98-186
Roller Coasters: Background and Design
Spring 2015
Week 4 Notes

Basics of Roller Coaster Design

How a Roller Coaster Works

- At its simplest, most abstract form, a roller coaster has two main components; the part where it gains energy, and the part where it loses energy (and for most coasters, this ends up equaling out, since you get off at the same station you got on). Gaining energy can be slow, like a lift hill, or fast and exhilarating, like a launch. Losing energy can consist of the majority of the ride (friction) or the end of the ride with the brake run.
- There are many ways to gain energy. You can separate these into two main groups: lift systems (which focus on increasing height) and launches (which focus on increasing speed)
- Here are several types of lift systems
    - Most common is a chain lift hill. This involves using a chain to hoist riders up an incline to the top of the ride. These inclines tend to be between 25 degrees and 40 degrees.
    - Cable-lift systems function like chain lift hills but rather than a long heavy chain use a lighter cable with a catch car at the end. They allow for faster, higher lift hills and are often used on giga coasters. These tend to be steeper than chain lifts, between 35 and 50 degrees. Used almost exclusively by Intamin
    - Elevator systems involve a moving section of track which is raised vertically. Trains are stopped in the section, raised, and then continue on the higher section of track. These are uncommon on standard roller coasters but were used on Caripro Batflyers.
    - Some Schwarzkopf coasters feature spiral lift systems, where motors on the car are powered by a third rail as they move up a spiral of track. During the rest of the ride, the motor is off.
    - Zamperla's Volare flying coasters use a variant of the spiral lift which is powered by a turning shaft in the center of a tight spiral (see pictures of Volare at Wiener Prater to see what I mean)
- Almost all launch systems (save tire launches and LIMs/LSMs) work by pulling a cable attached to the bottom of the train via a catch car. This catch car detaches once the train reaches full speed
    - Flywheel launches use the inertia of a large spinning flywheel to pull the cable. Some Schwarzkopf coasters as well as Zamperla Motocoasters use these.
    - Weight drop launches uses the force of a falling weight to pull the cable. Used exclusively by early Schwarzkopf shuttle loops.
    - Hydraulic launches work by compressing fluid to high pressures and then releasing them through a turbine. This turbine is attached to a drum which winches in the cable, accelerating the coaster train. Used exclusively by Intamin.
    - Compressed air launches work the same way as hydraulic launches but with air instead of hydraulics. Compressed air launches allow for higher rates of acceleration. Used exclusively by S&S.
    - Tire launches used a series of tires which spin at a high rate of speed while contacting either a brake fin or the bottom of the train to launch the train. While only used on Incredible Hulk for many years, they have recently been adopted by Intamin for smaller scale launched rides.

    - Linear induction motors (LIMs) work by using magnets. Electro-magnets mounted to the track alternate poles in succession. Magnetic fins on the train which move very closely to these magnets are first attracted to the magnets and then, after the poles switch, are repelled. Linear synchronous motors are a more modern implementation of LIMs. Premier Rides first use LIMs in 1996 (although Disney had used the idea back in the 1970s for their People Movers). Currently, many different manufacturers use LIM/LSM technology.
- After gaining energy, the coaster begins to lose energy. Most commonly, this is through friction. While friction includes aerodynamic drag on the trains as well as sound (not technically friction per sea…), we mostly consider friction associated with the moving trains. This includes friction with the rails, the wheel assembly, the car connections, etc. Many factors can influence this, including track and wheel material.
- Alternatively, any extra energy is removed via brakes (in a section called a brake run). These can either be in the middle of the ride (mid-course brake runs, or MCBRs), at the end of the ride, or in sections like drops to regulate speed (called trim brakes, or trims). Several different kind of brakes exist:
    - Skid brakes operated by raising a ceramic covered length of wood in the middle of the track under the train, which the train then slides upon (raised slightly off the rail) slowing down to the friction. Only used on wooden coasters, these brakes were almost exclusively used during the First Golden Age of coasters in the 1920s. Due to their inadequacies in wet weather and other reliability issues, they are rarely ever used now-a-days.
    - Clamp brakes, or fin brakes, work by clamping two pieces of metal mounted to the track together so that a fin on the coaster train slides between them and is slowed down due to the friction. These make up the vast majority of brakes today.
    - Magnetic brakes work by having a metal fin on a coaster train pass through a set of magnets on the track (or a set of magnets on a train pass over a fin on the track). When the fin moves through the magnets, eddy currents are produced which resist motion. This force of resistance is proportional to the speed of the train, making for a much smoother decrease in speed than clamp brake, which can bring riders to a sudden, uncomfortable halt. They also have no moving parts, making maintenance easier. These brakes are becoming more popular and are used on both wooden and steel coasters.
    - Some coasters in East Asia used tire brakes (see Big Boom at Nasu Highland Park) where tires on the side of the track rub up against the coaster trains, slowing them down.

