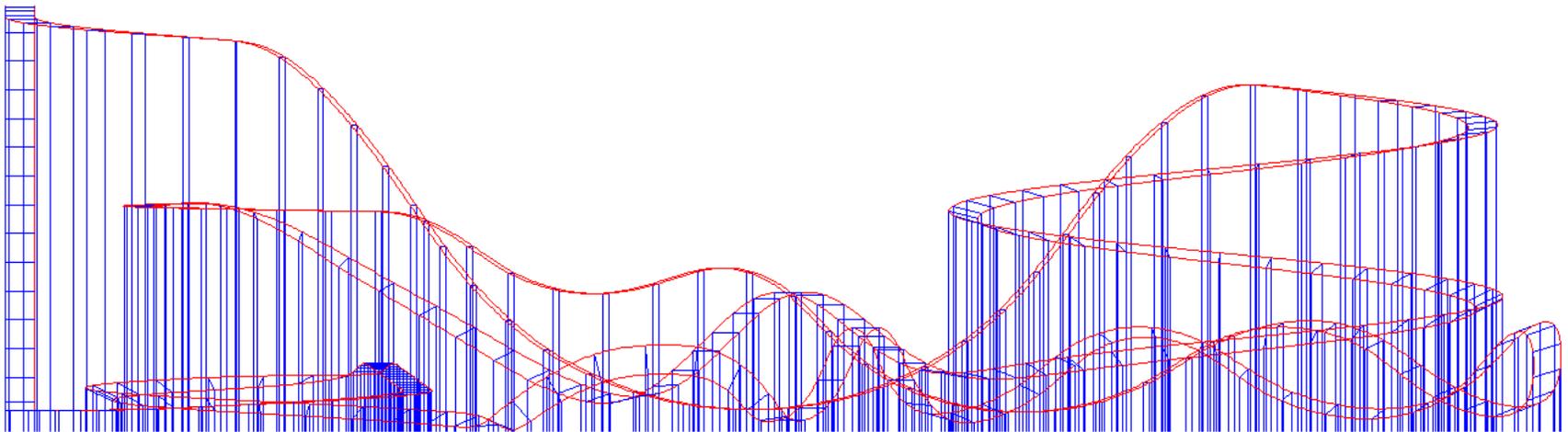
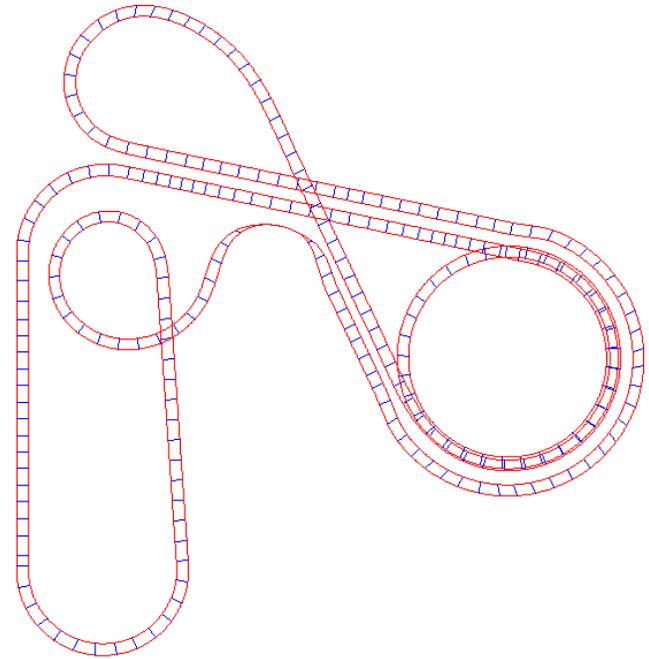


Roller Coaster Design:

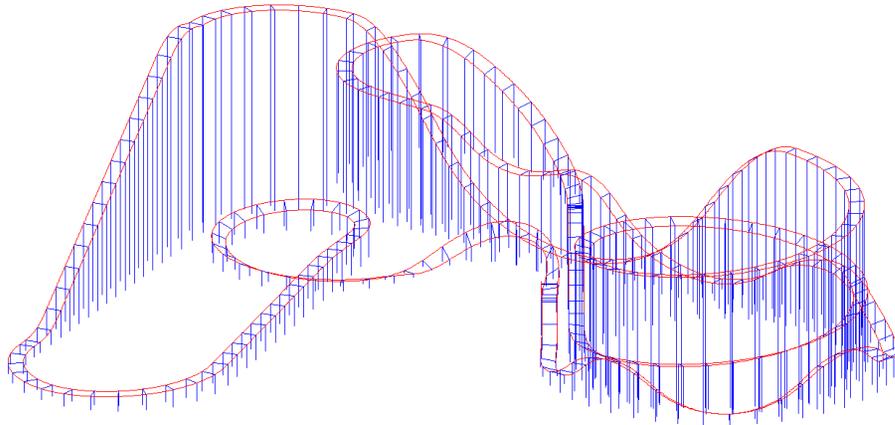
“David”

Designed by Travis Rothbloom

TROTHBL1@gmail.com



Introduction

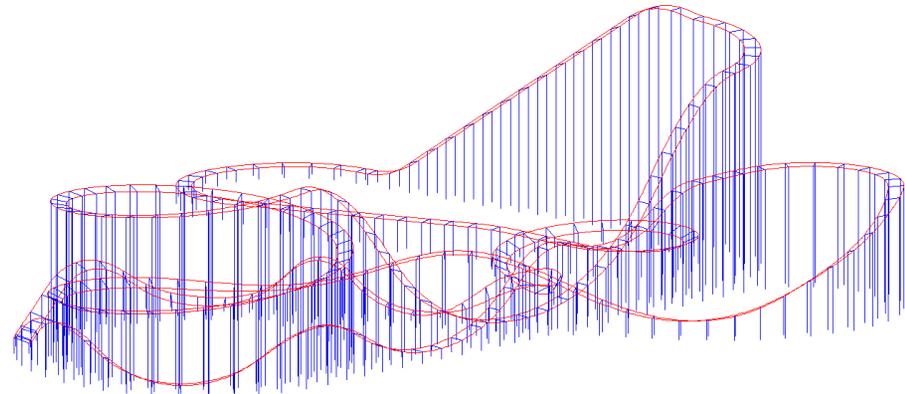


“David” is the culmination of my college senior engineering project (E90) and represents the logical progression between designing roller coasters in NoLimits Roller Coaster Simulation and my ultimate dream of becoming a professional roller coaster designer. While the

name “David” was chosen for multiple reasons, the one most relevant is the design’s aim of being a relatively small wood roller coaster while still providing the intensity of larger, more “Goliath” type rides.

