98-186
Roller Coasters: Background and Design
Spring 2015
Week 8 Notes

Roller Coaster Physics

Energy

- There are many types of energy, but for roller coasters, we generally care only about three types of energy: potential energy (the energy at the top of a high hill), kinetic energy (moving energy), and thermal energy (specifically friction).
- Energy will describe to us things related to the speed of a roller coaster at a certain, for instance how fast it will be going at the bottom of a drop.
- If we are preforming calculations on a small scale, such as a single drop or a small turn, we can fairly safely ignore friction and just estimate it by taking off a few miles per hours. If you want to estimate speed over an entire course, you will need to estimate friction.
    - As a brief aside, friction will be more prevalent in coasters with long trains than small trains (more wheels / moving parts)
- Equations and worked out examples can be found in the **Equations and Examples** page on the website under Week 8.
- Notice that mass of the train has no effect on the speed at the bottom of the drop. This is because gravity accelerates at the same rate regardless of mass. This is convenient because now our speed calculations don't rely on train size (when you start thinking about friction, you will need to rely on this however).

G-Forces

- For those not familiar with terminology, acceleration is change in velocity. So when you are speeding up in your car and you feel pushed back in your seat, that is acceleration acting on your body.
- Acceleration is extremely important for roller coasters, since it is what makes a roller coaster fun, boring, or dangerous. One must be very careful to make the accelerations safe. The term "force" will also be used in situation like this, but in this context it is synonymous for acceleration (but in physics, the two are different)
- For roller coasters, we measure acceleration with a unit called "G-Force". G-Forces measure acceleration in terms of gravity, so 1 G is the equivalent of the normal force that gravity pulls down on us every day. At the bottoms of drops, the force will be greater than 1 G, whereas at the top of a hill, the force will be less than 1 G.
- The effect of G-Forces depends on in what direction they are experience. Imagine that you are sitting in a chair:
    - Vertical G-Forces push you up or down in your chair. Commonly these are referred to as "positive" and "negative" G's, with positive G's pushing you into your seat and negative G's pulling you out of your seat upwards.
    - Lateral G-Forces push you left or right. There is generally no distinction between left or right
    - Acceleration G-Forces push you into your seat back, while deceleration G-Forces make you want to move forward, like when you slam on the brakes in a car.

- Even though humans are best at withstanding acceleration G-Forces (which is why astronauts take off on their backs), most G-Forces on a roller coaster are positive G's.

Safety with G-Forces

- You cannot measure the danger caused by G-Forces based solely on the G-Force. We experience high G's every day. Sitting in a chair suddenly can be as much at 10 G's. What is important is the duration of the force in addition to the quantity. If the force is high but duration is short, then safety can be achieve (some F1 drivers survive crashes of 150 G's because it is so quick). If the duration is long but the force is low, you are also okay (we constantly experience 1 G all the time). It's when both are high that bad things happen.
- The following link has some good graphs showing the standard G-Force guidelines for roller coasters: http://nolimits-exchange.com/news/g-force-lesson/35
  - These are *maximums*; not something most coasters try to achieve.
- In general, most coaster will be within these ranges for max forces
  - Positive G's: 3 to 4 for steel coasters (5 on some loopers), 2 to 3 on wooden coasters
  - Negative G's: -1 to -1.5
  - Lateral G's: 1 to 1.25 on wooden coasters, strive for 0 on steel coasters
  - Acceleration G's: Depends on launch, around 1
  - Deceleration G's: No more than 1.5, especially if no OTSRs

Designing with G-Forces in Mind

- In some cases, you think of G-Forces in a linear sense, like the forces involved in a launch or brake run
- In most cases, you think of forces in a curve, such as the bottom of top of a hill or a turn. As a designer, you get to pick the radius of such a curve, and you can calculate the radius so that certain forces are achieved based on a given speed.
- Be careful when calculating the forces at the bottom of a hill; there is an additional 1 G caused by gravity. So if you design the forces in the curve to be 4 G's, the actual forces will be 5 G's.
- In turns, you can apply banking to the turns (also called canting in CivE terms) to turn lateral G-Forces into vertical G's. On a steel coaster, you want no lateral forces, while on a wooden coaster you might under-bank a turn so that some lateral forces remain (this is contemporary wooden coaster designing).
- Lots of equations and examples can be found in the **Equations and Examples** page on the website under Week 8.
- Most of the examples consider calculating for a single radius for a curve. This is how it was done originally because it is simple. However, if we consider the bottom of a hill, the forces at the beginning of the pull out will be lower than at the bottom because the train will be slower there. To fix this, you can calculate two radii and transition between them.
  - But if you are going to calculate two, why not three? Why not make it a continuous function using calculus? This is the whole idea behind a modern design technique called FVDs, which solve this problem. This is an *advanced* design technique which we will discuss in future weeks but will never talk about the full set of math involved.