BACKYARD ROLLER COASTER RESEARCH

Volume ll - 3D Coasters

A retired aerospace engineer makes safe and amazing backyard roller coasters

BY PAUL GREGG

Backyard Roller Coaster Research and Development

Volume II: Three-Dimensional Backyard Roller Coasters

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Dedication: To Belize, Rio, Mayan, Cruz, Westin, and Kensington. Nana would have never let me do this without you.

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We request reader feedback or suggestions as to how we can make this book even better. The author is active on his blog on backyardrollercoasters.org, the backyardcoasters subreddit and is contactable via email at paul@backyardrollercoasters.org

Publisher's Warning- Before you read this book

Building a backyard roller coaster has inherent dangers, both in fabrication and use. Using hand and power tools improperly or ignoring safety practices while using a backyard roller coaster can lead to injury or even death. The operation of a backyard roller coaster has just as many safety risks. This book is not intended as an instructional manual. Do not use it as one. Our hope for this book is that by the numerous tests, certification, safety features and warnings contained herein that what is an inherently dangerous activity will be made safer by than it otherwise would be. The use or misuse of the information in this book constitute no guarantees or warranties of safety whatsoever. Your use of any information or materials in this book or on the associated websites is entirely at your own risk, for which we shall not be liable. There may be mistakes within this book. The information contained herein is intended to be of general interest to you and is provided "as is", and it does not address the circumstances of any particular individual or entity. Nothing herein constitutes professional advice, nor does it constitute a comprehensive or complete statement of the issues discussed thereto. Therefore, the text should only be used as a general and introductory guide and not as the sole source for backyard roller coaster engineering. While we have proscribed what we feel are adequate safety precautions for operating a small backyard roller coaster with total energy under 1000 Joules, we cannot guarantee fabrication quality, certification, or the safe operation of any backyard roller coaster. Backyard Roller Coaster Research, LLC or any other persons who have been involved in working on this publication, cannot accept responsibility for any injuries, loss, or damage that may result in the use or misuse of any of the information contained herein, nor be liable for legal prosecutions or proceedings that may arise as a result of it's reading or application. By reading this book you, the reader, contract with Backyard Roller Coaster Research, LLC to abide by this waiver. If you are unwilling to assume full and complete responsibility for your own safety and the safety of others that may result from the use of information in this book, stop reading now. If you do build a backyard roller coaster, by using it yourself, or allowing others to use it, you assume any and all liability for injury, death or harm that may occur. We advise that you give the same warnings to anyone who you choose to allow to use it, or even be near it when it is capable of operation. If any lawsuit does come forth it will be brought forth in Utah County.

Table of Contents

1.0 Introduction

After finishing work on my first “Out-n-Back Negative G” coaster, documented in volume I, I felt prepared by everything I’d learned to step things up a notch. A 3D coaster requires completely new design considerations and presents it’s own new set of problems to be solved. A 3D coaster cart’s wheels need to be able to pivot on two new axis. Bank angles need to be calculated accurately so that there isn’t too much side to side jerking. And because my new track would be a complete circuit, I needed to be much more precise in calculating energy loss to ensure the cart neither stopped short of the end, or arrived with too much speed. This book is a documentation of my efforts to solve those problems.

Volume I presented elementary physics, essential track fabrication methods, such as track tie fabrication, PVC rail hot sand forming, and cart fabrication. It also contains general and specific design information about my first backyard roller coaster, the “Negative G”, which is an out-n-back coaster, with no turns or banks, and a simpler fixed-wheel four wheel cart. Volume II builds on the information presented in in Volume I and is incomplete without it. The two BYRCs presented in this volume are “3D” in that they make banked turns and change elevation simultaneously, have circuit tracks (meaning the end connects to the beginning of the lift hill) and the cart only travels one way round the track.

