Utilizing Systems Engineering Design Processes to Imagineer a Themed, Backyard Ride

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Kellogg Honors College Capstone Project

Objective

Amusement rides have entertained people for centuries and continue to provide thrills in theme parks all over the world. The engineering systems design process is essential in the development of these rides to create an exciting experience with an emphasis on safety. This development process requires a wealth of knowledge in static/dynamic stress analysis, material properties, failsafes/redundancies, testing, human acceleration tolerances, rider comfort, theming/storytelling, and more.

This project's goal is to utilize the appropriate methods and tools to design a new suspended type "flying" coaster for Dobbsland, the Disney-inspired backyard theme park. While the ride must provide a safe experience, it must also meet certain "fun" criteria for it to be a worthwhile investment. In this project, theming, interactivity, and rider accelerations were taken into consideration which influenced this overall fun factor. The theme and interactive elements selected for this ride are based on the sport "Quidditch" from the Harry Potter franchise. Several system architectures were defined and compared to one another in order the select the optimal candidate that would best help convey that story as well as work together as one ride system.

Safety Considerations

Safety is regarded as the top priority when designing and building any type of ride or even a backyard structure for that matter. If safety is not considered or if there's lack of attention on some important details, the consequences could potentially be fatal. Therefore, several safety factors where considered to ensure that the design requirements were met, and structural and functional safety was not overlooked. In the structural and fatigue calculations, a minimum factor of safety of 2.0 was used. Several redundancies were also implemented into the overall design. For example, two methods of securing the track's "T" cross-section/structure was used which included using both truss ties and long hex head bolts that extend through the entirety of the T-track and the overhead 4"x6" wooden beams. Another example is the use of a redundant steel "catch" on the bogie that would prevent it from falling on the head of the rider if the wheels were to fail or detach.

Calculating Design Load

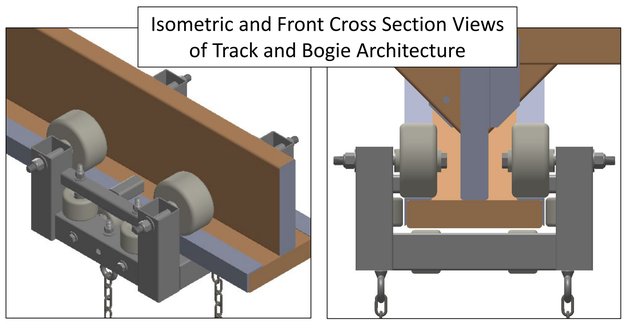
This ride was designed with riders of almost any age, height, or weight (within reason). Therefore, a max rider weight of 250 lb was considered when designing the ride structure. This was also used when analyzing the ride dynamics. In the figure below, the total design weight was calculated to be about 314 lb considering the normal acceleration experienced, the weight of the ride vehicle, and the weight of the bogie.

$W_{bogie} := 25\ lb$ $\quad W_{vehicle} := 10\ lb$

$W_{rider} := 250\ lb$ $\quad a_{maxnormal} := 1.10 \cdot 32.2\ \frac{ft}{s^2}$

$$W_{des} := \frac{(W_{bogie} + W_{vehicle} + W_{rider})}{32.2\ \frac{ft}{s^2}} \cdot a_{maxnormal} = 314\ lb$$

Isometric and Front Cross Section Views of Track and Bogie Architecture



Stress Calculations

The following calculation is an example of the sizing and stress considerations for selecting the appropriate off the shelf parts such nuts, bolts, and steel tubing. In this case, a ½" grade 8 steel hex head bolt was selected for the main wheel's axle which resulted in a factor of safety (FS) of 4.61, more than double the minimum required.

