

Bike Suspension

Preliminary Proposal

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DISCLAIMER

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TABLE OF CONTENTS

Contents

DISCLAIMER.....	1
TABLE OF CONTENTS.....	2
1 BACKGROUND.....	1
1.1 Introduction.....	1
1.2 Project Description.....	1
2 REQUIREMENTS.....	3
2.1 Customer Requirements (CRs).....	3
2.2 Engineering Requirements (ERs).....	3
2.3 House of Quality (QFD).....	5
2.4 Functional Decomposition.....	6
2.4.1 Black Box Model.....	6
3 DESIGN SPACE RESEARCH.....	7
3.1 Literature Review.....	7
3.1.1 Source 1.....	7
3.1.2 Source 2.....	7
3.1.3 Source 3.....	7
3.1.4 Source 4.....	7
3.1.5 Source 5.....	7
3.1.6 Source 6.....	8
3.1.7 Source 7.....	8
3.2 State of the Art - Benchmarking.....	8
3.2.1 System Level State of the Art - Benchmarking.....	8
3.2.1.1 Existing Design #1: Specialized Brain.....	8
3.2.1.2 Existing Design #2: Fox Live Valve.....	8
3.2.1.3 Existing Design #3: Quarq Shock Wiz.....	9
4 CONCEPT GENERATION.....	10
4.1 Full System Concepts, 4.2 Subsystem Concepts.....	10
5 DESIGNS SELECTED – First Semester.....	14
5.1 Technical Selection Criteria.....	14
5.2 Rationale for Design Selection.....	14
6 REFERENCES.....	16

1 BACKGROUND

1.1 Introduction

Mountain biking is a sport, hobby, and even a lifestyle for those working in the industry. A key component on modern day mountain bikes is the suspension. For some mountain bikes there are only front suspension forks on the bikes giving them the name “hard tail”. However, the most versatile suspension platform is the full suspension bike. A full suspension mountain bike has a front suspension fork and a rear shock which is known to provide comfort and stability when going over harsh terrain, increased traction, and be more capable than their hard tail counterparts. Suspension on mountain bikes is meant to be taken over terrains ranging from a smooth surface to drop offs.

The best method to ensure the suspension can handle these differences in terrain is by utilizing air shocks rather than spring, or coil shocks. Air shocks have various types of adjustments that allow them to be adjusted based on the riding conditions and rider’s preference. This ability to adjust the way the bike rides, as well as weight advantage, have made air suspension the best choice for most bikes. The front fork can be locked out with a level to make the front completely rigid; the rebound can be adjusted to dictate how fast the fork reacts to bumps, and air can be added based on the weight of the rider. Rear shocks can also lock out with the damping adjustment, rebound can be increased or decreased, and air and volume spacers can be added to ensure the shock is setup properly. With all the various adjustments, adjusting suspensions can be daunting for the average consumer. Most of the time bike shops will help the rider setup the bike that will handle most terrain decent. To create the best riding bike for differing terrains, adjustments need to be made before each ride if the riding varies. For example, suspensions that are setup for jumps and drop offs will need to be adjusted if the same bike is taken to a flatter terrain with more small bumps. Without knowing exactly how each adjustment affects the bike, the average consumer could feel overwhelmed or helpless when it comes to adjusting their suspension. This project aims to define what a well setup suspension system is along with a mathematical model to follow. This then will lead the team to use a mountain bike and rear shock to apply real-world testing to validate the mathematical model. Once the mathematical model has been validated, a device will be made to help riders adjust their suspension easier. By creating a way for mountain bike suspension to be more easily adjustable, all consumers will be able to ensure their bike is perfectly dialed in no matter what terrain they are riding.

1.2 Project Description

Following is the original project description provided by the sponsor:

“Mountain bike suspensions are configurable based on the rider and the types of terrain where the bike is expected to be used. This project involves reverse engineering suspension systems for a mountain bike and analyzing how it would perform for varying terrains for a subset of riders using mathematical modeling. Reverse engineering a design is a common technique used to understand choices/trade-offs that a designer had to make to when developing their product as well as a starting point for creating something similar yet improved or optimized for a subset of customers. The final report should include an easy to use guide for selecting suspension parameters based on rider details and the range of terrains that the rider is expected to use the bike.”

The original project description involved creating a database as a reference that mountain bikers can use to fine tune their suspension. After some initial discussions with our client, Brandon Lurie, the team decided this idea would be less feasible with either too much variance in suspension platforms or products on the market that already accomplish the same goal. The only components our client wanted to keep are the idea of a mathematical model due to his knowledge in creating these models throughout his career.

