# Cycling Dynamics and Measurements

*Mountain Bike Suspension Analysis & Data Acquisition*

by

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# Abstract

The purpose of this Senior Project was to perform a literature review on mountain bike design and test their suspension systems to better understand their differences in dynamics. This year long project was broken down into two separate phases, while each phase was conducted over the length of one semester. The first phase was the initial literature review where heavy amounts of research was performed. With this research, key differences and benefits that some designs may have over others and quantify the differences that many manufacturers in the industry may make their design better. Based off the findings, categories were then created for mountain bikes based off certain bike designs, their hardware and geometric parameters. Then a handbook was compiled which not only defined many of the important technical terms used to describe the behavior of any design, but also evaluates many of the top existing suspension designs on the market, concluding the first phase of this project. The second phase of this project was the testing for the front and rear suspension. The overall scope of this phase was to fine tune mountain bike suspension systems using the adjustments available to riders. These include sag, rebound, and compression. The latter two have multiple adjustments for effecting high and low speed differently. Several different methods for tuning the system were used and compared. With this, it was possible to not only define specific goals in tuning suspension to make it more effective but were also able to quantify the benefits of instrumentation and data analysis vs simply tuning suspension by feel.

# 1. Objective

The objective of this project was to create a handbook for mountain bikes and analyze front and rear suspension. The handbook was created with the main purpose of helping individuals who have little to no experience with mountain bikes. Mountain bikes can be developed for different purposes and riders often tend to modify their bikes to their liking. This handbook is intended to introduce novice and inexperienced riders to the various types and designs to boost their knowledge, as well as make more educated decisions when purchasing bikes and parts. The suspension analysis portion of this project was aimed at the fine tuning of front and rear suspension. The same rider and bike trial were used for all the trials to gather data from linear potentiometers that were placed on the front and rear suspension of the mountain bike.

## 2. Introduction

A mountain bike's main purpose is for riding on offroad trails that may vary in ruggedness. These bikes are engineered with a few different application methods in mind. The type of features included with mountain bikes that differ from other types of bicycles that are ridden on pavement mainly focus on their tires, frame structure and suspension package. These features are specifically designed for durability because of the harsher riding conditions in comparison to riding on pavement. Mountain bike designs slightly differ from each other and are intended to be used in different types of applications. Even within the same exact application for a bike, there are many different designs that will have different characteristics. For this reason, not all mountain bikes are the exact same and are typically designed for one main point of interest. A mountain bike can be defined by its riding type, suspension design and geometrical parameters.

# 3. Literature Review

A mountain bike’s riding type can be categorized into four groups based on the style of suspension used for the front and rear as well as frame geometry, and components used. The four major categories that mountain bikes are designed for are Cross Country, Trail, Downhill and Enduro. The primary focus when designing a Cross Country type of mountain bike is for it to be lightweight and easy to pedal. The rider needs to be able to pedal this type of bike for long durations and be able to ride up and down hills as well. Also, the ability to ride this type of design fast across flat portions and hills is especially important in the racing environment. The two types of designs that are popular within this category among riders are hardtail and full suspension bikes. The full suspension designs include both the front and rear suspension systems on their bikes while the hardtail bike designs do not have a rear suspension. Hardtail designs have a front suspension, and the rear linkage system is directly welded to the frame of the bike.

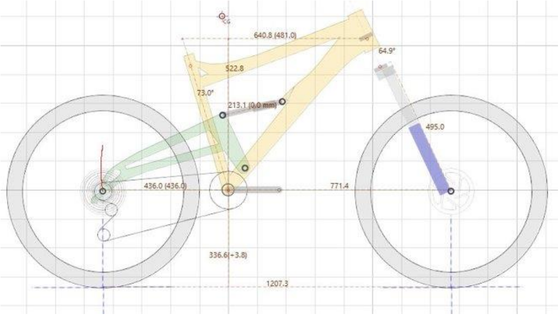
(a) Cannondale F-Si Hi-MOD 1[1] (Hardtail)

(b) Cannondale Scalpel Hi-MOD 1 [2] (Full Suspension)

(Figure 1, Hardtail vs Full Suspension Cross Country Bikes)

A Trail design for a mountain bike revolves around its suspension and ease of pedaling. These mountain bikes are designed in a similar way to the full suspension Cross Country designs with a slightly more focus on the suspension system. The Downhill type of mountain bike is purely designed around its ability to travel as fast as possible down the hill. These bikes are the heaviest types out of all four categories because of their suspension and durable frame. There is no design emphasis around the pedaling for this design type and it would be very inconvenient and tiresome to ride these bikes uphill. The Enduro style of mountain bikes is a hybrid design between the Trail and Downhill categories previously described. It must have a robust suspension, but also must be relatively easy to pedal uphill. These designs and their suspension systems fluctuate depending on the purpose of the bike.

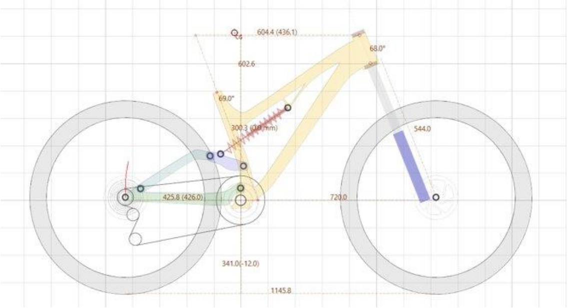
There are five main rear suspension designs for a mountain bike. These designs each have their own purpose intended either for general use or specific applications. The five main categories are single pivot, linkage driven single pivot, four-bar, high pivot and twin link (VPP). The single pivot mountain bike is the simplest and most general use type of design out of these five categories. The wheel is connected to the rear swingarm and moves in a circular arc. This swingarm is also connected to the front triangle. Single pivot designs are very “linear” in nature meaning that the force needed to cycle the wheel through its travel follows a linear relationship. The leverage ratio is harder to tune and thus the suspension platform is limited as to what shock size it can use for a given amount of wheel travel. Compared to other designs, the maintenance is easier due to the frame having less pivot locations, overall pieces, and bearings. The suspension is going to react very predictably because of this linearity.