2.0 Safety

I wanted to build fun roller coasters, with little risk to safety. The cart and track have to be able to survive repeated use, with some margin built in, but more important are the safety rules we adhere to, with discipline. I came up with the following list of safety guidelines:

1. Use chain and padlock to prevent unauthorized use, or always store cart away from track.

2. No one but the rider and a supervising adult should be on or near the roller coaster when in use.
3. Use automobile grade lap safety belt on cart, attached through steel cart frame.
4. Cart design shall include provision which will under no circumstances let riders feet or hands get near the wheels and track.
5. Parental oversight is required at all times.
6. Surround coaster track with a construction fence or at minimum, caution tape, far enough away to keep other children out of arm's reach.
7. No motorized lift hill, for safety, and to better ensure there is always adult supervision.
8. Lift hill will have anti-rollback provisions to prohibit the cart from sliding down backwards, in case the adult slips.
9. Certification of the roller coaster track and cart will be accomplished by dynamically testing with sandbags strapped to the cart. Sandbag weight shall exceed 1.5 times the maximum allowed rider weight. Certification testing will be repeated after any track or cart modifications, and at least once per year, in the spring, on a cool day.

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4.0 Three-Dimensional Backyard Roller Coasters

Designing a roller coaster begins with determining the specifications for what you want the end product to be.

1) The "Smaug the Terrible" BYRC has a 8.5-ft (2.6 meter) lift hill, and was built in place on uneven ground, with combination banked turns which rise and fall at the same time. It was designed for older grandchildren and can carry up to about 100 pounds safely. I built two carts of different designs for this coaster.

2) The “Little Rocket” BYRC has a 4.5-ft (1.37 meter) lift hill, dip, and hill, then transitions to a 180 degree banked turn, then a small bump, and a few flat left/right turns, and finally a 180 degree flat turn back to the start of the lift hill to complete the circuit. The Little Rocket was designed for younger children under 30 pounds, and uses “Ackermann” steering. The track was made in sections on a flat floor so it could be disassembled and transported. The Little Rocket is the best designed and built coaster, as it was last, and benefitted from lessons learned on the other coasters.

Track width and cart length are important decisions. Track width is based on intended rider weight and height. If the rider is larger and taller, a wider track width is needed, to accommodate a longer cart, and to better handle a higher center of mass. Tracks for lighter, shorter riders can have narrower track width (gauge) so the cart can be shorter, which means the track turn radii can be smaller, and the track fits in a smaller space.

All of the basic physics and construction methods introduced in Volume I on the 2D Out-N-Back “Negative G” BYRC are applicable to 3D coasters. The 3D carts were quite a bit more complicated to design and build. The tracks are somewhat more complicated as well.

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5.0 “Smaug the Terrible” Design Requirements and Objectives

“Smaug the Terrible” Design Requirements and Objectives:

1. Provide a fun ride, with moderate 2-3g accelerations, with a high initial drop angle, and banked turns
2. Passengers will be children between 5 and 9 years old, weighing between 40 and 100 pounds
3. The cart will be designed to run the entire ~180 ft circuit, with under 4MPH velocity at the end
4. Cart will not be able to leave the track via upstop wheel provisions
5. Track will be 3 dimensional in path, with turns and track roll
6. A factor of safety of 1.5 will be applied to maximum expected operating design limit loads

A 3-dimensional coaster will be more difficult than a 2D coaster, as it will have to accommodate not only peaks and valleys, but also left/right curves, and banked track gaining and losing elevation.
With a 2D track, with no curves or tilts, four fixed coaster wheels can contact the tracks fairly evenly. But, when there is 3D shape to the track, only three of the four main wheels would contact the tracks at any one time (three points define a plane, but there are four points of contact). So a fixed-wheel 2D coaster would bind on a 3D track, unless the wheel

assemblies have large gaps, which would result in an unacceptably rough ride, and a threat to safety.

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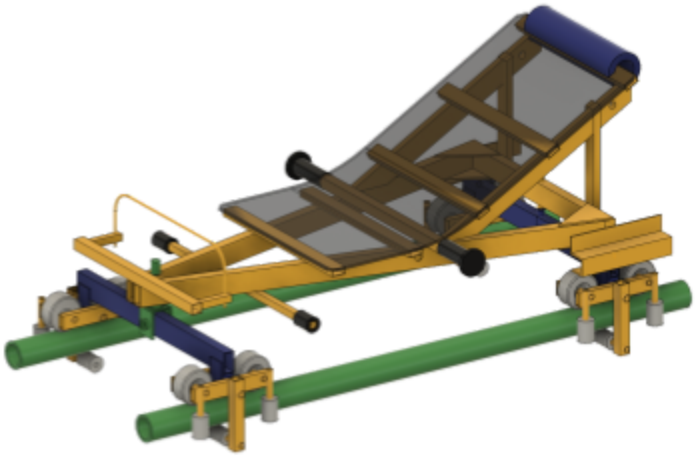
6.4 Fusion 360 CAD Model of 8-Wheel Cart

I originally modeled the -06 cart in FreeCAD. After I built it I decided to model it in Autodesk Fusion 360, partly as an exercise, and partly because it would be more clear and to make drawings.



