Exam next Tuesday
- Posted similar exam solutions

Review on Thursday
Clickers
Energy Usage in Transportation

- Newton’s Laws:
  1) body in motion stays in motion
  2) $F = ma$
- You are driving at constant 60 mph
- Q: what is $a$?
  A: 0
- Q: then why does the engine need to run?
  - A: FRICTION
  - Microscopically: weak bonds are made and broken converts KE into thermal energy

Energy Usage in Transportation

- Friction
  Rolling, Sliding, Static
- In a car: engine; tires
  - Sliding or rolling friction:
    - $F = \mu m g$ : coeff. of friction X weight
    - If $ma = f = \mu mg$ then the max $a = \mu g$
    - $\mu_{\text{slide}} << \mu_{\text{rolling}}$

The actual forces acting on the wheel and the surface. As one can see in this exaggerated view, both the wheel and the surface undergo deformation to an extent determined by the elastic properties of the two surfaces.
Aerodynamic Drag

Air is a fluid
- must expend energy to move air around vehicle

\[ F = \frac{1}{2} \rho C_d A v^2 \]
\( \rho \) is fluid density; \( C_d \) is coeff. of drag; \( A \) is area;

\( C_d = 1.17 \) for flat plate, \( 0.3 \) for good aero car, \( 0.9 \) for bicyclist

Miles Per Gallon

- HOW MUCH POWER IS EXPENDED IN MOVING AT VELOCITY \( v \)?
- Power from things that are independent of speed = \( A \)
  - Engine losses (friction from rotating parts)
  - AC
  - Radio, etc.
- For motion, Power = Force \( \times \) velocity = \( F \ v \)
  - Rolling friction -> \( F_{\text{roll}}v = B \ v \ (= C_{rr} m g v) \)
  - Drag -> \( F_{\text{drag}}v = C \ v^3 \ (= \rho C_d A \ v^3) \)

POWER = \( A + B \ v + C \ v^3 \)
Miles Per Gallon

- Power = F v = A + B v + C v^3
  - Mpg is units of distance/energy (since what counts is energy in a gallon of gasoline)
- Energy = Power X time
- Time = distance/v
- Energy = (A + Bv + Cv^3)d/v = d(A/v + B + Cv^2)
- MPG = d/E = 1/(A/v + B + Cv^2)
- Goes as ~v/A for small v, 1/Cv^2 for large v
- Typical max around 40–60 mph depending on A,C

VW Golf GTI

- ~v/A for small v
- 1/Cv^2 for high v
• Four places energy is expended

1) idling/AC/radio etc.
2) accelerating
3) overcoming friction (rolling, drag)
4) climbing hills

A 1300 kg car on asphalt w/reg tires will need a force of 400 N (90lbs) for rolling.
This limits a car of this wgt to about 60MPG even at slow speeds.
If you use low resistance tires you can push this a factor of 2.
(The Prius has low resistance tires) – This is why it is important to keep your tires inflated properly
Examples

- Drive 30 miles in 30 mpg car at 60 mph
- use 1 gallon of gas ~ $1.3 \times 10^8$ J
  - (note internal combustion is only ~ 25-30% efficient)
- accelerating to 60
- kinetic energy of a 2000kg car at 60 mph ~ $7 \times 10^5$ J
- Do it in 5 sec
  - power = energy/time = $1.4 \times 10^5$ watts ~ 200hp
  - In reality it takes a 300hp engine to do it as it takes power to go that fast and there are losses...

Less than 1% of energy was for acceleration - everything else lost to friction...
**Improvements**

- Drag

  - Prius - 0.26  (6)
  - Mazda 6 - 0.27
  - Mini - 0.35
  - Hummer H2 - 0.57
  - GM EV1 - 0.195
  - BMW 335 – 0.31 Top down  0.30 Top up
Improvements

Reduce A - power expended when not moving
- turn off engine when stopped
- better engine oils
- more efficient accessories

Reduce B - low resistance tires
My bicycle tires are inflated to 100 psi, but my car tires to only 32 psi.

Why?