(Figure 2, Single Pivot-Linkage Model)

(Figure 3, Single Pivot- Orange Stage 6 Evo[3])

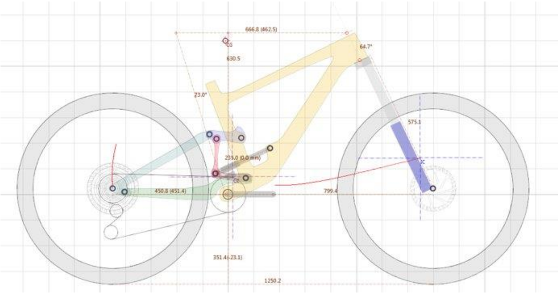
A linkage driven single pivot is a derivative of the single pivot design. Instead of having a solid swingarm, the rear triangle of the bike has linkages at select points. The rear pivot of the bike is located on the seat stay. This means the rear axle is still rigidly connected to the main frame. There is only one main pivot point, and the linkage system is what connects to the rear shock or coil. Changing the placement of the main pivot positions has a great effect on the parameters. The instant center is therefore located on the main pivot, just like the regular single pivot design. However, the linkage allows this design to have more control of the leverage ratio and therefore progressivity.



(Figure 4, Linkage Driven Single Pivot-Linkage Model)

(Figure 5, Linkage Driven Single Pivot- Kona Process 134[4])

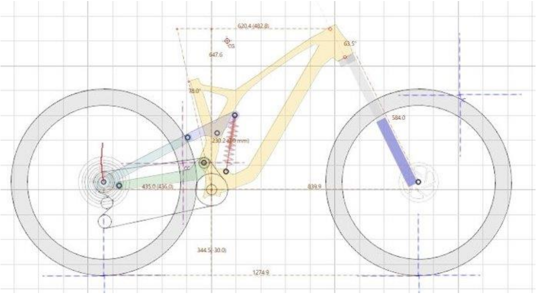
The four-bar suspension type is a linkage system designed so that the rear axle is not directly connected to the main body. This type of suspension can also be referred to as a Horst-link and it is unique in comparison to the single pivot. It is unique because of the additional pivot point that is located in between the rear axle and main pivot point. This additional pivot point is located on the chain stay just below the rear axle. It is designed to help minimize the anti-rise and anti-squat that can occur from the rear suspension. This design allows for the rider to have more control due to the rear axle not being directly connected to the main body. The rear axle in this design type moves with respect to the instant center of the bike. The parameter most affected is the anti-rise, which has a peak that is not at the beginning of travel. This means we can expect that the curve of the anti-rise and anti-squat will not be as linear as the single pivot case. Otherwise, the other parameters are still relatively linear. The high anti-squat means that this suspension system will be efficient with pedaling.



(Figure 6, Four-Bar - Linkage Model)

(Figure 7, Four-Bar - Specialized S-Works[5])

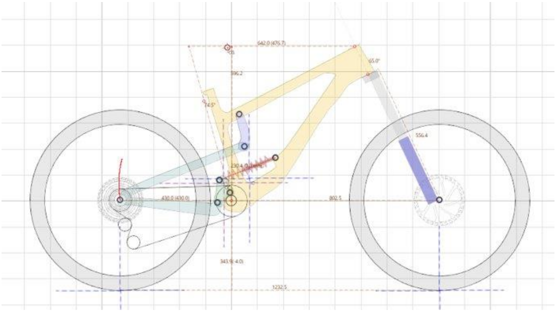
The high pivot suspension type defines the location of the main pivot point on the body of the mountain bike. In comparison with the previous suspension types discussed, the main pivot for this suspension type is simply placed at a higher location. This allows for the rear axle to have a higher axle path so the rear wheel can have an easier time clearing large obstacles. It can be beneficial for the rider to use this type of suspension when riding on rugged terrain. These suspension types also use an idler to help minimize or eliminate any pedal kickback that occurs due to the engagement of the rear suspension. An idler is placed at or above the main pivot point and is part of the chain path.



(Figure 8, High Pivot - Linkage Model)

(Figure 9, High Pivot - GT Force[6])

A twin-link suspension, which is also known as a virtual pivot point suspension (VPP), uses a modified Horst-link suspension design and pivots around a point in the air rather than at a physical pivot. The two links can rotate in the same direction (co-rotate) or opposite directions (counter rotate) depending on the desired kinematics of the suspension. This suspension type allows for a more tunable axle-path, anti-squat, and anti-rise where the anti-squat and anti-rise are consistent throughout its travel. Twin-link suspension is characterized by good pedaling efficiency and decent bump compliance. This is the broadest category out of the four.



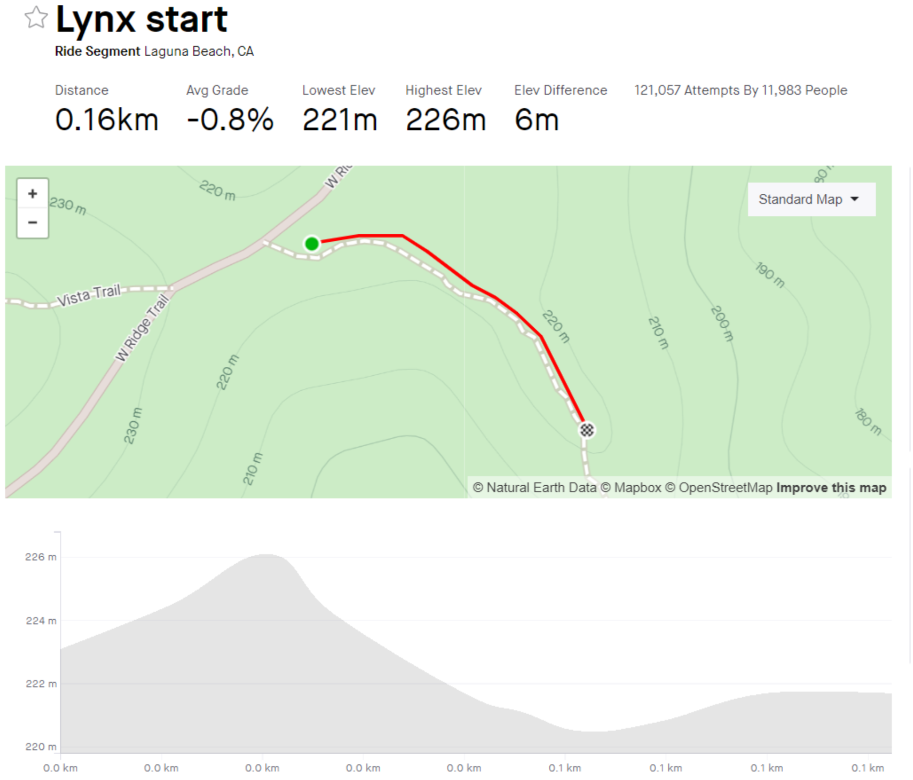
(Figure 10, VPP - Linkage Model)