The client was still very open to ideas and provided the team full control of the future of the project. With this, understanding how mountain bike suspension works is pivotal to this project and the team decided on attempting to build a physical device for this project. With an updated goal in mind, the team now aims to create a mathematical model to help define a well damped suspension system and use physical devices to test the viability of the mathematical model. Once the mathematical model has been created and validated, a device will be made to allow for all riders to adjust their suspension easier.

2 REQUIREMENTS

This Senior Design Project is the capstone requirement for Mechanical Engineering majors where the team has chosen Reverse Engineer Mountain Bike Suspension project. The team has further clarified the project to designing a system that allows for increased dynamic adjustability for a full suspension mountain bike. To accomplish this the team must develop a MATLAB code to model and predict ideal suspension settings based on rider, bike, and terrain characteristics. From the code, a physical prototype mechanism will be developed and fitted to a to-be-determined test bike.

2.1 Customer Requirements (CRs)

The project sponsors Gore and NAU engineering, represented by Brandon Lurie and David Trevas respectively determined the baseline for customer requirements during this initial stage of project development. The team and clients together determined five customer requirements being: Base research on current mathematical models, perform extensive research on bike suspension systems, ensure the average user can utilize design, incorporate Solid Works and MATLAB models, and perform validation testing. These customer requirements focus on the team pursuing an analytical approach to the first semester of the design project. There is a large emphasis on truly understanding the mechanisms and properties of current mountain bike suspension in order to move forward with designing a system to work alongside and optimize suspension. This led to the team all taking on individual analysis of suspension systems such as shock quantification or linkage analysis. Each customer requirement was given a weight on a scale one to five. The Solid Works and MATLAB models are given a five, validation testing a four, bike suspension research a three, and user friendly and current systems research was given a two. These weights were assigned based on their correlation to gaining better understanding of the suspension system and how well they progressed the team's understanding.

2.2 Engineering Requirements (ERs)

The engineering requirements based on the previous customer requirements can be seen below in table 1.

Table 1: Engineering Requirements with units and target value

	Engineering Requirements	Unit	Target
1	Spring and Damping Rate Critical in all Cases	lbs/in	critical
2	Validate Mathematical Models with other Models	%diff	+5%
3	Test Bike Compatibility (Clamp Diameter and Geometry)	mm	28mm
4	Minimize Weight Addition	g	<45
5	Compact Design to Fit on Handlebars	cm ²	3
6	Durability (Material Strength)	MPa	50

The team looked into the project objective and our current hypothetical problem solution ideas to form six engineering requirements of: Spring and damping rate critical for all cases, validate mathematical model with other models, compatibility with test bike, minimize weight addition, compact design to fit on handlebars, durability. The first requirement, spring and damping rate critical for all cases, is measured by minimal to no oscillation during the rebound motion of the suspension system and characterized by the damping coefficient. Validating mathematical model with other models is characterized by percent difference in values when comparing to Solid Works stress analysis for a specific example. The tolerance for this engineering requirement is currently hypothesized to be +5% however once further analysis is completed that tolerance will be set. The compatibility with test bike will come down to the future prototype being able to be fitted onto the test bike, classified by clamp diameter and mounting geometry. Tolerance for these fits will be measured with millimeters of diameter and part clearance, likely sitting around +.5mm but subject to change. Minimizing weight addition to the bike will be targeted at sub 45

grams to limit additional weight and size. Compact design to fit on handlebars will be measured in the systems additive volume in cm^2 as well as clamp diameter in mm. Target volume is 3 cm^2 with a suspected tolerance of $\pm 1 \text{ cm}^2$. Durability will be measured in material strength as well as impact resistance and will need to be determined through testing of current handlebar systems such as brake levers and shifters to imitate benchmarked durability. The engineering requirements will likely evolve with the project, especially during second semester when the prototyping begins. The current stage is very analytical and research based, but tighter tolerance expectations and criteria for the project will develop alongside the move to a more physical approach to the project.

2.4 Functional Decomposition

Since this project primarily focuses on a mathematical model for the current state of the project, the team could not create some diagrams that were more concept based. The Black Box Model seen below helps the team visualize how the system is affected by various inputs.