This document will briefly explain the design process and the philosophy behind the ride. Inspiration was taken from many real-life roller coasters to create a sensible layout. Due to a lack of specific information available, g-force values were generally chosen to be in accordance with what has been accepted by the No-Limits community.

As shown in Figure 1, the design was calculated using an Excel spreadsheet. All 3D images were produced with a custom program written for Matlab. Please refer to the E90 report for a much more thorough explanation on the design methods.

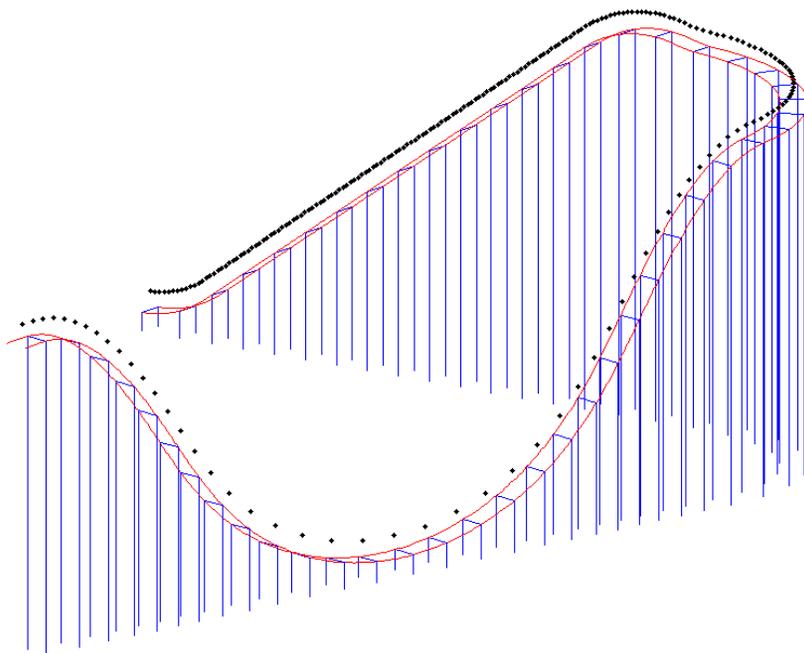
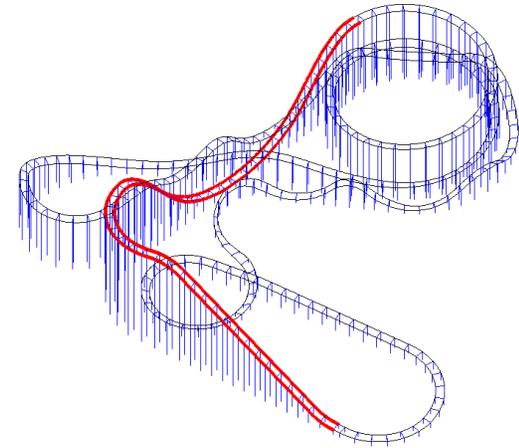


	A	B	C	D	F	H	J	M	N	O	P	U	V	W	AD	AO	AP	AQ	AR	AS	AT	AU	AV	AW
1	Time	Vert G	Lat G	Roll	Pitch	Yaw	RV(ft)	RL(ft)	X (ft)	Y (ft)	Z (ft)	V (ft/s)	g (ft/s^2)	Notes										
2	0.00	1.00	0.00	0.00	0.00	0.00	15.00	0.00	0.00	5.00	0.00	7.33	32.20	Incline to lift hill										
3	0.01	1.11	0.00	0.00	0.00	0.00	15.00	0.00	0.07	5.00	0.00	7.33		Values are Fixed										
4	0.02	1.11	0.00	0.00	0.28	0.00	15.00	0.00	0.15	5.00	0.00	7.33	step											
5	0.03	1.11	0.00	0.00	0.56	0.00	15.00	0.00	0.22	5.00	0.00	7.33	0.010	Values Change to Govern Track Shape										
6	0.04	1.11	0.00	0.00	0.84	0.00	15.00	0.00	0.29	5.00	0.00	7.33												
7	0.05	1.11	0.00	0.00	1.12	0.00	15.00	0.00	0.37	5.00	0.00	7.33	Vert F	Values Result from Change in other Column										
8	0.06	1.11	0.00	0.00	1.40	0.00	15.00	0.00	0.44	5.01	0.00	7.33	0.017											
9	0.07	1.11	0.00	0.00	1.68	0.00	15.00	0.00	0.51	5.01	0.00	7.33												
10	0.08	1.11	0.00	0.00	1.96	0.00	15.00	0.00	0.59	5.01	0.00	7.33	Lat F											
11	0.09	1.11	0.00	0.00	2.24	0.00	15.00	0.00	0.66	5.01	0.00	7.33	0.017											
12	0.10	1.11	0.00	0.00	2.52	0.00	15.00	0.00	0.73	5.02	0.00	7.33												
13	0.11	1.11	0.00	0.00	2.80	0.00	15.00	0.00	0.81	5.02	0.00	7.33	Heartline (ft)											
14	0.12	1.11	0.00	0.00	3.08	0.00	15.00	0.00	0.88	5.03	0.00	7.33	2.50											
15	0.13	1.11	0.00	0.00	3.36	0.00	15.00	0.00	0.95	5.03	0.00	7.33												
16	0.14	1.11	0.00	0.00	3.64	0.00	15.00	0.00	1.03	5.04	0.00	7.33	Width (ft)											
17	0.15	1.11	0.00	0.00	3.92	0.00	15.00	0.00	1.10	5.04	0.00	7.33	3.50											
18	0.16	1.11	0.00	0.00	4.20	0.00	15.00	0.00	1.17	5.05	0.00	7.33												
19	0.17	1.11	0.00	0.00	4.48	0.00	15.00	0.00	1.25	5.05	0.00	7.33	Supports (ft)											
20	0.18	1.11	0.00	0.00	4.76	0.00	15.00	0.00	1.32	5.06	0.00	7.33	6.00											
21	0.19	1.11	0.00	0.00	5.04	0.00	15.00	0.00	1.39	5.06	0.00	7.33												
22	0.20	1.11	0.00	0.00	5.32	0.00	15.00	0.00	1.46	5.07	0.00	7.33												
23	0.21	1.11	0.00	0.00	5.60	0.00	15.00	0.00	1.54	5.08	0.00	7.33												
24	0.22	1.11	0.00	0.00	5.88	0.00	15.00	0.00	1.61	5.09	0.00	7.33												
25	0.23	1.11	0.00	0.00	6.16	0.00	15.00	0.00	1.68	5.09	0.00	7.33												
26	0.24	1.11	0.00	0.00	6.44	0.00	15.00	0.00	1.76	5.10	0.00	7.33												
27	0.25	1.10	0.00	0.00	6.72	0.00	15.00	0.00	1.83	5.11	0.00	7.33												
28	0.26	1.10	0.00	0.00	7.00	0.00	15.00	0.00	1.90	5.12	0.00	7.33												
29	0.27	1.10	0.00	0.00	7.28	0.00	15.00	0.00	1.97	5.13	0.00	7.33												
30	0.28	1.10	0.00	0.00	7.56	0.00	15.00	0.00	2.05	5.14	0.00	7.33												

