be doubled, with all other parameters kept fixed? Why or why not?

Many of the energy consumption terms in a vehicle analysis depend on the *EV* mass. For example, at low speeds the drag is low and a doubling of the vehicle mass doubles the energy consumption and requires double the stored energy to attain the same distance. At extremely high speeds, most of the required traction force is drag, the mass is less impactful, and a doubling of the stored energy nearly doubles the range. Note that the total mass exceeds the mass of the batteries. For instance, the case with the batteries' mass at 20 % of the total *EV* mass, the doubling of the mass of the batteries increases the *EV* mass by 20 %. Then, under low-speed driving, energy consumption increases by 20% when stored energy is doubled. The problem requires a "no" answer since mass does impact energy consumption and we cannot get double the range with double the batteries. Indeed, the actual result depends strongly on the nature of the *drive cycle*, with generally better outcomes under high-speed cruising and worse ones for in-town driving.