Year 12 physics extended experimental Investigation

An experimental analysis of Dreamworld’s “Tower of Terror 2”.

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# Abstract

# Introduction

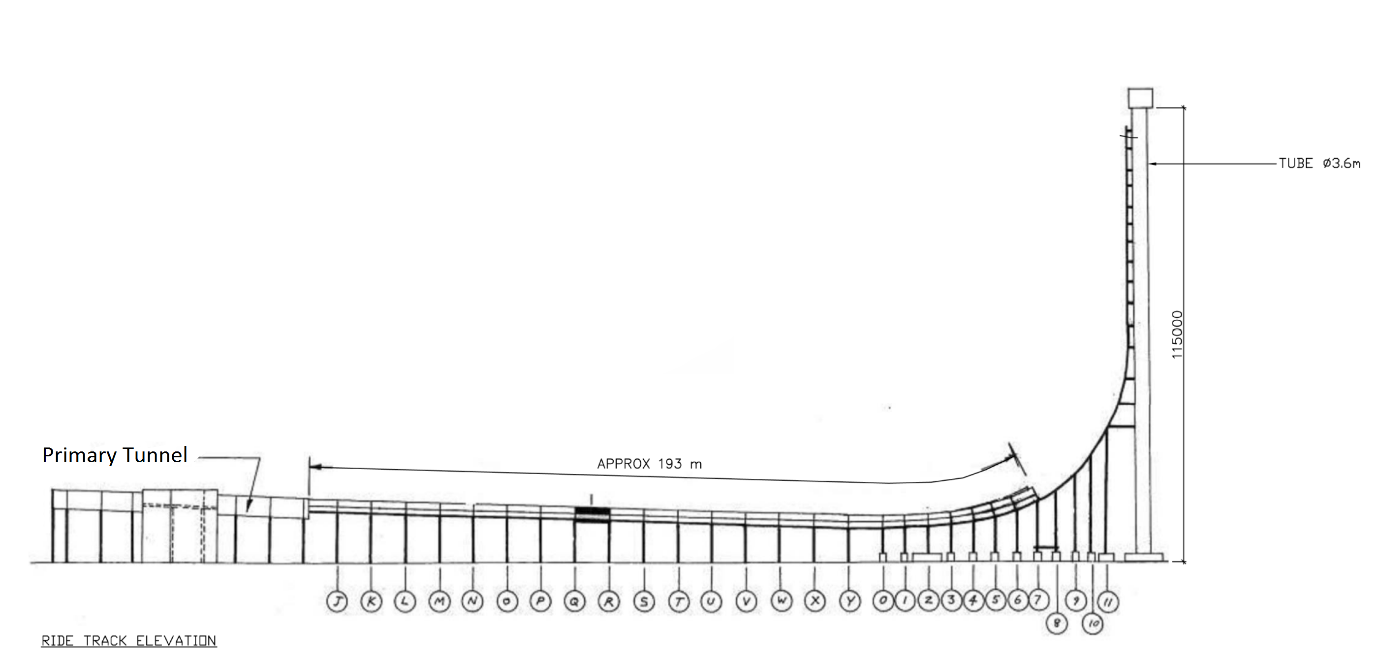


Figure 1: Tower of Terror 2 Schematics

The *Tower of Terror II* is a reverse free-fall ride, residing in the Dreamworld Theme park in the Gold Coast, Australia. Although there are a number of physics concepts that can be examined on this ride, the focus of the following investigation will be drag and energy. The investigation will focus on the kinetic and gravitational potential energy of the ride’s cart at various points, but will further evaluate the kinetic energy of the cart when it leaves and re-enters the primary tunnel (See Figure 1)

An object that possesses motion or a position also possesses mechanical energy. Mechanical energy is defined as the sum of potential and kinetic energy, or

Figure 2: Mechanical Energy. Equation from Physics Classroom Online

Where is potential energy, and represents kinetic energy. Since this ride only deals with gravitational potential energy, the formula for mechanical energy can be rewritten as

Figure 3: Modified Mechanical Energy Equation

Kinetic energy is energy possessed by an object in motion, and is defined as the work required to obtain a stated velocity through acceleration. In the Tower of Terror, the cart possesses kinetic energy at every point except for when the cart is momentarily paused at its maximum height. Since the cart is accelerated to approximately 44 during the initial stage (Data from Wikipedia), it exits the tunnel with a large amount of kinetic energy.