Geometric Properties

$t_g := \frac{1}{16}\ in$ Washer/spacer thickness

$t_w := \frac{1}{16}\ in$

$t_s := .09\ in$ Steel tube thickness

$L_1 := 2\ in$ Steel tube width

$w := 2.4375\ in$ Wheel width

1/2" Grade 8 Steel Bolt Properties

$\sigma_y := 150000\ \frac{lb}{in^2}$ $\quad d := \frac{1}{2}\ in$

$I := \frac{1}{4} \cdot \pi \cdot \left(\frac{d}{2}\right)^4 = 0.003\ in^4$

$E := 29 \cdot 10^6\ \frac{lb}{in^2}$

$W_{des} := 314\ lb$ Design Load — Assume half of design load is held by one cantilevered bolt

$F := \frac{W_{des}}{2}$ Force applied to edge of one wheel

$R_1 := \frac{w + t_g + \frac{t_s}{2}}{L_1 - 2 \cdot t_s} \cdot F = 220\ lb$ $\quad R_2 := R_1 + F = 377\ lb$

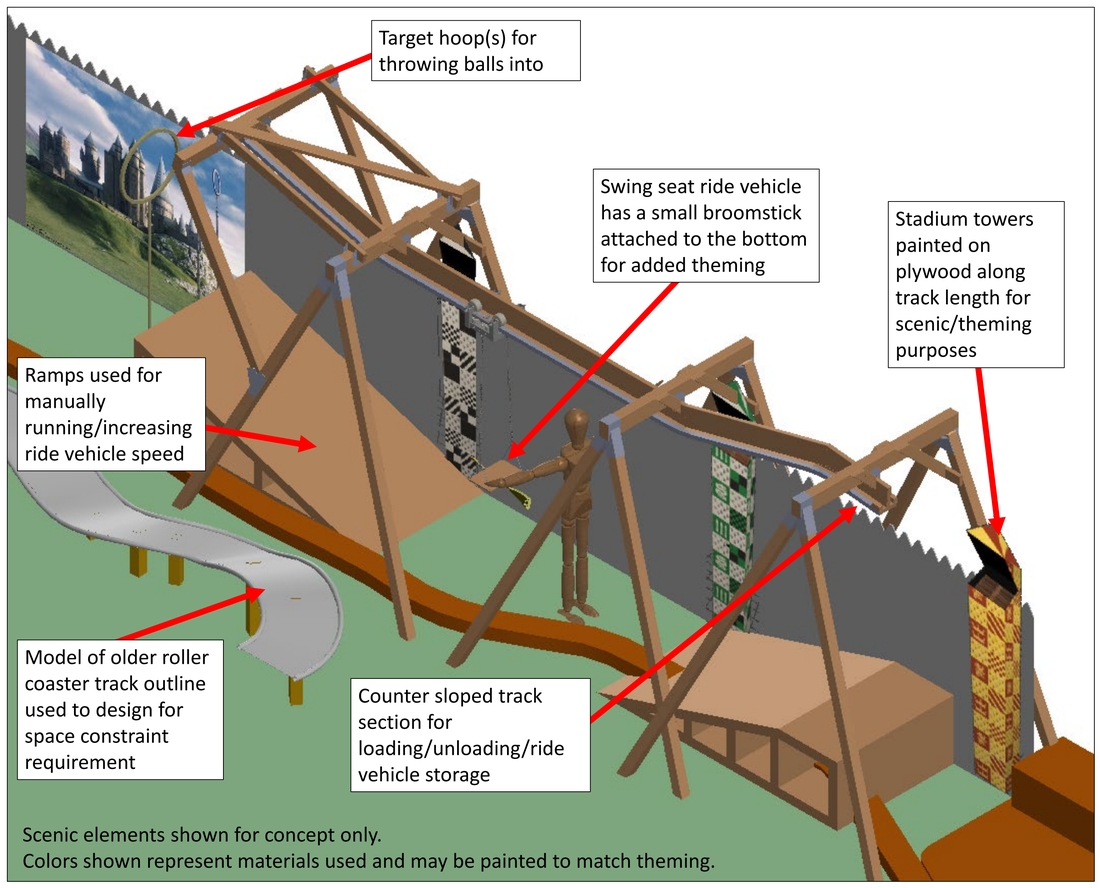
$M_{max} := F \cdot \left(w + t_g + \frac{t_s}{2}\right) = 400\ lb \cdot in$ $\quad \sigma_{max} := \frac{M_{max} \cdot d}{2 \cdot I} = (3.26 \cdot 10^4)\ \frac{lb}{in^2}$