The results follow.

Everything looks pretty good, but it does stand fairly tall off the tracks, about 4.5 inches which is more clearance than is needed. This caused the cart to not function as well with bigger riders, as there was more drag due to higher center of mass and more friction.

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7.4 Cost Breakdown of "Smaug the Terrible"

Estimate of track cost, per 10 ft section:
two 1-½" ID 10-ft PVC grey electrical conduit $5.54 X 2 = $11.08
2X4 KD: $2.64 for 8' is $0.33 per foot, PT $5.37 for 8-ft is $0.67 per foot
8 2X4 cross ties: 14" X 8 = 112", 112 X $0.33 = $3.08
Frames every 5 feet: average height 3 ft, 24 ft @ $0.33 = $7.92
4" PT 2X4, 4' X $0.67 = $2.68
#10 3-½ galvanized deck screws, 5# (43 per #), or 215 for $28.00, $0.13 each
8ties X 4 screws = 32, frame needs 24, 56 X $0.13 = $7.28

total $32.04 per 10 ft section, figure 10% waste, total $35.24 per 10 ft section
180 ft track costs 18 X $35.24 = **$634.39**

Cart cost: 4 longboard wheels $35, 20 lb steel @ $1.20, 17 5/16ths bolts and nuts @$1.25
8mm bearings for other wheels 24 @ $1.25 = $30, heavy duty storage tub $15, car seat belt $12
total cart materials cost **$137.25**

Even with miscellaneous costs, the total materials cost of 3D coaster was under $1000.

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8.0 BYRC-2D-04 "Little Rocket" Backyard Roller Coaster

"I know what you're all thinking, and I've come to the same conclusion: Two backyard roller coasters are just not enough…." Paul Gregg, January 2015

I realized my younger grandchildren, between 2 and 5 years old, were not going to get on the Negative G or Smaug the Terrible, so I set about designing and building a smaller roller coaster especially for them. I wanted to explore Ackermann steering, and used the "Little Rocket" to do so. I also want to explore the idea of a transportable track, built in sections on a flat surface, unlike the first two coasters which were custom fit to uneven ground. I call the Little Rocket a 3D coaster, but it primarily separates peaks and dips from left/right turns, so you might call it a 2.5D coaster, as opposed to the Smaug coaster, which combines elevations changes with banked curves nearly everywhere. Building on my experience with the first two coasters, the Little Rocket is the best designed and fabricated of the three.

Pretty much the coolest garage in the world

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8.8 Little Rocket BYRC Summary

- Total materials cost: around $450 for both track and cart
- Labor estimate: about 50 hours
- Time from design to finish: 2.5 weeks!

Research and development is a lot like path finding in the woods. The trail you haven't gone down seems to look appealing when you're in the middle of the problems of the trail you are on. But that's what researchers do, they go down an unknown path to see what's there, to see what the problems and risks will be.