2.4.1 Black Box Model

A Black Box Model, as seen in figure 2, aims to show the inputs to the proposed system and the outputs of this system in the form of materials, energies, and signals. For this project the goal is to create a device to adjust mountain bike, MTB, suspension on the trail that is easy to understand. The material inputs will be the weight of the bike and the rider, with the rider and bike weight also being the material outputs. Material inputs can be controlled, or known, which allows the team to adjust the system based on the weight of both the person and the bike. Terrain impacts are the energy input, which causes an acceleration of the shock. This reaction to the terrain is something the team wants to be able to adjust with the device. Current adjustments on modern mountain bikes can sometimes be difficult to understand, leading to the output of a modified, or easier, way to adjust mountain bike suspension.

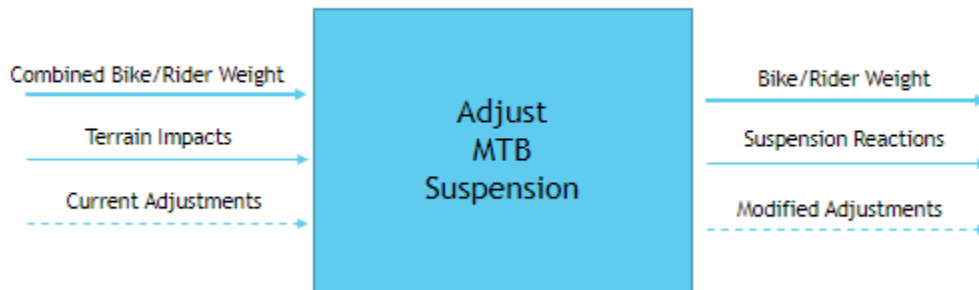


Figure 2: Black Box Model

3 DESIGN SPACE RESEARCH

Since this project is primarily research based, the design space research section will include the literature review and benchmarking. This section will lack any concept generation techniques since the team is currently creating a mathematical model.

3.1 Literature Review

For the Literature Reviews we used websites, peer reviewed papers, and design tools to get information about the desired design. These sources will help us gain knowledge about the current state of the art alternatives for different parts of the suspension. They will also help us get more information about the required calculations for our design testing. Lastly, they will help us improve the quality of our designed suspension.

3.1.1 Source 1

The following website contains useful information on how to run SolidWorks stress analysis studies, along with motion studies. Both are important to the team, for the study calculates the applied given load, material, etc... to find the final Von Mises stress along with the deflection within a time lapse duration. The following source allowed the team to better understand what fixed geometries to use, along with tutorials on how to compose a stress analysis study [1].

3.1.2 Source 2

This study explores the vibrations in different parts of the mountain bike: The Air-oil suspension frame, Air-oil rigid frame, Linkage rigid frame, Linkage suspension frame, Elastomer rigid frame, and Rigid frame. Vibrations have proven to cause injuries to human bodies after a certain level of hertz. They did some experiments on gravel and trail roads. The data shows the components that receive the most shock and what road surface gives the higher shock. This will help the team identify the parts that need the most attention when trying to minimize the vibrations on the user [2].

3.1.3 Source 3

This article investigates how Magnetorheological (MR) fluids could be used in suspensions. MR fluids are known for their field-dependent yield stress and fast response time making them a good fit for many applications. They behave either Newtonian-like or not depending on the existence of a magnetic field near it making them a fit for both needs. The article also shows the properties of a MR damper designed for bicycles. After a comparison between the performance of MR hybrid semiactive and passive suspensions the results showed better performance using the MR hybrid semiactive suspensions [3].

3.1.4 Source 4

This paper did some studies on shock absorbing bicycle wheels. These are wheels that have a spring system between the hub and rim of wheel, this provides the rider with tangential suspension from bumps. They had four concepts, Hexagonal hub bow spoke, Square hub bow spoke, Existing loop spoke wheel, and Telescopic spoke wheel. The main downside that this system has is its need for more power from the rider in exchange for that tangential suspension. We could look into using these wheels in case we needed that extra shock absorbing [4].

3.1.5 Source 5

In this paper the focus is on how the type of spring affects its performance instead of what material it is made of. They did Statistical analysis of fatigue fractures, Model analysis of spring set in series with rubber pad, Dynamic stress calculation and comparison, and many other tests. They did tests at different

frequency ranges. This could help in finding the ideal spring shape and type that we can choose for our suspension [5].