$FS := \frac{\sigma_y}{\sigma_{max}} = 4.61$ FS surpasses minimum of 2.0

$\delta_{max} := \frac{-F \cdot (t_g + w)^3}{3 \cdot E \cdot I} = -9.19 \cdot 10^{-3}\ in$ Max deflection of bolt can be simplified as a simply loaded cantilever beam (fixed-free) and it is within reason

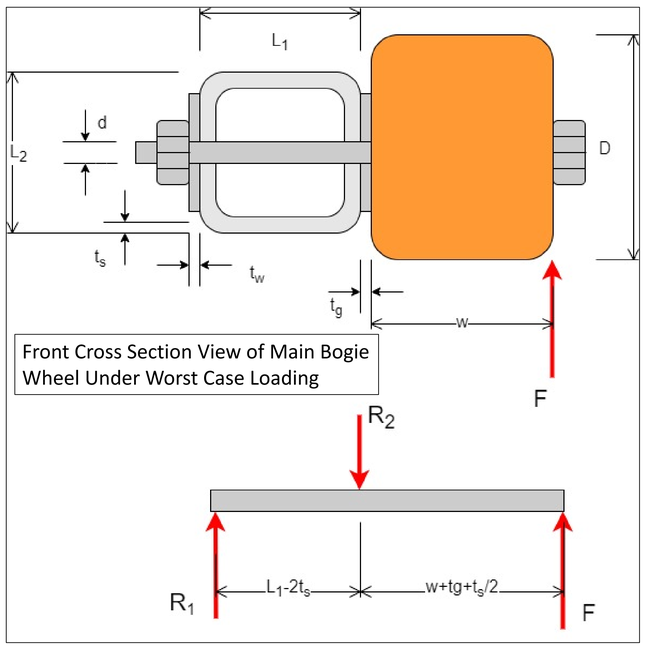
Overview of Major Design Requirements

- Must be safe
- Must accommodate no more than one maximum 250 lb rider
- Must have themed and interactive elements to greatly increase the fun factor
- Must be able to fit within the given space constraints between the backyard fence and the existing rollercoaster
- Rider normal acceleration cannot exceed 1.2 g's
- The ride structure and ride vehicle must be weather and corrosion resistant
- It should be designed to be built with mostly commercial, off the shelf parts
- Bogie must be over designed (higher FS) or have a failsafe to prevent it from deflecting around and off the track
- The ride must be built within a budget of $1000



Theming

Theming and interactivity plays a key role in the purpose of this backyard ride. Without it, the ride lacks much of its appeal. Those interactive elements that play into the "Quidditch" theme include throwing a ball into the hoop(s) at the end of the track, right before the rider reverses direction. This encourages the rider to do more than just ride. Rather, they can test their Quidditch skills while riding a "broomstick" between the towers of cheering fans. The ramps at each end of the track encourages the rider to use their legs to get a boost down the hill and potentially throw even further. It would also be easily possible to add the golden snitch to the ride experience. Having it dangle within reach of the rider while they fly by could be an added bonus. Incorporating physical decorations or scenic into the ride will greatly improve the ride experience, and it helps get the theme across to those who are unfamiliar with the ride or the game itself.



Front Cross Section View of Main Bogie Wheel Under Worst Case Loading

Rider Acceleration Limits

The chart below shows the calculated normal and tangential accelerations of the rider. Given the maximum vertical displacement for the track, the track shape was developed in order to fit between the older roller coaster and the fence. The data shows that the rider normal acceleration does not exceed the desired limit of 1.2 g's.