(Figure 11, VPP – Santa Cruz Nomad[7])

The distinct types of mountain bike designs create a wide range of geometrical differences across all suspension and riding types. There are six parameters of interest that depend on the bike’s geometry that can affect how the rear suspension will behave. The six parameters are: Axle Path, Anti-Squat, Anti-Rise, Progressivity, Pedal Kickback and Force Curves. The axle path of a mountain bike deals with the travel of the rear axle from when the rear shock is at rest to fully compressed. It is the full path of motion the rear axle takes throughout travel. Anti-Squat is a measurement of resistance to pedal bob, while Anti-Rise is the resistance to rise due to braking. Progression is the rate at which the amount needed to move the rear wheel through its travel increases. Pedal kickback occurs when the rear axle travels backwards and increases tension in the train. Finally, the Force Curves parameter are the curves that relate wheel travel to the force. These parameters are dependent on one another, so mountain bike designers balance them in a way that is suitable for their application.

# 4. Front and Rear Suspension Testing

This phase of the Senior Project involved getting hands-on for testing a full suspension, enduro type of mountain bike. The scope for this portion of the project emphasized fine tuning the front and rear suspension. The same rider, trail and bike were used for all the trials performed. The testing was performed at Canyon View Park in Aliso Viejo, CA on the Lynx trail. The bike tested was a 2017 Giant Reign SX, which has a co-rotating virtual pivot point (Maestro) suspension system.



Lynx start

Ride Segment Laguna Beach, CA

Distance 0.16km

Avg Grade -0.8%

Lowest Elev 221m

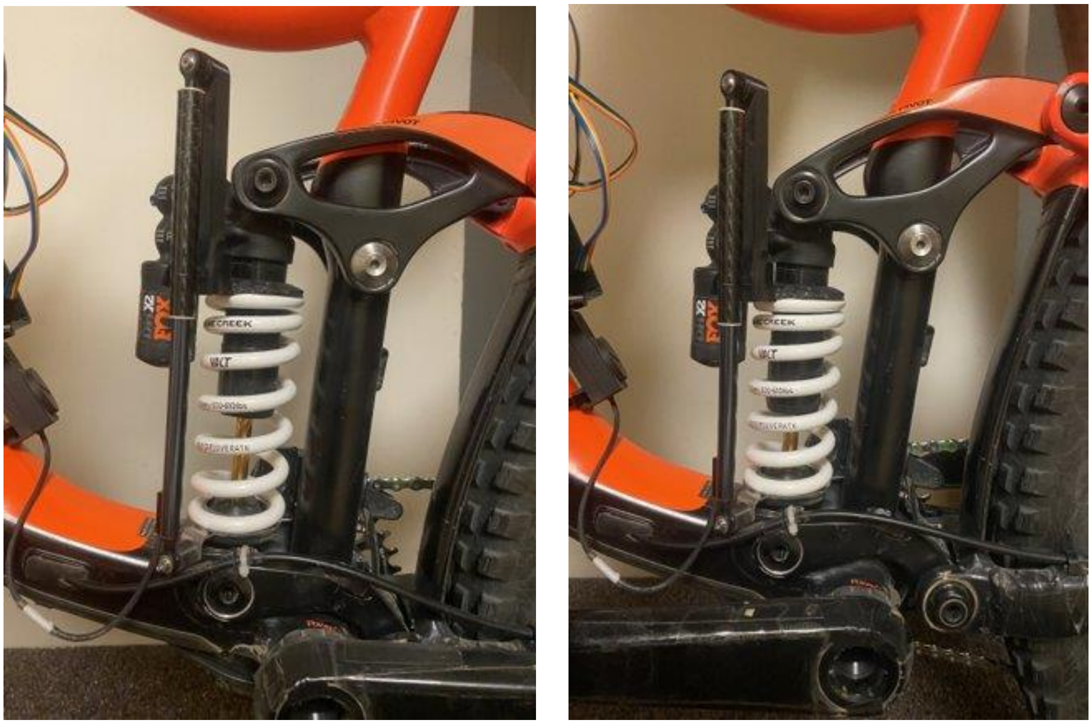
Highest Elev 226m

Elev Difference 6m

121,057 Attempts By 11,983 People

(Figure 12, Lynx Trail)

Before test riding the bike, a basic setup was needed. This included the sag for the rear, the sag for the front, and setting all the adjustments on the fork and shock to the middle positions. Sag was measured in percentage of total travel of the shock for the rear and percentage of total travel of the fork for the front. The front and rear sag were measured with a tape measure and set at 30% and 20%, respectively. The shock sag reference point was the oil line the shock left on the shaft and the reference point for the fork was an O-ring mounted on the fork. To obtain the correct sag, the correct spring rate for the rear shock and air pressure were needed. The rear used a progressively wound 500-610lb spring for correct sag numbers while the fork ran 92 psi of air. The fork also allowed spring progressivity tuning (force curve tuning) with the use of volume spacers inside the air spring mechanism. The amount of volume spacers was set in the middle at 2 out of the four possible spacers. The fork and shock both had high speed compression and rebound adjusters as well as low speed compression and rebound adjusters. The adjusters' working ranges were measured in clicks. The fork had 16 clicks of low-speed adjustments and 8 clicks of high-speed adjustments. The low-speed adjustments were set at 8 clicks from open (clockwise clicks) and the high-speed adjustments were set at 4 clicks from open. The high and low speed adjusters on the shock exhibited 24 clicks of adjustment and were set at 12 clicks from open. Figure 15 shows the adjusters of the shock and the fork. Blue are the compression adjusters and red are the rebound adjusters.