3.1.6 Source 6

In a dissertation, Michael Orendruff studies the damping effects of mountain bike suspension forks compared to fully rigid forks. This study was performed by using three different suspension settings: soft, medium or hard. With these three settings as well as an entirely rigid fork, tests were performed on three different bump sizes. An accelerometer was used in this case to measure impact acceleration during the impact with the bump and the landing after being in the air. The slope of impact acceleration was then analyzed to show the differences in each setting. The results ended up showing that softer fork settings significantly reduced acceleration transmitted to the rider by the fork. The fork on the middle setting provided the best impact acceleration damping [6].

3.1.7 Source 7

Rosenberg and Karnopp write in chapter 5 of their book *Introduction to Physical System Dynamics* about the Laplace Transform, and how to use Laplace Transforms to solve second order time-response systems. The chapter includes a short table of Laplace Transform relations and works out derivations of Laplace Transforms, then shows worked examples of second order differential equations. This chapter will be instrumental in developing the program that solves for critical damping coefficients in the mathematical model [7].

3.2 State of the Art - Benchmarking

Benchmarking is a vital step to the design process in engineering. It is described as the process of measuring designs and/or processes from other designers or companies in order to gain insight on what is already on the market. In doing this, engineers and designers are able to find ways to help smooth out the process of designing and producing products.

3.2.1 System Level State of the Art - Benchmarking

For benchmarking, the team looked specifically at what was on the market for devices that adjusted suspension on the fly rather than prewritten programs that would help with the mathematical model. These products are listed and explained below.

3.2.1.1 Existing Design #1: Specialized Brain

This product was designed specifically for cross country mountain bikes by the company Specialized. The Specialized Brain uses the inertia of a bump to open up a valve and let oil flow in the shock, letting it compress. When the biker is stationary and/or peddling on a smooth surface, the valve stays closed so the biker is not wasting energy through the shock compression. However, whenever the biker hits a bump on the trail, the shock will compress as normal because of the opening of the valve. This product covers our want for an easy to use product but doesn't necessarily cover all of our requirements. [8]

3.2.1.2 Existing Design #2: Fox Live Valve

The Fox Live Valve is similar to the Specialized Brain in that it automatically senses the terrain to open and close a valve in the shock to control the rebound except it uses an electronic controller to control flow rather than the inertia valve used in the Specialized Brain. This electronic system makes it possible for the user to choose what kind of ride they want to have using the included app controller. This system comes closer to what we would like to create because you have the option of what terrain you will be riding on.

[9]

3.2.1.3 Existing Design #3: Quarq Shock Wiz

The Quarq Shock Wiz is a device that relays information from the front and rear suspensions on a mountain bike. The information given gives riders advice on the best ways to tune their suspension to fit their needs on the trail. This is kind of similar to the Fox Live Valve except it only can give suggestions and not actually adjust the suspension accordingly. This may seem like a drawback, but this is probably the most viable option for people because it can be fitted on most suspensions, not just a single brand.

[10]

4 CONCEPT GENERATION

4.1 Full System Concepts, 4.2 Subsystem Concepts

Stress analysis: Excel vs. SolidWorks

The following stress analysis was conducted in two primary platforms of Excel and SolidWorks. Both programs have pros and cons when conducting the analysis, however, are both well known for the team to use. The primary reasoning for using these two programs are to calculate the final Von Mises stress {Equation 1} when applying a load throughout different locations on the frame. The following paragraphs will discuss the differences of Excel and SolidWorks when calculating the final values for the desired equations. And to better understand equation 1, Sigma1 is the Maximum stress, and sigma2 is the Minimum stress. Both sigma variables include the tensile stress and the shear stress as well.

$$\sigma_v = \sqrt{\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2}$$

Equation 1: Von Mises Stress

Excel is rather simple to use when inserting equations into cells to find specific values. This program was perfect for the team to use in finding the Von Mises stress along with other equations that correlate with stress. When using the program, an applied load, specific length, and the diameter of the tubing are used as givens. With this, the team was then able to insert the bending and torsional moment, along with tensile, shear, maximum, and minimum stress equations into cells. As seen in figure {3}, highlighted cells in green are the givens, and yellow are the desired equations to find the final Von Mises stress. This allows the team to know more than just a breakdown on high and low stress frequencies throughout the geometry of the bike. The highlighted blue cells are excess informative information to find the axial deformation when the load is being applied. Throughout this process, the team was able to use current measurements on a bike and manually find the desired values of the Von Mises stress along with the deformation. However, the cons to using Excel are as simple as not being able to find other locations of stress throughout the frame. For this model is just a final calculation on one region of an applied load. While it is possible to obtain these values, the time and effort to find them would not suffice due to other programs on the market. With this, the team found that Excel was perfect for analyzing one specific load on the frame to find the Von Mises stress and deflection, but an inconvenience for finding the remaining values.