Figure 1: Spreadsheet Design Interface - Shown above in the spreadsheet is when the train enters the lift hill, as seen under the “Notes” column. The spreadsheet’s default method is to input curves for vertical g, lateral g, and roll to create the corresponding track curvature. 2D plots are produced in Excel under the Z, Y, and X tabs. A Palette tab enables design by other methods such as designing with specified curvature radii and having g-forces subsequently calculated to ensure they are in safe (and fun) limits. Here, many columns used for intermediate calculations are hidden from view; please refer to the Ego report for a full explanation.

First Drop

The first drop on a roller coaster is often considered the scariest by its riders. This is probably due to many things, namely that the preceding lift hill builds up anticipation and that the first drop is usually the largest one on the ride. One point that I feel is overlooked is that the first drop is usually the largest change in velocity on the ride. With this in mind, we can see how elements between the lift hill and the first drop can add to the excitement.

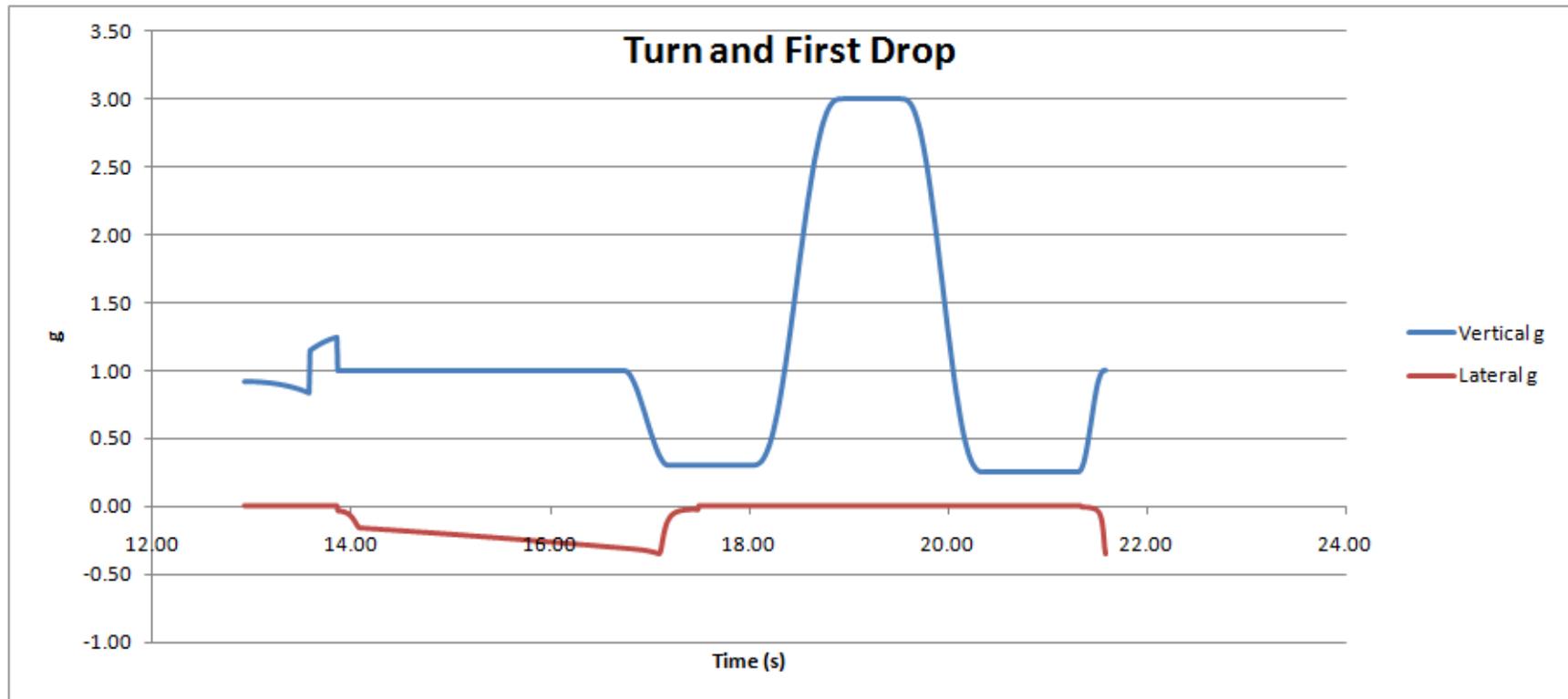


Black dots represent the location of the middle car every tenth of a second

The first row in a roller coaster train is often the only one that can fully see what track lies ahead. While this may seem like a downside to riding in the “other rows”, one benefit is the element of surprise. What has been coined as a “pre-drop”, a little dip after the lift hill that has dynamic benefits, also serves to signal a false start to the “other rows”. A slow turn after the lift then gives the riders a view of the track (quick enough not to ruin any surprises). While this describes the beginnings of many existing roller coasters, a small nuance incorporated here was inspired by Six Flags Great Adventure’s “El Toro”, where the crest of the drop starts before the

turn is over. This provides just a little dose of lateral g (more towards the rear of the train) to the experience. The first drop also goes underneath other track, creating a “head-chopper” illusion for riders.