(a) Unloaded Rear Shock

(b) Loaded Rear Shock

(Figure 13, Bike Set Up Rear Sag)

(a) Unloaded Fork

(b) Sag Point Shown by O ring

(c) Air Pressure

(Figure 14, Bike Set Up Front Sag)

(Figure 15, Adjusters)

Using the Motion Instruments DAQ system, the bike's suspension system was tested with the following settings: Factory (Box Stock) setting, an intuitive set up based solely on rider input and a mathematically balanced setup based on the data from Motion Instruments. Each setting was tested seven to eight times to gather a large sample size to reduce variability. The third setting, the mathematically balanced bike, had the best performance. The tables below show the results of each setting (tables 1-3 and 10 respectively) and the settings that were used (tables 4-9).

The tables below show the settings and results of each suspension setup tested. It should be noted that the compression stroke happens when the suspension is compressing from an obstacle and the rebound stroke is the extension of the suspension (recovery) after the obstacle. Table 1 shows the results for the Box Stock Test, Table 2 shows the results for the Rider Input test, and Table 3 shows the results for the Motion Instruments test. The percentages were based off the rear axle of the mountain bike. As an example, In Table 1 the average of the axle travel ratio was -9%. This meant that the rear of end of the bicycle used 9% less travel on average for the experiment. The compression ratio was -37% which meant that the compression speed of the rear was 37% slower on average than the front. The rebound ratio was -31% which meant that the rear rebound was 31% slower than the front. The best setup was achieved with the Motion Instruments DAQ. This suspension setup yielded an axle travel ratio (balance) of 10%, a compression ratio of 3%, and a rebound ratio of 2%. This is a difference of 19% in axle travel ratio from the Box Stock test and 21% from the Rider Input test. The compression speed ratio exhibited a difference of 28% and 11% for Box Stock and Rider Input tests, respectively. The rebound speed ratio exhibited a difference of 33% and 43% for Box Stock and Rider Input tests, respectively. The lap times decreased significantly with both the Rider Input setup and the Motion Instruments setup over the Box Stock setup. However, the largest decrease came from the Motion Instruments with the average dropping 25 seconds from 1:45 to 1:20. The lap times can be seen in table 10.

Box Stock fork settings, Box Stock shock settings, Rider Input fork settings, Rider Input shock settings, Motion Instruments fork settings, and Motion Instruments shock settings are shown in tables 4-9 respectively. The base point was fully open which meant that the adjusters were turned counterclockwise as far as they would go. This meant that the orifice in which oil would pass through was completely “open” and experienced the least restriction. It should be noted that the most drastic change was seen in the Motion Instruments test, most notably seen in the fork. The fork air pressure went up 4 psi to 96 psi and a volume spacer was added in the air spring mechanism to reduce the volume of the air spring chamber and increase the progressivity at which the force ramps up in relation to its travel.

Table 1. Box Stock Results

| Balance Results | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 | Run 7 | Run 8 | Average |
|---|---|---|---|---|---|---|---|---|---|
| Axle Travel Ratio | 15% | -11% | -15% | -12% | -12% | -13% | -15% | -10% | -9% |
| Compression Speed Ratio | -31% | -31% | -48% | -37% | -41% | -40% | -32% | -37% | -37% |
| Rebound Speed Ratio | -42% | -28% | -30% | -28% | -27% | -26% | -35% | -32% | -31% |

Table 2. Test Rider Input Results

| Balance Results | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 | Run 7 | Average |
|---|---|---|---|---|---|---|---|---|
| Axle Travel Ratio | -12% | -11% | -13% | -10% | -9% | -14% | -10% | -11% |
| Compression Speed Ratio | 9% | -9% | -12% | -14% | -10% | -15% | -9% | -9% |
| Rebound Speed Ratio | -45% | -45% | -42% | -40% | -47% | -37% | -32% | -41% |

Table 3. Motion Instruments Results

| Balance Results | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 | Run 7 | Average |
|---|---|---|---|---|---|---|---|---|
| Axle Travel Ratio | 9% | -14% | -8% | 5% | 7% | 14% | 16% | 10% |
| Compression Speed Ratio | 2% | 0% | 6% | 2% | 1% | 6% | 5% | 3% |
| Rebound Speed Ratio | 4% | 7% | 1% | -3% | 0% | -3% | 7% | 2% |

Table 4. Fork Settings (Box Stock)

| Fork | | | Compression (from open) | | Rebound (from open) | |
|---|---|---|---|---|---|---|
| Air | Volume Spacers | Sag | Low | High | Low | High |
| 92 Psi | 2 | 20% | 8 | 4 | 8 | 4 |

Table 5. Rear Shock Settings (Box Stock)

| Shock | | Compression (from open) | | Rebound (from open) | |
|---|---|---|---|---|---|
| Spring | Sag | Low | High | Low | High |
| 500-610lb | 30% | 12 | 12 | 12 | 12 |

Table 6. Fork Settings (Rider Input)

| Fork | | | Compression (from open) | | Rebound (from open) | |
|---|---|---|---|---|---|---|
| Air | Volume Spacers | Sag | Low | High | Low | High |
| 92 Psi | 2 | 20% | 6 | 5 | 6 | 3 |

| Table 7. Rear Shock Settings (Rider Input) | | | | | |
|---|---|---|---|---|---|
| Shock | | Compression (from open) | | Rebound (from open) | |
| Spring | Sag | Low | High | Low | High |
| 500-610lb | 30% | 5 | 10 | 5 | 7 |

| Table 8. Fork Settings (Motion Instruments) | | | | | | |
|---|---|---|---|---|---|---|
| Fork | | | Compression (from open) | | Rebound (from open) | |
| Air | Volume Spacers | Sag | Low | High | Low | High |
| 96 Psi | 3 | 17% | 10 | 6 | 6 | 3 |

| Table 9. Rear Shock Settings (Motion Instruments) | | | | | |
|---|---|---|---|---|---|
| Shock | | Compression (from open) | | Rebound (from open) | |
| Spring | Sag | Low | High | Low | High |
| 500-610lb | 30% | 1 | 1 | 4 | 4 |

| Table 10. Lap Times | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Test | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 | Run 7 | Run 8 | Average |
| Box Stock | 1:45 | 1:46 | 1:43 | 1:47 | 1:45 | 1:48 | 1:46 | 1:47 | 1:45 |
| Rider Input | 1:30 | 1:29 | 1:28 | 1:29 | 1:27 | 1:31 | 1:30 | N/A | 1:29 |
| Motion Instruments | 1:22 | 1:20 | 1:21 | 1:21 | 1:19 | 1:18 | 1:20 | N/A | 1:20 |