Kinetic energy for an object in motion is defined in terms of object mass and object velocity, or more specifically:

Figure 4: Kinetic Energy. Equation from Wikipedia

Where is the mass of the object, and is the velocity of the object.

Gravitational Potential Energy is potential energy possessed by an object that would be converted to other forms of energy if it were to be moved a fixed distance by the force of gravity. It can also be defined as:

Figure 5: Gravitational Potential Energy. Equation from HyperPhysics

Where is the mass of the object, is the acceleration due to gravity, and is height above the resting elevation of the object. Note that on earth, is roughly equal to .

The next section of this document deals primarily with forces due to friction and drag. Force is an action that will cause an object to move, assuming there are no opposing forces acting on that object. Isaac Newton defined force in his second of his three famous laws as

Figure 6: Force. Equation from Isaac Newton

Where is the mass of the object, and is the acceleration of the object in question.

On the Tower of Terror, a measurable amount of energy is lost due to frictional and drag forces. Due to this, the ride will most likely have lost total mechanical energy between the point that the cart exits the primary tunnel and re-enters it. The formula for drag is:

Figure 7: Drag. Equation from NASA

Where is the density of the air, is the velocity of the object, is the drag coefficient, and is the affected surface area of the object. The drag coefficient is reliant on the speed of airflow, the skin friction and form drag of the object.

Dry friction (Hereon referred to as friction) is friction which opposes movement of two objects in motion, which is the secondary resisting force while on the Tower of Terror, the first being drag. Friction is defined in terms of , a dimensionless number, and the normal force of the two objects acting on each other:

Figure 8: Friction. Equation from Wikipedia

Where is the coefficient of friction, and is the normal force (The force perpendicular to the plane of contact between two objects). In the Tower of Terror’s vertical section, due to the majority of force being the force of acceleration due to gravity on the cart, and not the contact between the cart and the rail, is a small, and assumed negligible number. Once the cart enters the horizontal section, due to the entirety of the contact force between the cart and the rail being downwards, the normal reaction is , where is the mass of the cart, and is acceleration due to gravity. As the cart encounters the curve, the normal force increases due to the nature of objects travelling in a near circular motion.

Circular motion, while not the focus of this investigation, is a key factor in the friction experienced by the cart. The centripetal force on the cart as it enters and exits the curve is given by:

Figure 9: Centripetal Force. Equation from Hyper Physics

Where is the mass of the cart, is the velocity of the cart, and is the radius of the theoretical circle that the cart is moving in.

## Accelerometer Positioning

When data is to be collected, the following accelerometer setups are used:

|  |  |
| --- | --- |
| diagram_front  Figure 10: Accelerometer flat on chest (front) | diagram_side  Figure 11: Accelerometer sideways on chest (side) |
| Figure 12: Accelerometer Flat on Leg (leg) |  |

# Aim

To compare mechanical energy at various points on the Tower of Terror, mainly at the exit and re-entry of the primary tunnel.

# Hypothesis

Energy is not conserved in the vertical and curved section due to work done by resistive forces.

# Materials

|  |  |
| --- | --- |
| * Accelerometer | * Tower of Terror |
| * Clinometer | * Accelerometer Vest |
| * Person | * Accelerometer Straps |
| * Laptop |  |

# Method

1. The accelerometer was inserted into the accelerometer vest, and the accelerometer vest was then applied to the person.
2. The accelerometer was started, and the tower of terror was then ridden by the person.
3. The data from the accelerometer was transferred to the laptop, and the accelerometer was reset.
4. The ride was ridden again by the person, with the accelerometer oriented side on in the vest.
5. The data was transferred to the laptop, and the accelerometer was reset.
6. The accelerometer vest was removed and replaced onto the person’s leg, and the accelerometer straps were then applied to secure the accelerometer on the leg.
7. The ride was ridden, and the data was recorded.
8. The angle from the ground to the top of the Tower of Terror was recorded using the clinometer

# Data Selection

See following pages. Note the accelerometer’s position is labelled according to the accelerometer setups above.