<u>Roller Coaster Safety</u>

- Brakes are by default closed, and require power to open. This means that if there was a power failure, all brakes on the coaster would closed, bring the trains to a stop.
- On most launch coasters, there are sufficient brakes on the launch track so that if the train does not clear the first hill (called a rollback), the train can be brought to a stop, come back to the launch section, and be re-launched. Hydraulic launch coasters by Intamin will retract their brakes for the launch and then re-engage them as soon as the train passes.
- All coasters feature restraints of some form to keep people in the trains. Usually, this consists of lap bars, which has become a generic term for any restraints that covers a riders lap and connects to the train below the rider's torso. They were originally loose and were used for both riders in a 2 seat row, but over time, they have move towards being individual and tighter. There are also over the shoulder restraints (OTSRs) which still hold down a rider's lap but go over the

rider's shoulders. These are common on steel looping roller coaster and other coasters with intense elements since they provide support for the upper body, but are despised by coaster enthusiasts due to the lack of comfort and freedom.

  - Most restraints have issues handling guests "of atypical size", meaning many large amusement park patrons are unable to ride some coasters. They usually have a test seat at the entrance to a coaster to allow guests to check if they can ride.

- Every day, before a coaster opens, it has to be inspected as part of preventative maintenance. Personnel will inspect the track of a coaster, especially parts with high forces like bottom of drops and loops, for wear and tear, stress, and fractures. For wooden coasters, carpenters will walk the whole track twice (once on each side) tightening bolts and looking at the wood for sections that need repairs. Coaster trains, brakes, and other components are also inspected and parts are replaced as needed. After all of this, the train is sent around several times both with and without mechanics on it. They listen carefully for tell-tale signs of failure, like clunking. After all of this, the ride is given the go ahead to open for the day.

<u>The Block System</u>

- One of the best safety inventions of roller coaster history, the block system allows for coasters to safely operate many trains without fear of collision.
- The system separates the path of a coaster track into different sections, called blocks. Each block is only allowed to have one train in it at a time.
- At the end of each block is some form of brakes or other mechanisms that can bring the coaster train to a halt. If there is a train in the next block, the train in the previous block is brought to a stop before entering the occupied block.
- Blocks include such features as the station, lift hill, and brake runs (including MCBRs, but not trim brakes).
- With such a system, operators can guarantee that two trains will never collide, so long as the system functions correctly. Pretty much all coasters use computer systems and sensors on the track and trains to automatically regulate blocks without operator intervention.
- When designing a coaster, a designer should try and strategically place blocks so as to maximize the number of trains while not breaking the flow of the ride. They much also be careful of E-Stops, a term referring to when the system decides to bring all trains to a stop. This means that a coaster must be able to bring a train to a stop at any block and still have the train able to complete the circuit.