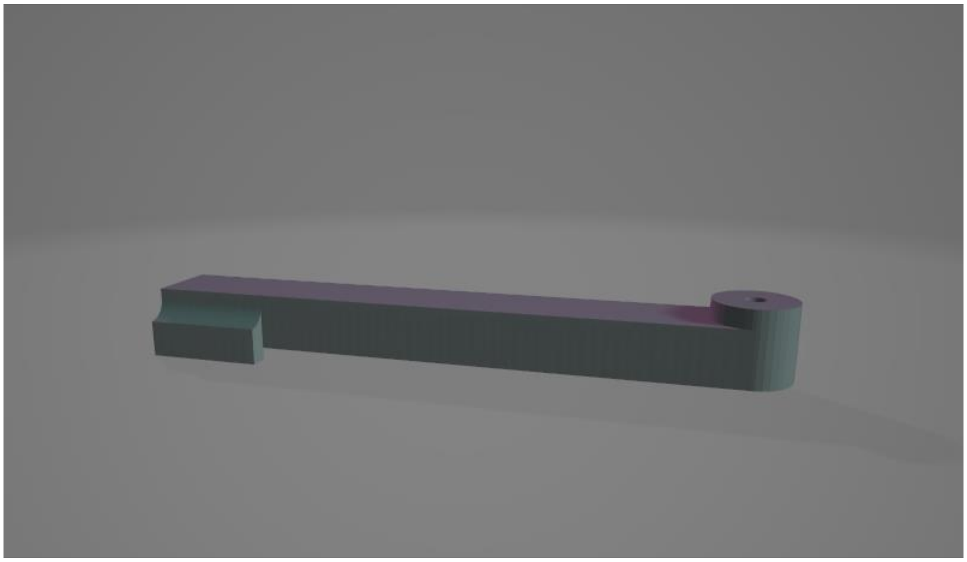
# 5. DAQ Systems

Two data acquisition (DAQ) systems were used in the testing phase of this project. The first DAQ system used linear potentiometers with one located on the front and another located on the rear shock to measure the displacement of each shock. This group reached out and met up with the CEO of Motion Instruments to gain information about their testing systems to create their own DAQ system using off-the-shelf components. After several meetings, Motion Instruments provided insight on how they researched and developed their products. Due to the considerable number of resources that were required to create a similar product, they kindly sponsored this project and provided the group with a full suspension test kit. The DAQ system Motion Instruments provided the Enduro Kit setup which uses two linear potentiometers that measure the displacement of the front and rear suspension. The potentiometers are connected via Bluetooth to the rider's phone and transmit live data to the Motion Instruments' IOS app. The data would be stored alone with the position, time, elevation, and other calculated data into a csv file that was exported to be used to interpolate the data.

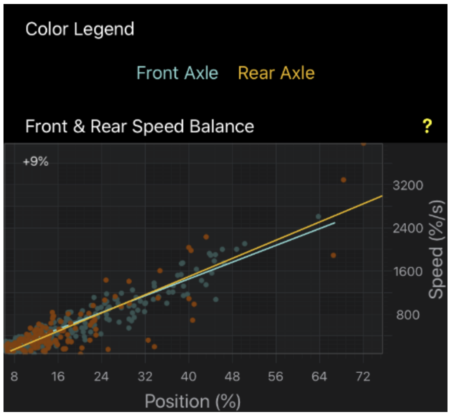
(Figure 16, Motion Instruments – Enduro Kit[8])

A Giant Reign SX 2017 was used as the test platform and had the Enduro Kit outfitted to it. Since mountain bikes are not designed to incorporate linear potentiometers, there were potential issues for mounting. Ideally, the sensors should be mounted onto the bolts that hold the shock or in line with the shock. As the front shock travels linearly**,** the potentiometer was mounted directly to opposite ends of the shock and out of the way to protect it from debris and harm**.** However, for the rear shock a different method was required to attach the potentiometer to measure the shock displacement. To attach the potentiometer, mounts included with the Enduro Kit were attached to both ends of the rear shock springs. These mounts provided tabs that would allow the potentiometer to be attached inline to the shock. To prevent damage to the sensors during testing, the minimum eye-to-eye length for the rear shock sensor needed to be 87.4mm, which was greater than the distance between the two tabs. To address this issue, a 3D printed mount was constructed to aid in the placement of rear potentiometer. The transmitter modules of the kit were securely attached to the downtube of the frame.

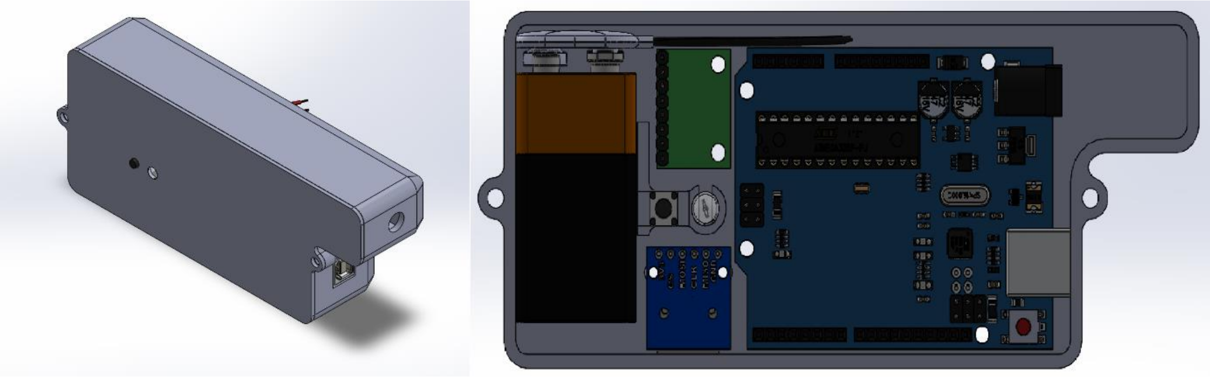
(Figure 17, Installed Motion Instruments – Enduro Kit)



(Figure 18, Bracket for Motion Instruments – Enduro Kit)