The instantaneous g-force changes at the beginning of the vertical g curve arise from the vertical radii of curvature dictating the track geometry at that location. However, the amplitude of the changes is small

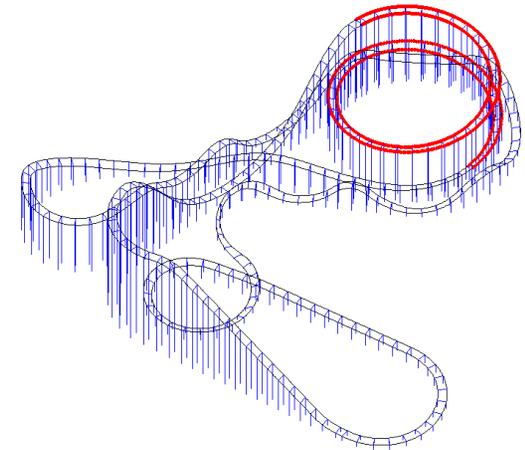
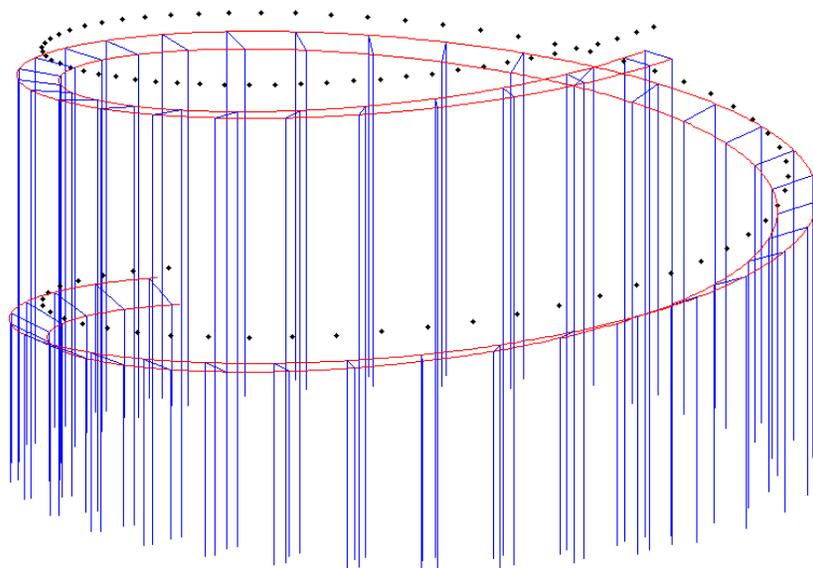


enough to remain safe and not require a smoother transition. All other g-force transitions are done over a period of time to ensure comfort. One can also see that the vertical g decreases before the lateral g goes to zero, implying that the drop starts before the turn is completed. The lateral g that arises at the end is the lead into the next element, a large downward helix.

Large Downward Helix

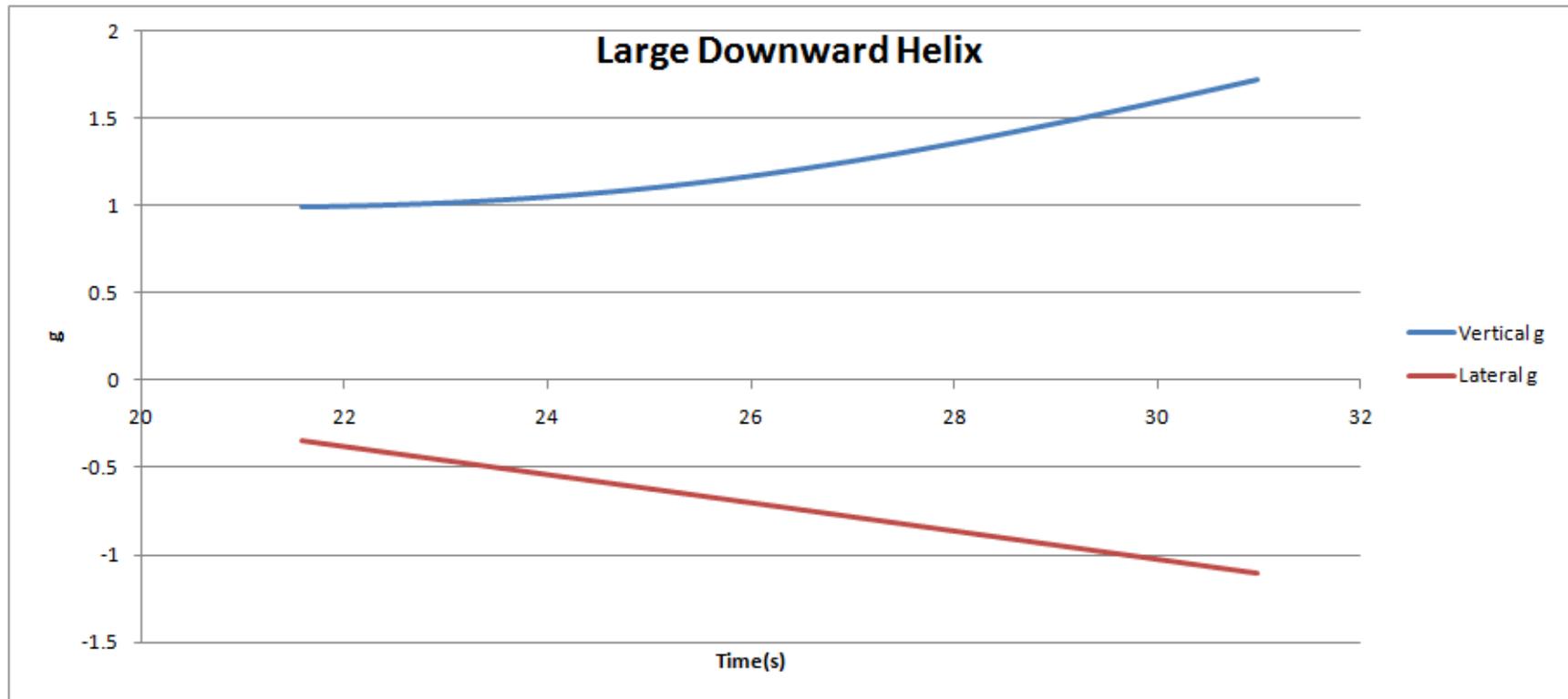
Downward helices are a crowd favorite in terms of roller coaster elements. From the high speed downward helices like Darien Lake's "Ride of Steel" to the high intensity downward helices like Six Flags Magic Mountain's "Goliath", the combination of prolonged rising speed and g forces has always been a winning formula.