The primary selection data was chosen as it displayed the most well defined features. This means that the data has clearly discernable different axis in the first section of the graph. It was also selected for having the lowest amount of noise, meaning that the data fit into a mostly uniform curve, with fewer outliers and a smaller deviation of points across any selected time interval.

## Primary Selection

## 

Figure 13: Accelerometer leg data

## Secondary (unused) Selections

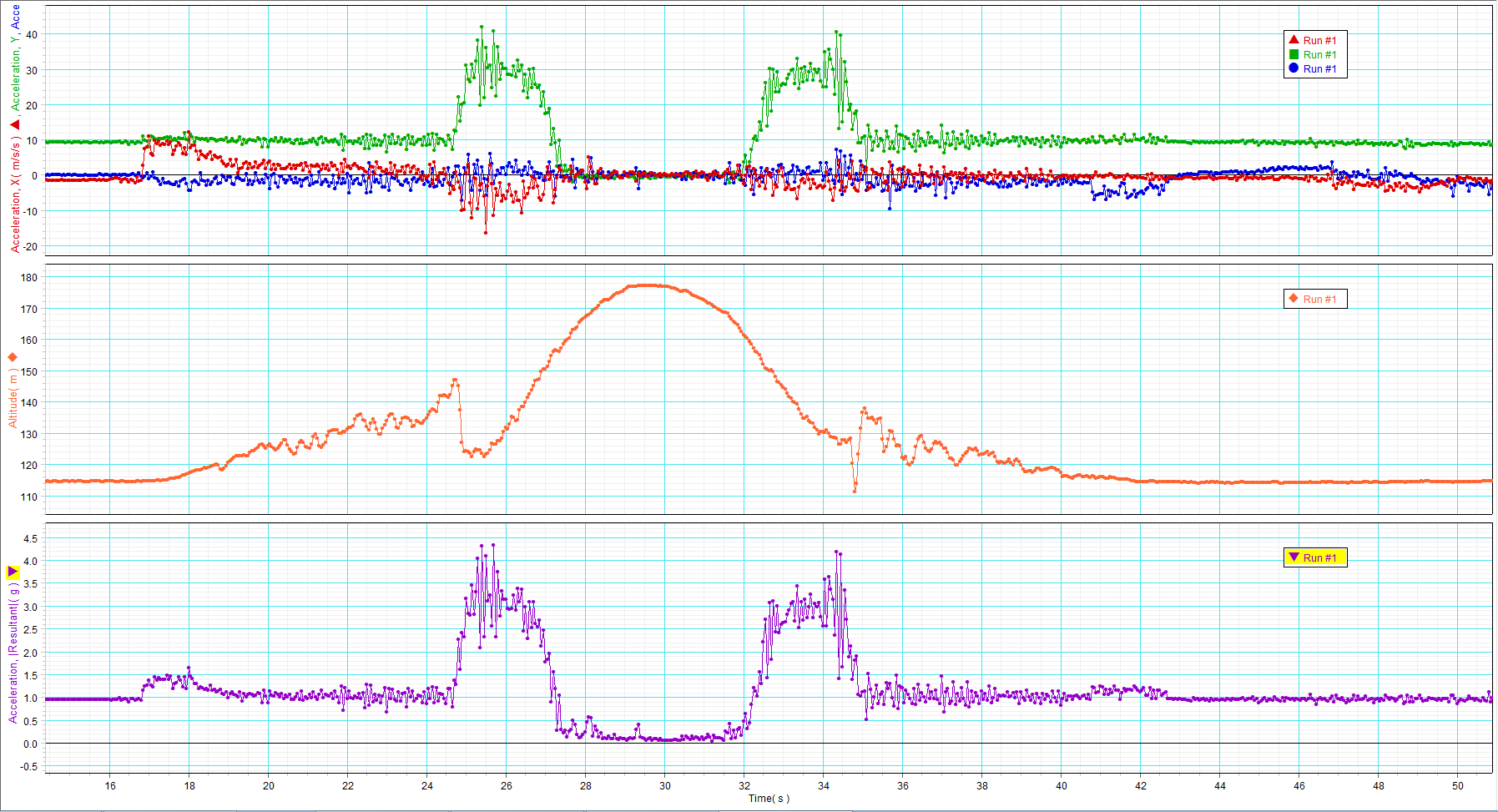


Figure 14: Accelerometer side data

## 

Figure 15: Accelerometer front data

# Critical Points

The following section lists the critical points. Firstly, the critical points will be listed based on the rider’s perception at each point (anecdotal observations). Secondly, the critical points will be listed based on a scale diagram of the ride, and finally, the critical points will be listed on the primary graph.

## Anecdotal Observations

|  |  |
| --- | --- |
| Critical Point | Observation |
| 1 | The ride has started to initially accelerate. The rider is pushed into their forward chest restraints as the cart accelerates to approximately 44 (Wikipedia). The rider feels a constant amount of G-Forces as they are accelerated uniformly. |
| 2 | The cart exits the tunnel. At this point, the ride has already started sloping into the curve. The rider feels a small amount of acceleration into their seat. The cart has reached its maximum velocity and is no longer being accelerated by the magnetic motors. The rider may be momentarily stunned as the ride is exposed to sunlight. |
| 3 | The cart is in the middle of the curve section of the track. The rider experiences the seat pushing into them due to centripetal acceleration. At this time, the rider experiences approximately 4.5 G-Forces. |
| 4 | The cart has exited the curve section, and the ride is moving vertically upwards. The rider experiences a weightless sensation, but since the rider will (in general) have a smaller cross sectional surface area than the ride, they still experience being pressed into the back of the seat, as they decelerate more slowly than the cart. |
| 5 | The cart has reached its maximum height. It possesses no kinetic energy, and is stationary. The rider experiences a 1 G-Force, from the influence of gravity. |
| 6 | The cart has started to fall again. The rider is once again experiencing “weightlessness”, although in practice they will be slightly pressed into their front restraints, as they accelerate more rapidly towards the earth than the ride, due to experiencing a lower amount of drag than the cart. |
| 7 | The cart has once again entered the curve. The rider experiences a large amount of G-Forces, and they feel forced into their seat due to centripetal acceleration. |
| 8 | The cart has exited the curve, and re-entered into the tunnel structure. The rider is travelling at a high speed, but not as fast as they were when they initially exited the tunnel. |