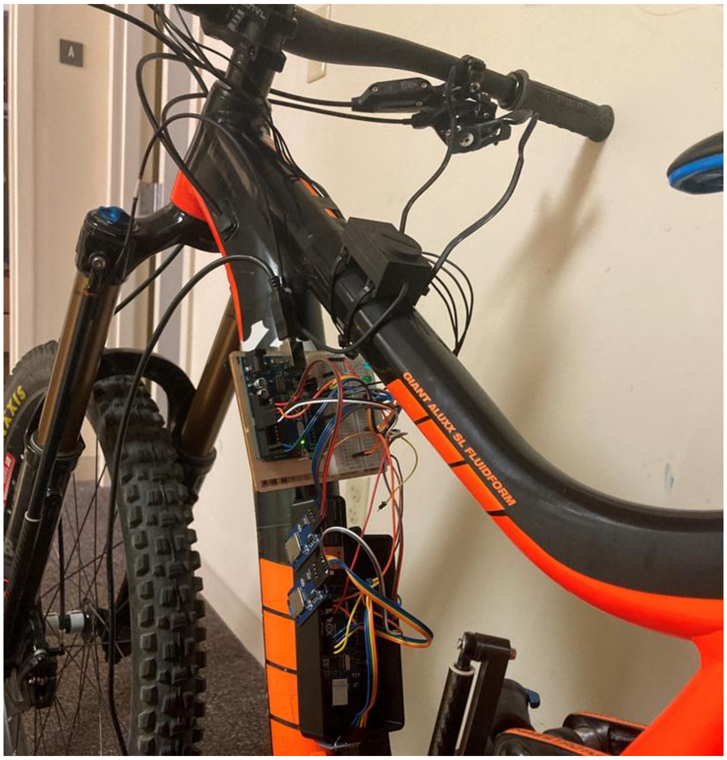
(Figure 19, Motion Instruments – Position vs. Speed)



(Figure 20, MPU 6050 Accelerometer and Arduino Uno Housing Model)

The second DAQ system used was designed using accelerometers that were placed onto the handlebars and bottom bracket of the mountain bike. The primary focus of doing this was to measure vibrations at key locations on the frame where the rider interfaces with the bike. In this case the location for one accelerometer was the handlebars since the rider's hands are positioned there. The second location was the bottom bracket because that is the closest location to the crankset and the rider's feet are positioned there. By measuring the vibrations and comparing the data between different suspension settings, this would quantify the "plushness" of the suspension and give us insight into how effective the suspension set up is at damping a harsh trail. By comparing how much less vibrations were measured, the overall dampening and how much energy the suspension absorbed could be quantified.

The goal was to have a standalone system with an independent power supply to allow it to be used for field testing. The system initially was going to consist of an Arduino Uno to control the system, two MPU6050 accelerometers and an SD card reader, as shown in Figure 19. Using the known sampling rate of the Motion Instruments DAQ of 200Hz, the Arduino needed to be programmed to achieve similar sampling speeds. However, this was difficult to achieve as the basic code for an SD card reader could only achieve sampling rates of approximately 60 Hz. The loop used to open, write to, and flush the SD card's cache and save the data substantially slowed down Arduino. This method was inefficient and was only viable for low sample rates. However, using a modified version of the low-latency logger in the MPU-6050 Arduino library, sample rates of 500Hz and above could be achieved [9]. This system accomplishes this by storing the data read at set intervals in a series of buffers as binary. The buffers are important so that data reading interrupts are not needed. These binary buffers are then written to a dump file on the SD card intermittently as the buffers fill up. At the end of the data recording when the run is completed, the system enters a separate loop that takes the binary dump file and converts it to a csv. This method works very well and was consistent at maintaining the fast speeds necessary. This solution was only configured for Arduino with one accelerometer. This meant to achieve the 500Hz desired for the sampling speed, two identical systems had to be used with two separate SD card loggers. The final DAQ system's major components consisted of two Arduino Unos, two MPU-6050 accelerometers, and two SD card readers. The system was prototyped and was in working condition when the prototype was mounted up to the bike. The Arduino system was installed on the downtube of the frame as shown in Figure 20. This prototype test system used a breadboard and several taped-on components. This was to be made into all soldered connections and repacked for the final design before it would be usable for testing on a real trail.



(Figure 21, Installed Arduinos and MPU 6050s)

## 6. Conclusion

This project focused on breaking down the different mountain bike suspension platforms and their characteristics as well as the different categories of mountain bikes. The categories of mountain bikes in least to greatest amounts of suspension travel included cross country, trail, enduro, and downhill mountain bikes. Ultimately, the enduro category was chosen to move forward on and test with the Motion Instruments data acquisition kit. After testing, the data confirmed that the data acquisition kit yielded a more balanced suspension setup and faster times on the test course. To support the results from the Motion Instruments testing, a prototype of a DAQ system that utilizes accelerometers was developed.

# 7. Suggestions for Future Studies

Future groups that are to take part in this project would greatly benefit from getting hands-on from the start of the academic year. This team was the first to partake in this literature review and suspension analysis, and the dividing the work up into two semesters limited the amount of testing that could have been done. The accelerometer DAQ prototype system could be further improved so that it could be used for testing on the trails. A in depth method for calibrating the sensors and analyzing the vibrational data obtained from the Arduino DAQ system still needs to be developed and the system needs to be repacked in a tidier form factor. These future groups that take part in this study could go much further into testing with accelerometers and linear potentiometers. The code developed so far is attached as part of the submission package for further testing and development. It would also be beneficial to get data on different types of suspension design as well as varying different parameters in the testing. This could include changing the shocks, testing different body types, frame sizes, tire type / pressure, and riding styles.