Hybrids – The Prius

- A vehicle that can be propelled by gasoline and/or electric power. Components of the system include:
- Regenerative braking, using motor-generators which converts kinetic energy of motion into electrical energy that is stored in the traction battery and reduces wear and tear on the brake pads;
A 1NZ-FXE internal combustion engine (ICE) using the more efficient Atkinson cycle instead of the more common Otto cycle.

The gasoline engine normally shuts off during traffic stops and the accessories (including the air conditioning) are powered by the battery pack.

The engine is used both to propel the vehicle and to recharge the batteries.

Because of the availability of extra power from the electric motors for rapid acceleration the engine is sized smaller than usual for increased fuel efficiency and lowered emissions with acceptable acceleration;

A Hybrid Synergy Drive (HSD) unit that combines a planetary gearset that behaves like a Continuously Variable Transmission (CVT) called the Power Split Device to increase efficiency. The computer controlled HSD transaxle adjusts and blends the amount of power from the gasoline engine and electric motor-generator(s) as needed by the front drive wheels and rechargeable batteries;
- It has a sealed 38 module nickel metal hydride (NiMH) battery pack providing 273.6 volts, 6.5Ah capacity and weighing 118 lb. They are normally charged to 40-60% of maximum capacity to prolong battery life as well as provide a reserve for regenerative braking;
- This $P = iV = 274 \times 6.5 = 1775 \text{W}$ Energy = 1775Wh = 6.5MJ
- Gasoline 130MJ/gallon
- Efficiency 20% – 26MJ 3x battery – may get 10-15miles
- Wind resistance is reduced by a drag coefficient of 0.26 with a Kammback design to reduce air resistance. Lower rolling-resistance tires are used to reduce road friction;
- A Vacuum flask for storing hot coolant when the vehicle is powered off for reuse so as to reduce warm-up time.

**Plug-in Hybrids**

- A plug-in hybrid electric vehicle (PHEV) is a hybrid vehicle with batteries that can be recharged by connecting a plug to an electric power source. It shares the characteristics of both conventional hybrid electric vehicles and battery electric vehicles, having an internal combustion engine and batteries for power.
- 10–20 miles without using gas engine
- The cost for electricity to power plug-in hybrids for all-electric operation in at less than \( \frac{1}{3} \) of the cost of gasoline
The source of energy for Hybrids (like the Prius) is:
1. A mixture of gas and electricity
2. Just gasoline
3. Just electricity
Plug-In electric
For sale now: Tesla Motors Roadster
$109,000, 248 hp
Range: 200 miles
Acceleration: 0–60 mph under 4 seconds
(faster than Porsche 911)

Plug-In electric
Electricity comes from fossil fuels... is this any better???

From Tesla: mileage = 180 Wh/mile

So electricity costs at ~$0.15 kWh – cost per mile $0.027/mile
Assuming gas is $3/gallon – this gives the Tesla the equivalent of 110 mpg
Plug-In electric

Electricity comes from fossil fuels... is this any better???

From Tesla: mileage = 180 Wh/mile

If I drive around here, PEPCO states they generate carbon at

1.3 Lbs /kWh, so driving the Tesla produces 0.24 lbs/mile

Burning a gallon of gasoline produces 20 lbs of carbon dioxide.
So a car with 30 mpg produces 0.7 lbs/mile

Tesla is ~ 2.5X better

Gets even better if electricity comes from renewables

Chevy Volt - Plug-in Hybrid
Chevy Volt

- 16 kWh battery which has 8.8 kWh of useable storage
  - It charges to 85% and the engine kicks in at 30%
- 40 mile all-battery range corresponds to $1.32 at 15 cents/kWh
  - This is about 90 miles on $3 worth of electricity so this equivalent to 90 mpg
- The Volt will cost about $45k
- It can be fully charged in about 10 hours, depending on climate, with standard 120-volt line, or as little as 4 hours using a dedicated 240-volt line
- They sort of lie about it being fully electric powered in that it needs the engine at high speeds
Tiny Cars

- Tata Nano (India)
  - Low cost: $2,500
  - Low weight: 1300 lbs.
  - 33 hp
  - Top speed = 68 mph
  - 47 mpg

- Will greatly increase oil demand by selling to people who cannot currently afford cars...
Other Modes of Transportation
What is the most efficient mode of people transport? (passenger-mile/gallon)