Table : Anecdotal Observations

## Schematic Points

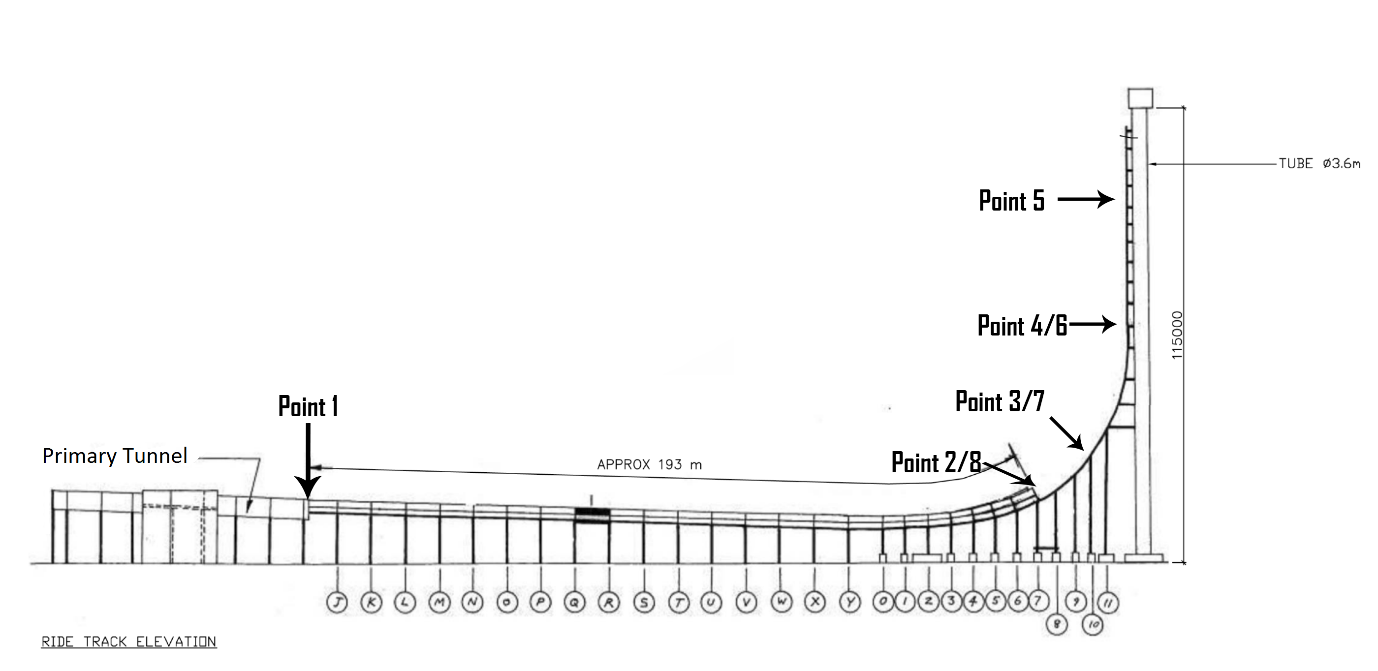


Figure 16: Tower of Terror Schematic with Critical Points identified.