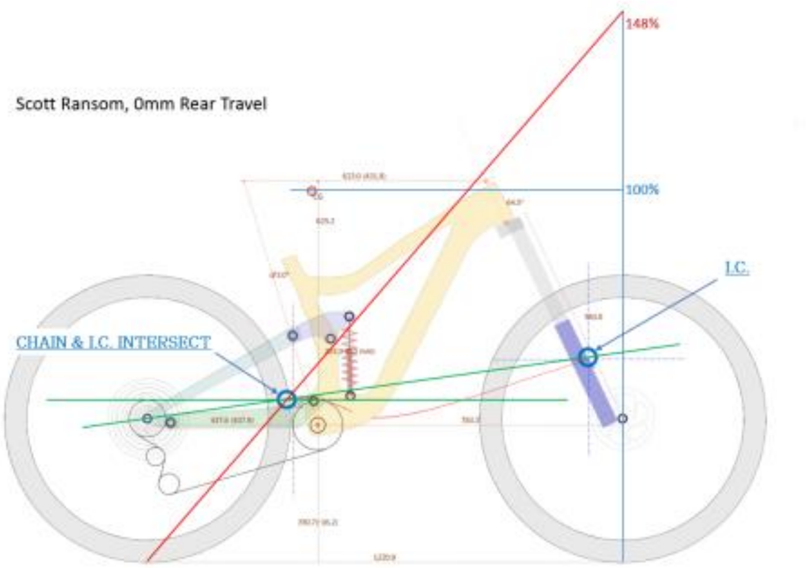
# 8. Acknowledgement

Thank you to Professor Tsuchiya for advising this project and providing support and advice throughout the year. Thank you to Gergely Kovacs from BikeChecker.com for providing access to the Linkage software used for a significant portion of the research in the literature review phase. Thank you to Robert Przykucki from Motion Instruments for proving the data acquisition equipment for the testing phase of the project.

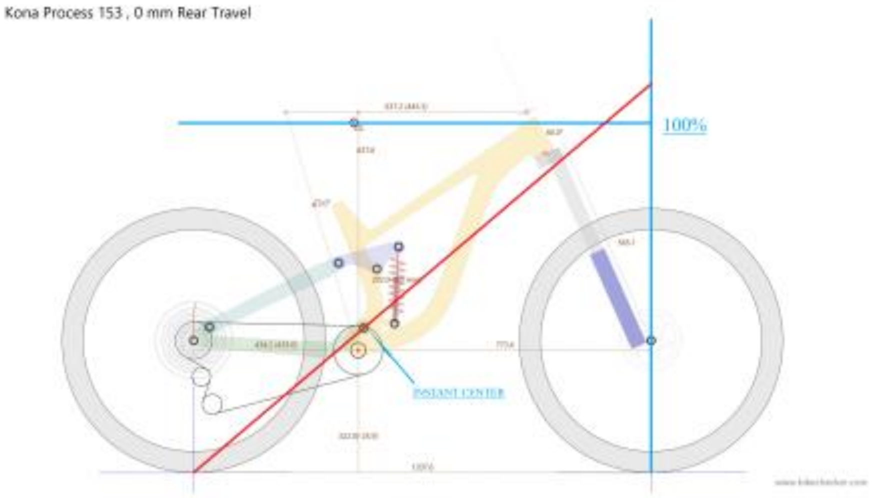
# 9. Appendix

The images seen below are for the six geometric parameters that are previously referenced in the Literature Review section of the report. Also, a sample text from the Handbook is displayed proceeding the parameters.

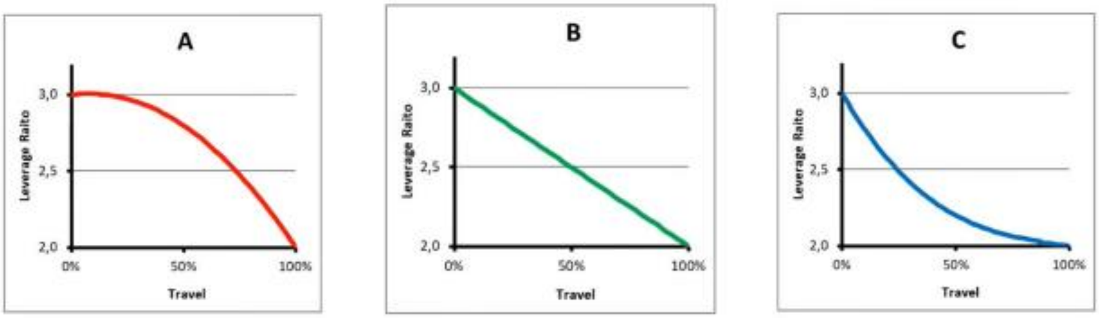
(Figure 22, Axle Path[11])



(Figure 23, Anti-Squat)

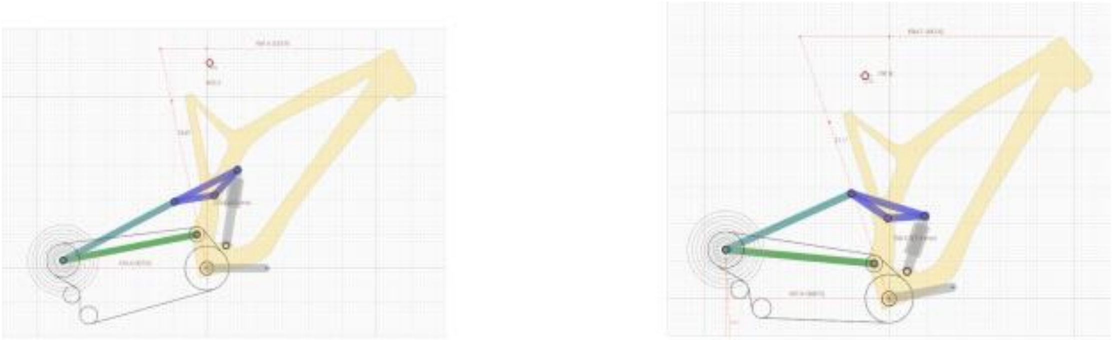


(Figure 24, Anti-Rise)



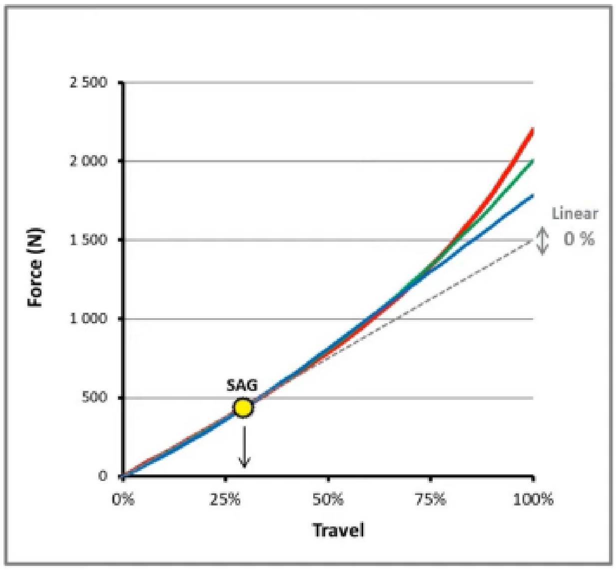
(a) Most Progressive (b) Consistent Progression (c) Least Progressive