<u>Accidents</u>

- Even with all the safety systems, accidents do happen on coasters from time to time.
- Most accidents are due to riders not following instructions given and being stupid.
  - For instance, a rider was killed once on the Raven at Holiday World when they found a way to get out of the restraint and stood up on the first drop.
  - Another case was when a park guest at Six Flags Over Georgia scaled two 6 foot fences to recover a hat, but was then struck by the train of Batman: The Ride, decapitating him.
- Other accidents are due to operator negligence.
  - There are many cases of park employees being injured or killed due to poor safety practices, such as riding on a test run without a safety restraint.
  - There are a few cases of operators ignoring a lap bar failing to fully engage on large riders, resulting in sometimes deadly failures

    - One accident involve a war veteran with both legs amputated being thrown from a ride, even though safety policy doesn't allow such a person to ride the coaster.
- Very rarely do coasters fail due to genuine issues in their design (coasters are very safe). When they do, it is usually in a safe way.
    - There was an incident on Demon at Six Flags Great America where a wheel axle failed. As designed, the failed wheel assembly dragged against the rail bringing the train to a halt. However, it came to a stop perfectly in one of its vertical loops. Some riders were upside down for 3 hours before being rescued.
- Other times, coasters fail in very bad ways. One of the worst instances of this was Mindbender at Galaxyland, an indoor Schwarzkopf coaster known for its high forces, in 1986. A bolt sheared off of the axle of the last car in the train, causing it to fish tail. Shortly after this, the coaster entered a vertical loop, but the back car smashed into a concrete pylon, slowing the train so it rolled back. The back car then was crushed as it was pushed into the same pylon. 3 were killed with one more almost killed.
    - Blame of the accident was placed on the operators, who had performed inadequate safety inspections, continued to run the ride despite the fact that they had heard strange noises coming from it earlier that day, and had never translated the safety manual from German to English.

<u>Designing / Building a Coaster from Idea to Opening Day</u>

- The process starts with the executives of a park deciding they want a roller coaster. If they are part of a chain like Six Flags or Cedar Fair, the chain executives will have a lot of pull, preferring some parks over others depending on the grand scheme of things.
- After fleshing out general ideas, like possible locations and what type of coaster they are looking for, they begin seeking manufacturers for bids. Smaller parks may find it hard to get the attention of high scale manufacturers like B&M or Intamin, but if word gets out that a large park like Cedar Point wants a coaster, manufacturers will approach the park themselves and do their best to woo the park and get the bid.
    - Manufacturers, after listening to what the park executives want, will sketch out rough layouts of coasters to give the park an idea of what to expect. As time goes on during the bidding process, these will become more detailed, with more exact measurements and analysis.
- Once a manufacturer is picked, the manufacturer or their contracted designer (e.g. Ing.-Büro Stengel GmbH) will begin making more extensive calculations of the finalized ride layout. These will take into account terrain, obstacles like buildings, and environmental elements (like how much it rains, natural disasters like earthquakes, etc). Also importantly, they will take into account forces on the rider so as not to make a painful / harmful ride.
- When the computerized version of the coaster has been thoroughly analyzed for safety and quality, the process splits for wooden and steel coasters.
    - Wooden coasters generally don't have any manufacturing and are completely assembled on site. Lumber is shipped to the site and after preforming ground work and pouring concrete, ledgers are erected for the coaster, with track being laid down later.
    - Steel coasters will have their track and supports manufactured in a factory off site. It is then shipped to the park (which has already done ground work and poured footers) where it is bolted together like a jig-saw puzzle.

- After the track is completed, electro-mechanics are installed. This includes moving parts like brakes, lift hills, and transfer tracks, as well as electronics, like sensors and the computer system that will run the ride.
- Once everything is installed, the trains will be run on the coaster, first empty and then with water dummies. During this time, engineers will watch the runs for abnormalities and will do things like adjust timing of brakes, speed of the lift hill or launch, etc.
- Inspectors then come and run a battery of test, mostly aim at making sure the structure is sound and the coaster is within safe forces.
- After all of this, the coaster is ready to go, and opens to the public.
- The time that this project takes depends on the project, with larger projects taking longer. While small project may take a year from idea to opening day, large steel coaster projects will take more like 3 years.
    - Regardless of how much planning there is, it usually takes about half a year or longer from the point of beginning actual ground work to opening the coaster.