## Data Points

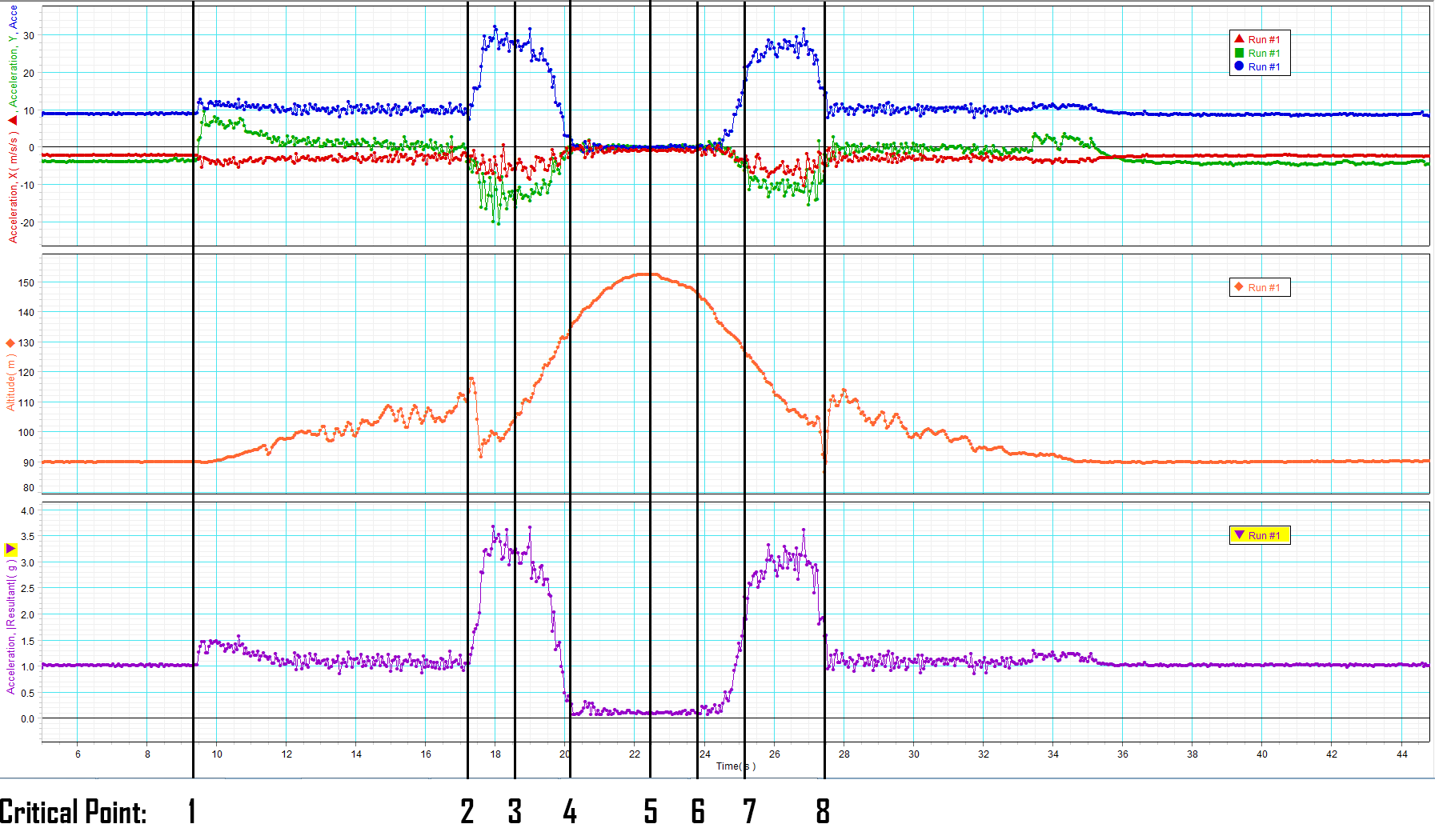


Figure 17: Accelerometer (Leg) Data With Critical Points identified.

Note: See Appendix A for a larger version of above diagram.

# Calculations

The following calculations will aim to show through 3 different methods that energy is lost during the vertical and curved sections of the track.

## Found Ride Constants (Wikipedia)

|  |  |
| --- | --- |
| Constant Name | Value |
| Height of Tower | 115 m |
| Max Height of Cart | 100 m |
| Max speed | 44 |
| Max g-force | 4.5 g |
| Mass of Cart | Kg |
| Mass of Passengers | Kg |

Table : Ride Constants Obtained From Wikipedia

It should be noted that the maximum height of the cart is not totally correct, as can be shown with equations of energy.

## Maximum Height of Cart:

Assuming:

In theory, , So

According to the data from Wikipedia, m, and

Therefore, more work is required to determine velocities and maximum height of the cart. Note that the kinetic and gravitational potential energies will not be the same, as resistive forces remove useful energy, but the kinetic energy must be the greater of the two figures. As this is not the case, the values given by Wikipedia must be wrong.

## Actual Maximum Height of Cart

The actual maximum height of cart is given first through accelerometer altimeter data, secondly through video data, and thirdly through trigonometric methods with data from a clinometer.

Accelerometer altimeter data measures pressure to determine height above sea level. Since the starting height of the cart is its lowest height, the data can be manipulated to show maximum height above starting point obtained. See the following page for the original and modified altimeter data.