(Figure 25, Progression[12])

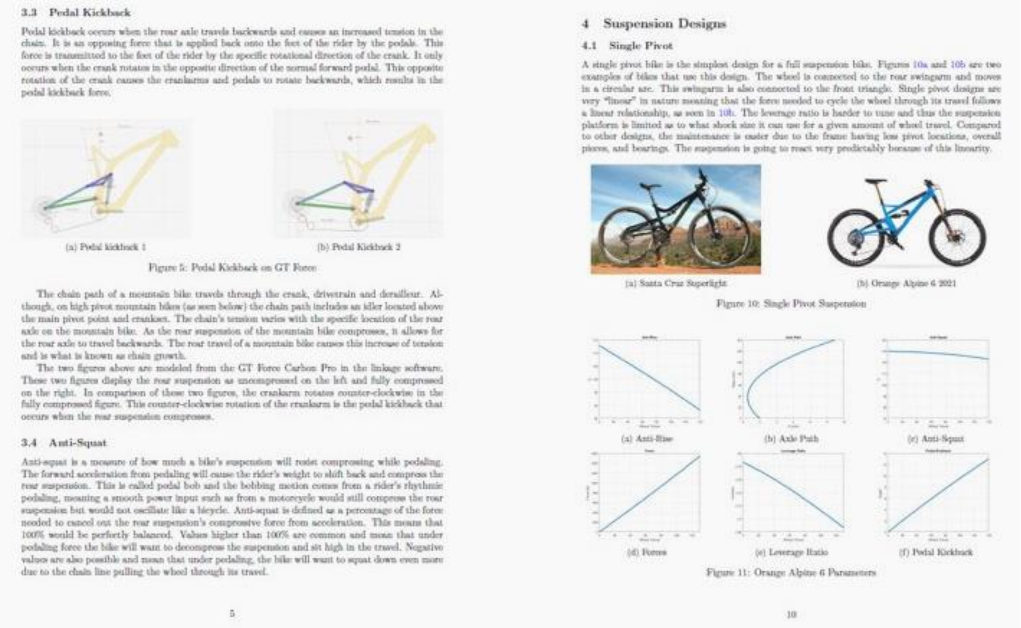


(a) Pedal kickback 1 (b) Pedal Kickback 2

(Figure 26, Pedal Kickback)



(Figure 27, Force Curves[12])



### 3.3 Pedal Kickback

Pedal kickback occurs when the rear axle travels backwards and causes an increased tension in the chain. It is an opposing force that is applied back onto the feet of the rider by the pedals. This force is transmitted to the feet of the rider by the specific rotational direction of the crank. It only occurs when the crank rotates in the opposite direction of the normal forward pedal. This opposite rotation of the crank causes the crankarms and pedals to rotate backwards, which results in the pedal kickback force.

(a) Pedal kickback 1 (b) Pedal Kickback 2

Figure 5: Pedal Kickback on GT Force

The chain path of a mountain bike travels through the crank, drivetrain and derailleur. Although, on high pivot mountain bikes (as seen below) the chain path includes an idler located above the main pivot point and crankset. The chain's tension varies with the specific location of the rear axle on the mountain bike. As the rear suspension of the mountain bike compresses, it allows for the rear axle to travel backwards. The rear travel of a mountain bike causes this increase of tension and is what is known as chain growth.

The two figures above are modeled from the GT Force Carbon Pro in the linkage software. These two figures display the rear suspension as uncompressed on the left and fully compressed on the right. In comparison of these two figures, the crankarm rotates counter-clockwise in the fully compressed figure. This counter-clockwise rotation of the crankarm is the pedal kickback that occurs when the rear suspension compresses.

### 3.4 Anti-Squat

Anti-squat is a measure of how much a bike's suspension will resist compressing while pedaling. The forward acceleration from pedaling will cause the rider's weight to shift back and compress the rear suspension. This is called pedal bob and the bobbing motion comes from a rider's rhythmic pedaling, meaning a smooth power input such as from a motorcycle would still compress the rear suspension but would not oscillate like a bicycle. Anti-squat is defined as a percentage of the force needed to cancel out the rear suspension's compressive force from acceleration. This means that 100% would be perfectly balanced. Values higher than 100% are common and mean that under pedaling force the bike will want to decompress the suspension and sit high in the travel. Negative values are also possible and mean that under pedaling, the bike will want to squat down even more due to the chain line pulling the wheel through its travel.

## 4 Suspension Designs

### 4.1 Single Pivot

A single pivot bike is the simplest design for a full suspension bike. Figures 10a and 10b are two examples of bikes that use this design. The wheel is connected to the rear swingarm and moves in a circular arc. This swingarm is also connected to the front triangle. Single pivot designs are very "linear" in nature meaning that the force needed to cycle the wheel through its travel follows a linear relationship, as seen in 10b. The leverage ratio is harder to tune and thus the suspension platform is limited as to what shock size it can use for a given amount of wheel travel. Compared to other designs, the maintenance is easier due to the frame having less pivot locations, overall pieces, and bearings. The suspension is going to react very predictably because of this linearity.

(a) Santa Cruz Superlight (b) Orange Alpine 6 2021

Figure 10: Single Pivot Suspension

(a) Anti-Rise (b) Axle Path (c) Anti-Squat

(d) Forces (e) Leverage Ratio (f) Pedal Kickback

Figure 11: Orange Alpine 6 Parameters

(Figure 28, Handbook)

Table 11. Bill of Materials for Accelerometer DAQ

| Item | Amount | Cost | Source |
|---|---|---|---|
| Arduino Uno | 2 | $22.77 | Amazon |
| MicroSD Card Breakout Board | 1 | $10.31 | Adafruit |
| MPU 6050 Accelerometer Gyroscope Sensor Breakout Board | 2 | $6.19 | Adafruit |
| 9 Volt Battery | 1 | $7.99 | Walmart |
| Small Components (I.e. LED's, switches, wire) | | $13.99 | Amazon |
| | Total | $84.02 | |

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