Differences between Wooden and Steel Coasters

- The most obvious difference is what separates wood and steel coasters: their track
    - Wood coaster track is constructed by laying 7-9 layers of flat wood one on top of each other, with the last 3 layers extending out horizontally so that the upstop wheel can run under them. The layers are laminated together and bolted down. A flat piece of steel is placed on the top layer and is the actual part of the track that the wheels contact.
    - Steel coaster track is manufactured by talking straight tubes of steel and bending them to pre-specified shapes. They are then welded to the track ties and spine to make the pieces of track.
- Steel coasters require a higher level of precision than wooden coasters, with minor imperfections creating the potential for a poor or unsafe ride experience.
- Wood coasters will have less friction than steel coasters, because they use steel wheels instead of softer polyurethane wheels. This allows wood coasters to be faster and longer than equivalent sized steel coasters.
    - However, this also makes them louder. Europa Park decided to use polyurethane wheels on their wooden coaster Wodan Timbur Coaster in order to reduce sound, at the expense of a shorter ride.

Costs

- Costs between wooden and steel coasters vary
    - Wooden coasters are relatively cheap to initially design and construct. However, they require much more than steel coasters in the form of maintenance. Daily checks on wooden coasters are more intensive, sections of track need to be replaced every year, and parks need to keep a skilled group of carpenters around to perform this maintenance, a group which is separate from the normal mechanics that maintain the other rides in a park
    - Steel coasters are more expensive that wooden coasters initially, since more engineering goes into producing one and the manufacturing is more intensive. However, once it is built, it is cheaper to maintain. Unlike wooden coasters, track rarely needs to be replaced, and usually once every decade or so.
- Costs of coasters depends very much on their size and technology used, with larger coasters being more expensive as well as coasters that require things like launches. For instance, Top

Thrill Dragster and Intimidator 305 each cost $25 million. Smaller steel coasters will cost more in the range of $5 to $10 million.

- As said above, wooden coasters will be cheaper, with large coasters being around $10 million. El Toro and Voyage, two large scale woodies, cost $12 million and $8.5 million respectively. Smaller wooden coasters will be $3 million to $5 million

<u>Capacity</u>

- Capacity refers to a coaster's throughput of riders, usually measured in riders per hour. Higher capacity means that lines will move faster and more riders can enjoy the coaster, while low capacity means dreadfully slow lines.
- A "good" coaster capacity will be in the range of 1,400 an hour to 1,800 an hour (with coasters toping 2,000 being very rare). "Poor" capacities would be 800 an hour and lower.
- Many factors affect capacity, the two most prominent being number of trains and size of trains. The larger each is, the better the capacity in general.
    - However, some designers sacrifice capacity so that they can achieve other desirable features, like no mid-course brake runs or single car trains for wild mouse coasters
- See the **Equations and Examples** page for the capacity equation and an example worked out (this will be part of Week 8's notes).
- The equation given is a theoretical capacity, and is usually higher than the real capacity for many reasons:
    - Duration measurements are usually inaccurate due to an inconsistent definition of the term (a proper duration for the equation would be the time it takes for a train leaving the station to enter the station again)
    - The equation assumes all trains are completely full; in practice, this is hard to achieve since riders will choose to sit alone if they are part of odd sized groups. Some parks assign seat and use a single rider line to try and fix this issue.
    - The equations assume the park is running the max number of trains. In practice, this is not always true. On days with less patrons, they tend to run one train less than normal to reduce maintenance costs, since a day of operation is tough on coaster trains.