This downward helix was designed by first finding the coordinates of the helix and then setting the lateral g to increase linearly for the entire element, which in turn dictated the roll angle along the helix. The coordinates were found by designing for unbanked, constant pitch, constant speed, and constant local lateral radius of curvature track; these conditions ensured that a constant global lateral radius was obtained.



This was desired in order to simplify the wooden support structure; the helix heavily mirrors those of Fredrick Church's "Airplane Coaster" which had constant global lateral radii on its helices for the same reason. Please note that the supports in the 3D image to the left are just an approximation to help visualize the track that are automatically generated by the code; optimally, the same bents that would support the lower track would support the corresponding upper track as well as in the "Airplane Coaster".

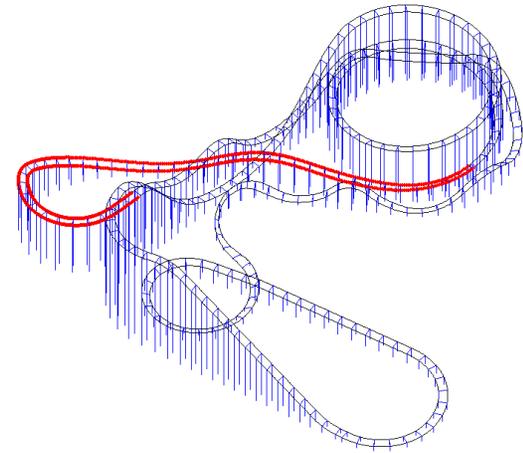
Once the coordinates were found, the spreadsheet columns were reworked to solve the equations in a reverse manner. Thus the lateral g and the coordinates now served to be the dictating factors of the riders' vertical g and roll angle. As shown in the g-force graph, the lateral g and vertical g increase (negative lateral g implies that the seat is forcing riders to their right) happens over the span of almost 10 seconds.



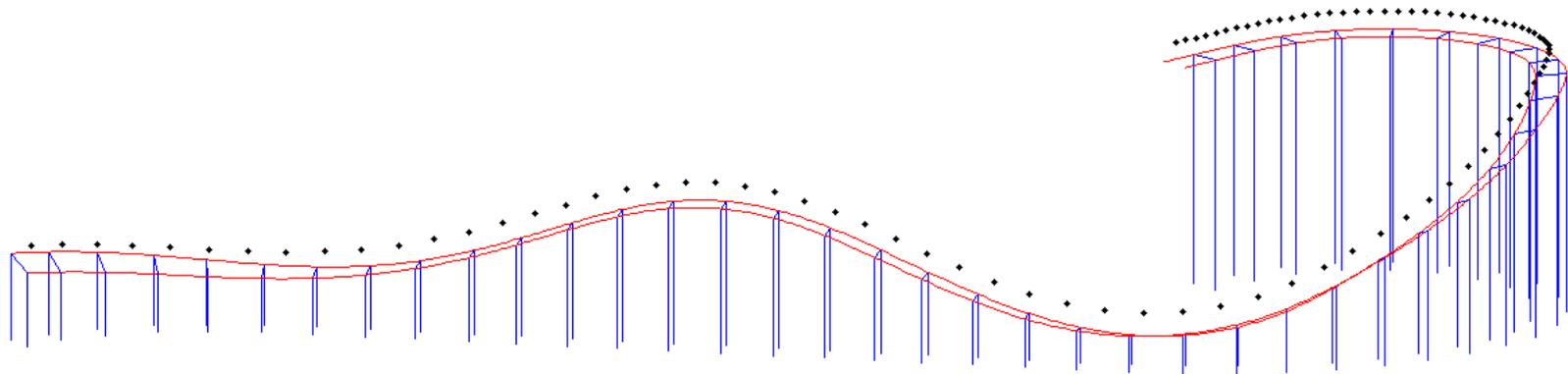
While the lateral g was specified, the vertical g was merely calculated based off the other factors to ensure that it remained within the riders' tolerances. Although not shown above, the roll angle also increased over time in a similar manner as one would expect.

Speed Hill and Slow Turn

A roller coaster's pacing should be as dynamic as its actual motion, and after two larger elements where the speed of the train was drastically decreased towards the highest points, it is time to alter the ride's tempo. The next element changes does this by staying lower to the ground while getting high enough to allow enough clearance for the first drop underneath. The speed hill that follows the pullout of the downward helix is also designed to put riders in a state of zero-g such that the speed of the ride is the main sensation during this time.