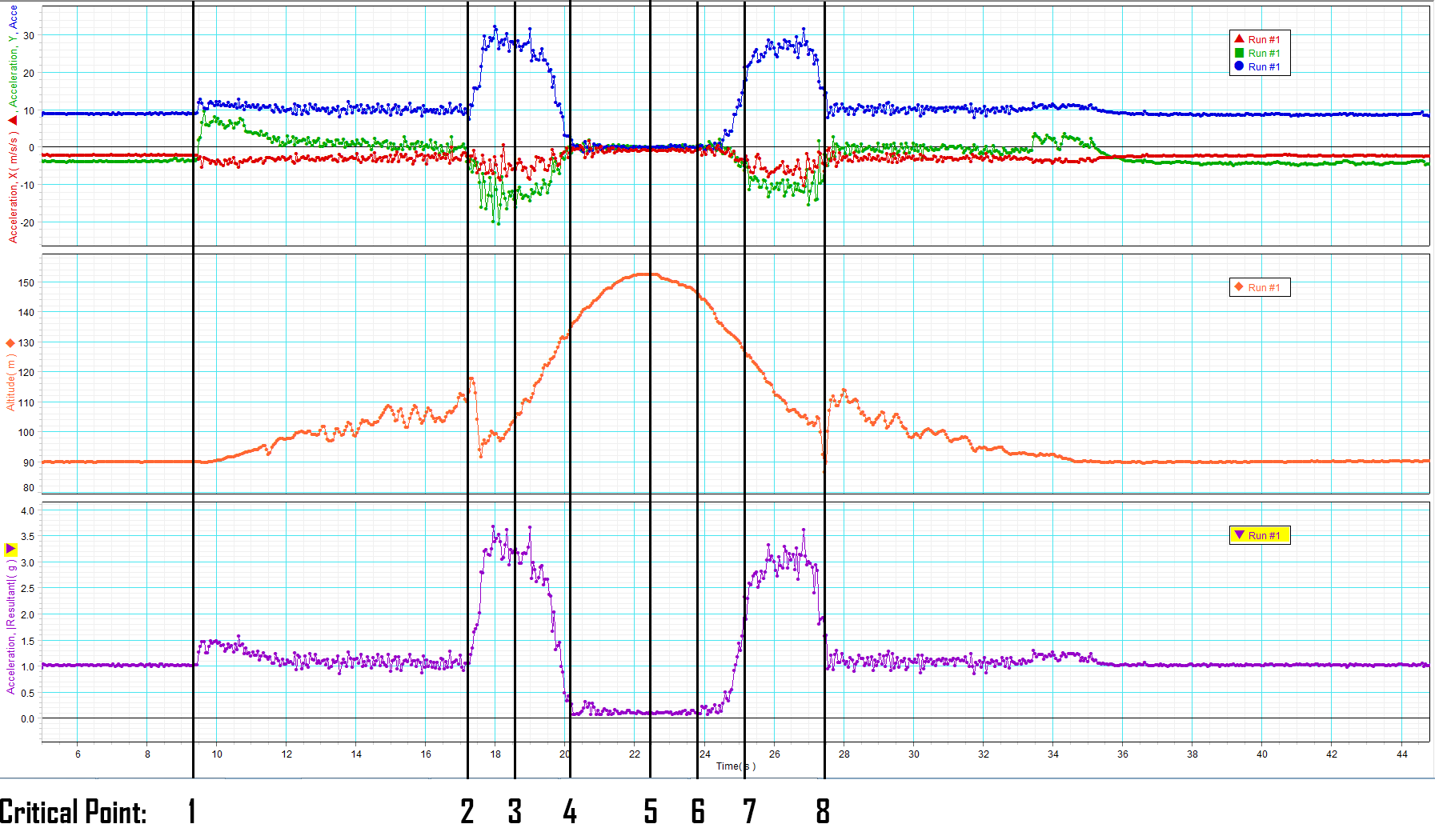
Figure : Original Altimeter Data (Orange) and Modified Altimeter Data (Brown)

In the above diagram, two sets of altimeter data can be seen. The orange set is the original altimeter data, obtained from the ride. The brown set is the data where all points have had their values reduced by 90, to give height above the cart’s resting position.

For the brown set of data, in the upper right corner of the diagram, it can be viewed that the “Max.” value is equal to 62.5m. This is the maximum height the cart obtains, and is of a large difference when compared to Wikipedia’s value of 100m.

# Appendices

## Appendix A



Appendix A: Accelerometer (leg) data with critical points identified