1. Automobile
2. Bus
3. Train
4. Airplane
Energy Content of my bag of candy
150 pieces 100 calories each

1. 1% of a gallon of Gas
2. 10% of a gallon of Gas
3. 50% of a gallon of Gas
4. 1 gallon of Gas
5. 10 gallons of Gas

150 pieces x 100 Calories = 15,000 Calories
15,000 x 4186 Joules/Cal = 62 MJ
Gas ~130 MJ
<table>
<thead>
<tr>
<th>MODE</th>
<th>Pass-mi/Gal**</th>
<th>Btu/pass-mi</th>
<th>CO2 g/pass-mi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>low</td>
<td>AVG</td>
<td>high</td>
</tr>
<tr>
<td>Motor Coach - bus</td>
<td>160.0</td>
<td>184.4</td>
<td>201.5</td>
</tr>
<tr>
<td>Van Pool</td>
<td>28.2</td>
<td>101.9</td>
<td>194.6</td>
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<tr>
<td>Heavy Rail</td>
<td>47.0</td>
<td>155.3</td>
<td>200.6</td>
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<tr>
<td>Commuter Rail</td>
<td>58.2</td>
<td>85.8</td>
<td>249.1</td>
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<tr>
<td>Intercity Rail</td>
<td>52.4</td>
<td>66.0</td>
<td>175.7</td>
</tr>
<tr>
<td>Car Pool - 2 person</td>
<td>41.2</td>
<td>55.4</td>
<td>111.4</td>
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<tr>
<td>Light Rail</td>
<td>14.4</td>
<td>120.5</td>
<td>214.9</td>
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<tr>
<td>Trolley Bus</td>
<td>53.4</td>
<td>104.4</td>
<td>122.1</td>
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<tr>
<td>Car - Avg Trip</td>
<td>32.5</td>
<td>43.8</td>
<td>88.0</td>
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<tr>
<td>Domestic Air Travel</td>
<td>42.3</td>
<td>32.5</td>
<td>126.8</td>
</tr>
<tr>
<td>Transit Bus</td>
<td>3.9</td>
<td>32.5</td>
<td>126.8</td>
</tr>
<tr>
<td>Car - 1 Person</td>
<td>20.6</td>
<td>27.7</td>
<td>55.7</td>
</tr>
<tr>
<td>Ferry Boat</td>
<td>2.0</td>
<td>12.6</td>
<td>31.0</td>
</tr>
</tbody>
</table>

**Passenger Miles per Gallon of Fuel**

*Per Diesel Equivalent Gallon (130,000 btu)*
Average Energy Use (btu) Per Passenger Mile

Average Carbon Dioxide Emissions (grams) Per Passenger Mile

Note: Btu/passenger mile for Rail and Trolley modes does not account for efficiency of electricity production.
<table>
<thead>
<tr>
<th>Transportation mode</th>
<th>Fuel consumption</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BTU per short ton mile</td>
<td>kJ per tonne kilometre</td>
</tr>
<tr>
<td>Class 1 Railroads</td>
<td>341</td>
<td>246</td>
</tr>
<tr>
<td>Domestic Waterborne</td>
<td>510</td>
<td>370</td>
</tr>
<tr>
<td>Heavy Trucks</td>
<td>3,357</td>
<td>2,426</td>
</tr>
<tr>
<td>Air freight (approx)</td>
<td>9,600</td>
<td>6,900</td>
</tr>
</tbody>
</table>

**Trains - 330 btu/ton-mile**
**Trucks - ~3,300 btu/ton-mile**

*Why are trains so much better?*

- aerodynamics
- rolling friction 30X less

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Energy (btu/gal)</th>
<th>Density (lb/gal)</th>
<th>Weight % Carbon</th>
<th>CO₂ g/gal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>138,000</td>
<td>7.1</td>
<td>87%</td>
<td>10,274</td>
</tr>
<tr>
<td>Gasoline</td>
<td>114,000</td>
<td>6.0</td>
<td>85%</td>
<td>8,482</td>
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<tr>
<td>LPG</td>
<td>91,330</td>
<td>4.4</td>
<td>82%</td>
<td>6,042</td>
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<tr>
<td>LNG</td>
<td>73,500</td>
<td>3.2</td>
<td>75%</td>
<td>4,017</td>
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<tr>
<td>CNG (DEG)</td>
<td>138,000</td>
<td>6.0</td>
<td>75%</td>
<td>7,517</td>
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<tr>
<td>Kerosene</td>
<td>135,000</td>
<td>6.9</td>
<td>86%</td>
<td>9,935</td>
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<tr>
<td>B20 Biodiesel</td>
<td>135,613</td>
<td>7.0</td>
<td>84%</td>
<td>9,748</td>
</tr>
</tbody>
</table>
Air Travel