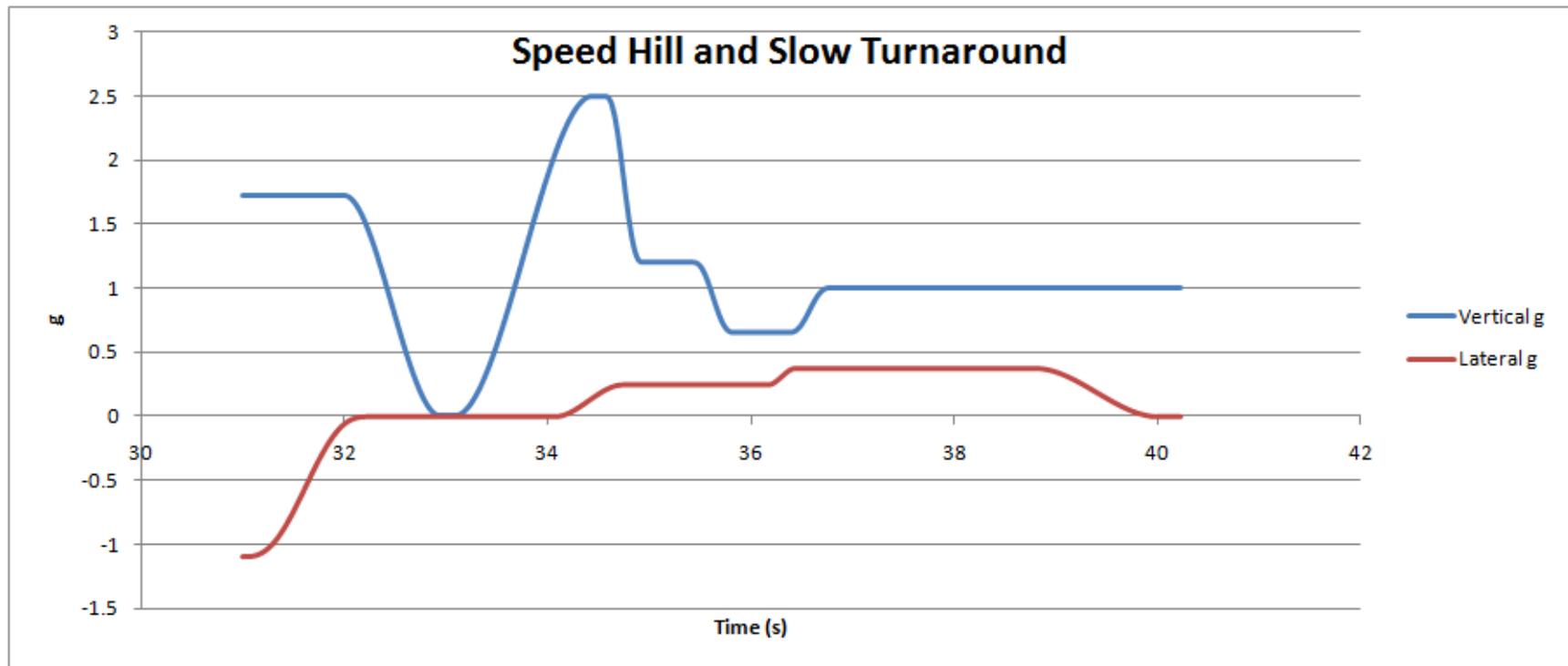


After the speed hill, another change in pacing occurs where the train is brought to its slowest speed since the lift hill. The riders are swept up to their left in a banked turn that eventually becomes flat at its apex, producing a little lateral g along the way. As shown in the overview, the track winds back around to become parallel with the first drop, signifying that the second half of the ride is about to begin. By design,



this sets up riders into expecting a similar ride experience to that of the first half, but as shown later in this paper, this is hardly the case.

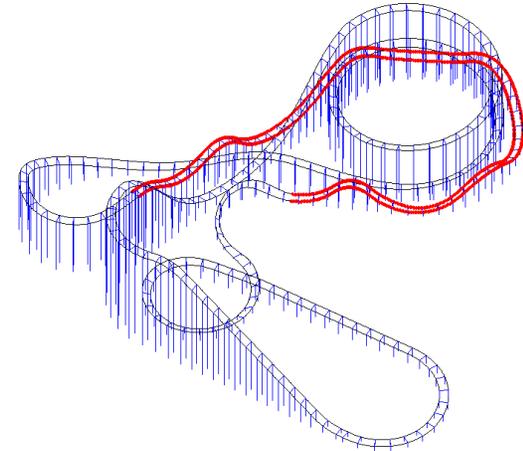
The beginning of the g-force graph below shows the pullout from the downward helix. The positive vertical g is kept at around 1.7 in order to set the track up for the speed hill. The hill sends riders in to a



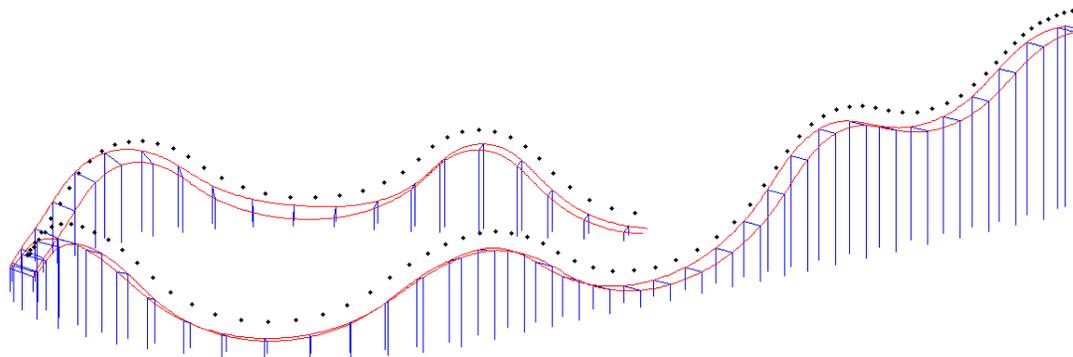
state of zero-g as mentioned before, and as the vertical g ramps back up to 2.5, the lateral g starts to kick in with the roll (not shown) to turn the track to the left. Different g-force levels for each direction are used for specific amounts of time (with smooth transitions in between) until the track is parallel with the first drop, where then both g are brought to their resting states. Riders are given a chance to catch their breath here before the second half of the ride, similar to passing through a mid-course brake run.

Double-down, Distorted Helix, and Ejector Hill

Instead of dropping all the way to the ground like the adjacent first drop, the second half of the ride starts out with some deception with a double-down, where the initial drop is cut short to be followed by a quick up then back down, producing a good amount of airtime. The ride continues to follow the footprint of the previous track but a very different experience is in store for the riders.