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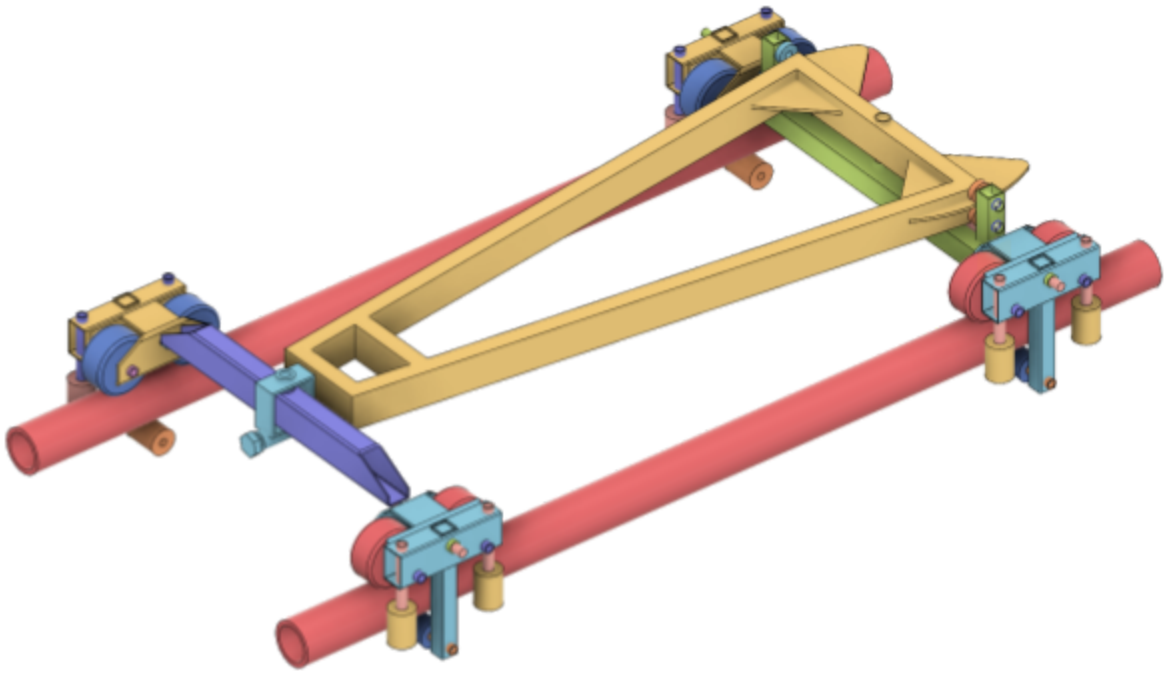
9.0 Advanced Cart Designs

Unable to suppress the engineering instinct to make it better, I generated some more designs which look pretty good, at least in a CAD model. I started using a much better CAD program about this time. Autodesk Fusion 360 is available to students and startups making under $100K per year. I will include in this chapter some cart designs, and cart design features, which I think merit further consideration.



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About the Author

Paul Gregg is father of four, grandfather of six, and a retired engineer. He had a childhood love of all things mechanical. He visited his grandfather's remote ranch in Wyoming where he was exposed to a life of mechanical wonders, from tractor hydraulic lifts, to an huge hay threshing machine a.k.a. spaceship to the moon. He dis- and re-assembled nearly every mechanical object in the Gregg household, with varying results. His favorite toys were a 1960's Gilbert Erector Set, with a powerful geared electric motor, and a Wilesco D1 single-acting-piston live steam engine, which he played with until the boiler burned through. When the carnival came to town, he was the kid looking under the rides at the whirling gears. Paul earned a Bachelors of Science degree in Mechanical Engineering at the University of Utah. His career at The Boeing Company centered mainly on development of advanced aerospace structures of composites and

titanium, advancing the processes of welding, diffusion bonding, and adhesive bonding. He was Engineer of the year of the Boeing Aerospace Division in 1988, was made an Associate Technical Fellow, and holds 30 US and foreign patents. His career touched a wide variety of aerospace programs, including short range missiles, large launch vehicles, space structures, hypersonic vehicles, military fighters, military transports, supersonic laminar flow control flight experiments, and a variety of new structures on commercial aircraft, including the 787 and 737MAX. Paul and his wife Debbie are prolific world travelers, and Paul's idea of a perfect souvenir is a miniature stirling cycle engine from Germany, a DaVinci clock from Italy, a putt-putt boat from Holland, or a toy steam engine from England. He currently owns and operates three backyard roller coasters.

Online Resources:

http://backyardrollercoasters.org/

YouTube Channel:

https://www.youtube.com/user/psg20101

Spreadsheets Used in this Volume II and available on the website:

Banked turn spreadsheet

"Smaug the Terrible" track performance

"Little Rocket" track performance

Autodesk Fusion 360 CAD models available at
https://gallery.autodesk.com/fusion360/users/8F6CPFTCMYPX