- 50 MPG/seat if full
- Typically 70% load factor
  - 35 MPG
- In 2007 I traveled about 70,000 miles by air so I used 2,000 gallons of jet fuel
- 18.3 of CO₂ pounds per gallon = 18.3 Tons of CO₂

<table>
<thead>
<tr>
<th>Green Skies</th>
<th>How airlines compare on fuel efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPROVEMENT SINCE 2000</td>
<td>SEAT MILES PER GALLON OF FUEL IN 2009</td>
</tr>
<tr>
<td>33% Alaska</td>
<td>75.9</td>
</tr>
<tr>
<td>-8% JetBlue</td>
<td>71.7</td>
</tr>
<tr>
<td>25% Continental</td>
<td>69.6</td>
</tr>
<tr>
<td>16% Southwest</td>
<td>68.6</td>
</tr>
<tr>
<td>19% US Airways</td>
<td>66.4</td>
</tr>
<tr>
<td>53% AirTran</td>
<td>64.1</td>
</tr>
<tr>
<td>12% United</td>
<td>62.1</td>
</tr>
<tr>
<td>14% American</td>
<td>60.5</td>
</tr>
<tr>
<td>20% Delta</td>
<td>60.4</td>
</tr>
<tr>
<td>Date</td>
<td>Activity</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
</tr>
<tr>
<td>Jan 05, 2007</td>
<td>591 V Class</td>
</tr>
<tr>
<td>Jan 15, 2007</td>
<td>999 V Class</td>
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<tr>
<td>Jan 13, 2007</td>
<td>992 V Class</td>
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<tr>
<td>Jan 13, 2007</td>
<td>872 V Class</td>
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<tr>
<td>Jan 18, 2007</td>
<td>320 T Class</td>
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<tr>
<td>Jan 18, 2007</td>
<td>225 B Class</td>
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<tr>
<td>Jan 27, 2007</td>
<td>491 T Class</td>
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<td>Feb 01, 2007</td>
<td>12-B T Class</td>
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<td>Apr 19, 2007</td>
<td>341 V Class</td>
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<tr>
<td>Apr 21, 2007</td>
<td>912 W Class</td>
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<tr>
<td>Apr 21, 2007</td>
<td>649ST W Class</td>
</tr>
<tr>
<td>Apr 23, 2007</td>
<td>627 T Class</td>
</tr>
</tbody>
</table>

**Plane flies five passengers from US to London**

By David Millward, Transport Editor

Last Updated: 1:35am GMT 06/03/2008

A major airline is under fire from environmentalists for flying an aircraft across the Atlantic with only five passengers on board.

- **Stunning pictures: Crocodile attacks backpacker in Australia**
- **Obesity epidemic spreads to Britain’s dog population**
- **Screen Break: Funniest viral videos, games and stories**

The flight from Chicago to London meant that the plane, a Boeing 777, used 22,000 gallons of fuel.

It led to American Airlines being accused of reckless behaviour by green lobby groups.

The latest “eco- scandal” flight took place on February 9 after American was forced to cancel one of its four daily services from Chicago to London.

While it was able to find places for nearly all the passengers on the fully-booked flight, five still had to be accommodated. Those who did fly were upgraded to the business class cabin.

But while they enjoyed lavish hospitality, the airline was accused of an “obscene waste of fuel” by Friends of the Earth.

It is estimated that each passenger produced 43 tons of CO2 – consuming enough fuel to carry a Ford Mondeo around the world five times.
Since 1988 fuel economy of American cars has gone up:

1. 50%
2. 30%
3. 20%
4. 10%
5. Almost 0
6. Gone down slightly