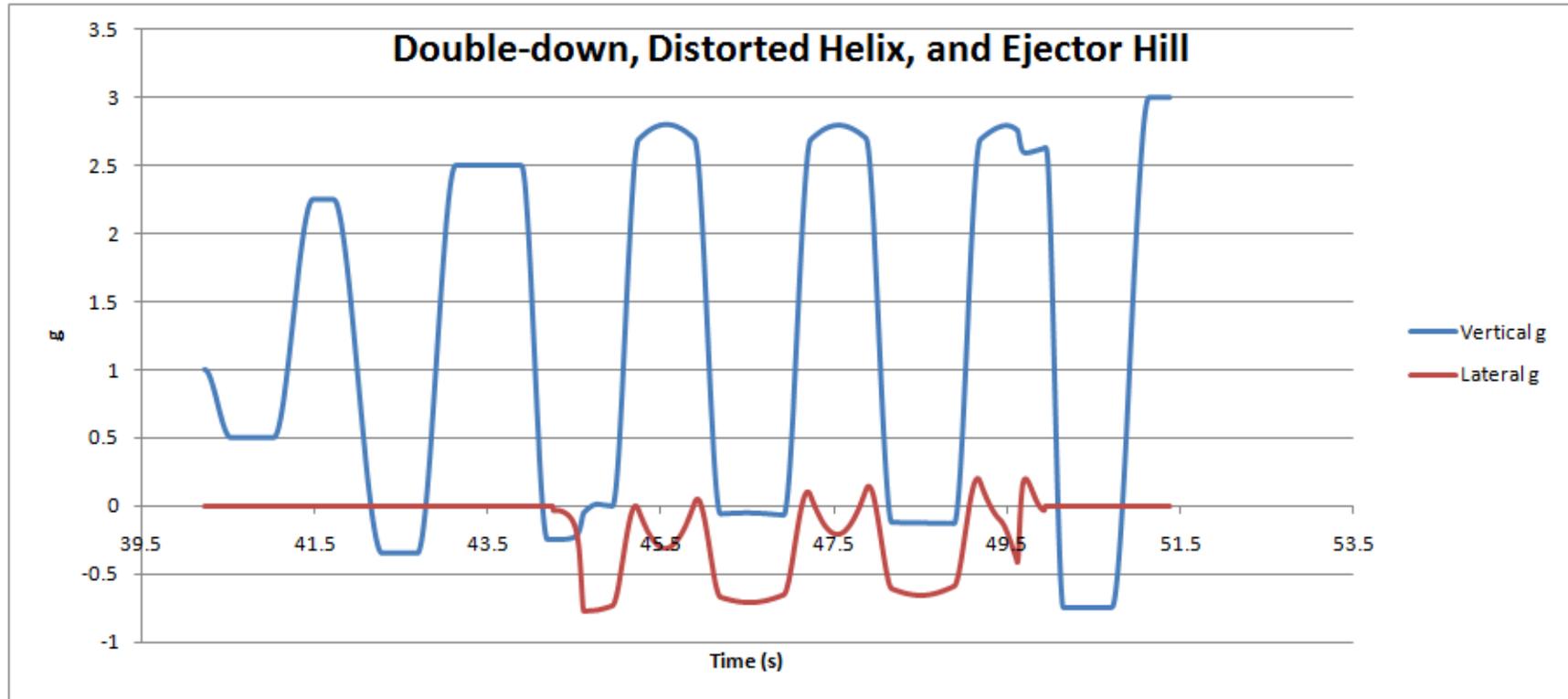
What follows is what I consider the highlight of the ride, which consists of three similarly shaped hills with almost identical behaviors leading up to what appears to be a fourth such hill, yet this last hill has a surprise in store for riders in terms of forces. The first three hills are banked into a constant global lateral radius helix footprint, which draws off of inspiration from various Custom Coasters International wooden coasters including Parc Astérix's "Tonnerre de Zeus" and Knott's Berry Farm's "Ghost Rider". Again, designing with a constant radius simplifies the required supporting structure, which is desirable in wooden coasters that utilize many frames and trusses. These hills were designed similarly to the large downward helix in that coordinates were found using zero-roll track and a



constraining geometric relation was used to ensure the radius was constant. With the coordinates then set, the roll was adjusted to give the final track shape.

By the time the train is about to enter the surprise ejector hill, the lateral g and banking are both brought to zero. Riders will be expecting another hill of similar forces but instead will experience 3 times as much negative g with no lateral g.

The g-force graph for these elements is by far the most dynamic. One can infer by the shape of the curves

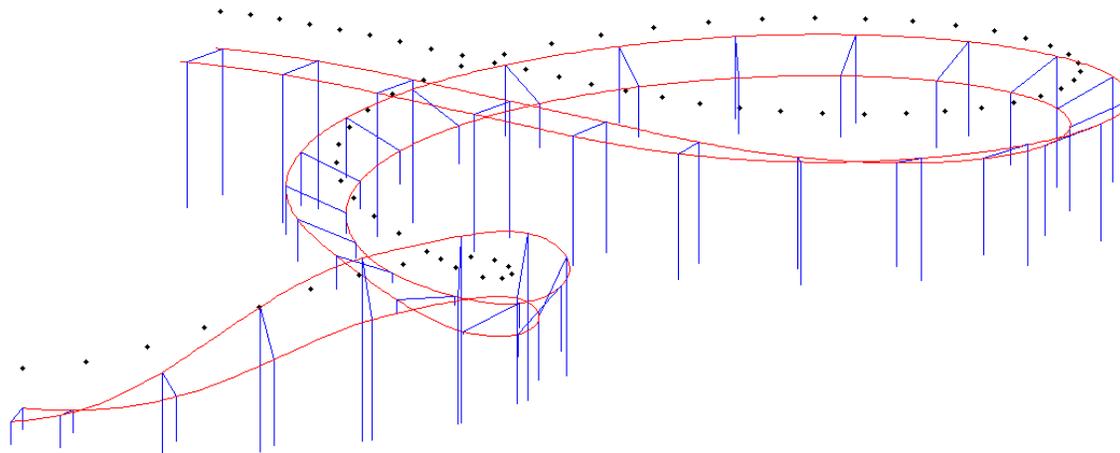
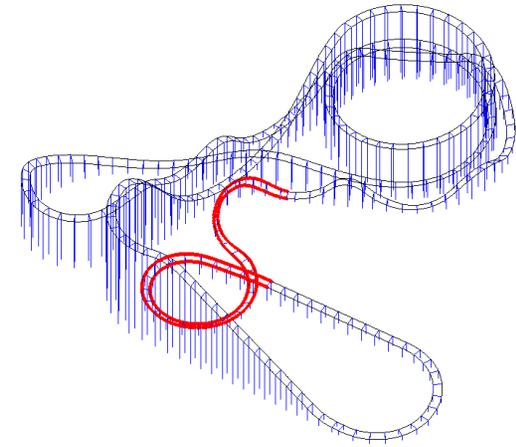


that the g-forces were calculated as a result of the geometry rather than used as inputs for the bulk of this time period. Not only does the ejector hill have the most airtime of any of the ride's elements, it also has the ride's greatest positive g right after, creating the largest g differential throughout the ride. This coupled with the extended lead-in to the ejector hill make it the undisputed climax of the design.

90-degree Turn and Upward Helix Finale

The wooden coaster 90-degree (give or take) turn is a more recently emerging element that is currently being implemented by almost all major wooden coaster designers. Despite its rather complex appearance, the turn is one of the most forceless parts of this ride, something that is needed after exerting so many forces on the riders just before. The other thing about the turn is that its placement breaks the layout from following the previous track plan. Whereas riders may expect to travel over the first drop yet again, they are surprised to veer from that course.

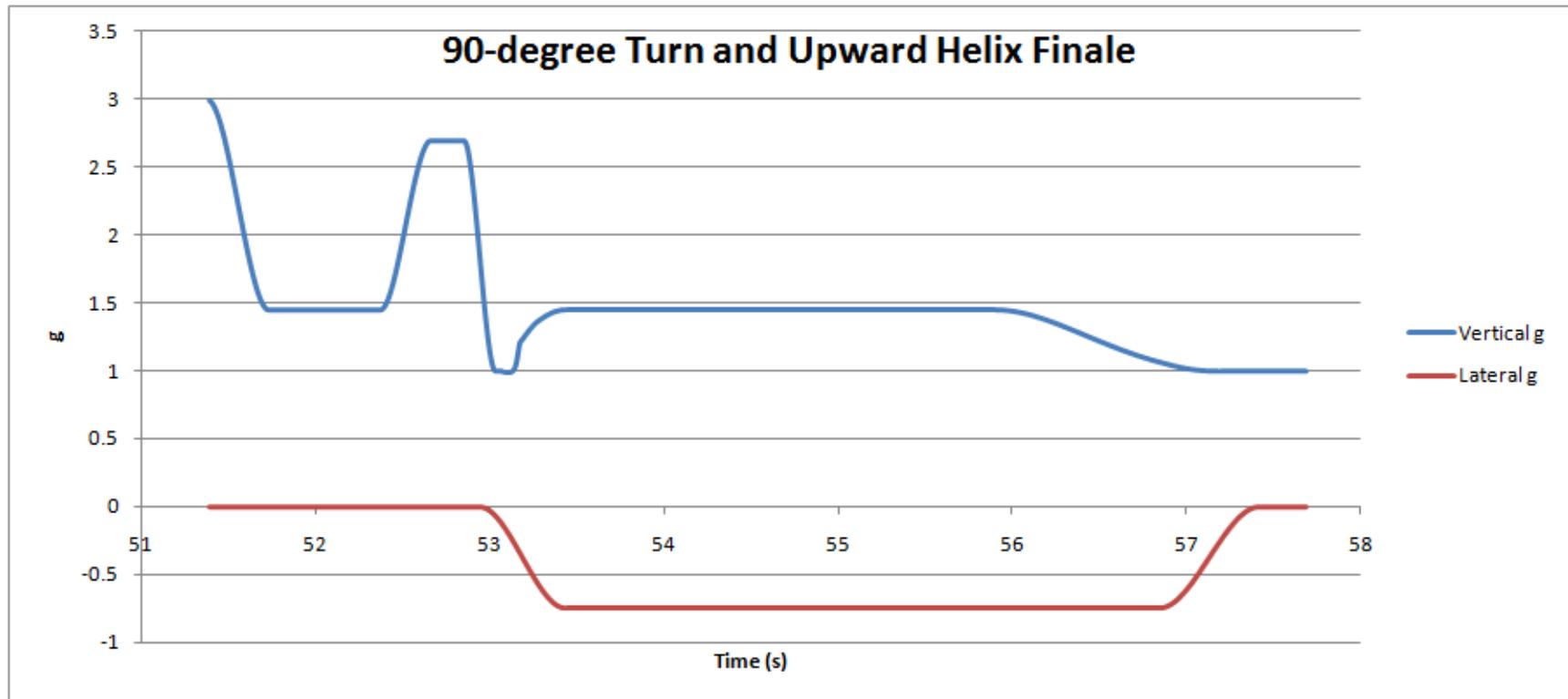
The relatively forceless 90-degree turn is immediately followed by an upward helix that applies a good amount of lateral g. I have found upward helices to work well as the endings for a roller coaster layout for they are a good way to create an exciting finale yet the fact that the train is traveling more slowly than



when it entered signals that the conclusion of the ride has been reached. The slower velocity also makes less work for the final brake run to slow the train. Some real roller coasters that make good use of an upward helix as a finale include Busch Gardens Tampa's "Kumba", West Edmonton Mall's

“Mindbender”, and even Dutch Wonderland’s “Kingdom Coaster” which this helix was modeled mostly after.

By this point, analysis of the g-force graph should be fairly straightforward. During the flat helix, a geometric relation was used relating the local vertical radius to the local lateral radius in order to keep the



pitch angle constant. Thus, the vertical g was calculated based in the lateral g input. The helix ends when the track is aligned with the brake run and, ultimately, the loading station. There is ample space for any required transfer track, train storage track, and other machinery needed for the lift hill.

End Note

I feel I have accomplished my goal with this ride, which was to create a small yet exciting roller coaster with many real-life, proven influences found in some highly-praised rides. As mentioned before, one thing to consider is that the g-force values were chosen to fit within a threshold that may or may not be what is used in the industry. Other than that, the main concern that I had with this system of g-force micromanagement was that the ride would lack any charm. Yet I feel like the measures I took to prevent the design to seem over-engineered paid off in creating a roller coaster I myself would love to ride and, hopefully, the amusement park attendees would as well.