1521 N					Diameter	Units
Bending Moment	Units	Torsional Moment	Tensile Stress	Units		12.77 mm
0.13689 N*m		0.6061185 N*m	0.678421171 MPA			
Shear Stress	Units	Max Stress	Min Stress	Units	Ultimate Tensile Strength of 6061 Alloy	
1.482364337 MPA		1.859890646	-1.181469476 MPA		310	
Von Mises Stress	Units	Factor of Safety				
2.6556482 MPA		116.7323292				
Surface area of seat post	Units	Radius	Units	Height	Units	Height / 2
159.0431281 in^2		1.25 in		19 in		9.5
Axial Strain	Units	Modulus of Elasticity	Axial Strain			
0.014823338 MPA		68,900 MPA	2.15143E-07			
Axial Deformation	Units					
0.140823752 in						

Figure 3: Excel Final Von Mises Stress

SolidWorks on the other hand was a more intricate process to start but became easy to use after some understanding with running the studies. With the permission of Dr. Trevas, the team was able to use a pre-designed full suspension mountain bike to use as a model. With this, the program allowed the team to choose the specified material, find fixed points, and place loads at any given point on the bike frame. Once all the givens were inserted onto the model, the study takes into consideration on all the following. Once the study was complete, a color coordinated diagram of the molded frame was provided {figure 4}, along with a chart to indicate the values of the Von Mises stresses throughout the entirety of the frame. This allowed the team to analyze other potential regions on the frame that may have a low factor of safety and find potential spots that the bike may fail. Along with this, the program also includes a motion study that has a time lapse frame of when the load is on and off the model. This concept then provided the team with a simulation of the deformation of the bike. The cons to using this program is the opposite of using Excel, for SolidWorks does not include the bending and torsional moment, along with the tensile or shear stress. While this information is not necessarily needed since SolidWorks auto calculates to find the Von Mises stress, the team found that knowing these values made the understanding of this calculation easy to follow. Another issue with this program is the complex structure of running the study, for if one does not know how to operate specific functions then running the calculation will take time.

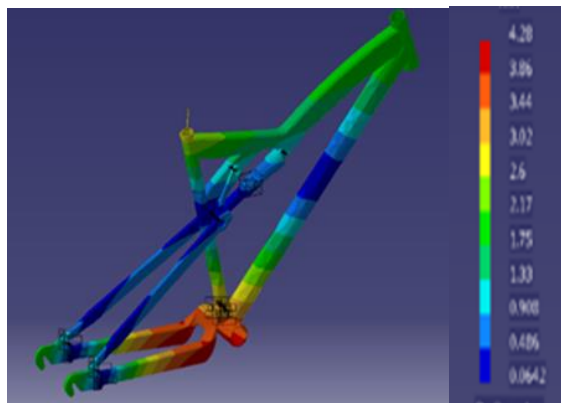


Figure 4: SolidWorks Stress Analysis

All in all, both programs provided roughly the same final calculation of the Von Mises stress at the desired load on the seat post, however, the team found that using SolidWorks would be more efficient. The time spent on SolidWorks was roughly half the time spent in Excel, so using a program that is both quick, and provides an entire model break down on the frame seems to be the best route to work with in the future. The final calculation of this analysis has an applied load of 1521 Newtons on the seat post and has a Von Mises Stress of 2.65 MPA. Using the SolidWorks chart at 2.65MPA, one can see that the seat post has moderate stress when applied at a specific load.

Terrain Analysis: LinkageX3 vs. MATLAB

Mountain bike trails encompass diverse terrain types, and usually the terrain varies greatly on just one trail. First, the team needed to quantify terrain types in engineering terms, then use the terms as inputs for a mathematical model that outputs ideal suspension adjustments for any given terrain. The International Mountain Bicycling Association (IMBA) has developed a chart that categorizes trail difficulties in North America based on both quantitative and qualitative data. The naming system begins at white circle for the

easiest trail type, and progresses in difficulty through green circle, blue square, black diamond, and double black diamond. The chart may be viewed in figure 5 below.






IMBA Trail Difficulty Rating System					
					
	EASIEST WHITE CIRCLE	EASY GREEN CIRCLE	MORE DIFFICULT BLUE SQUARE	VERY DIFFICULT BLACK DIAMOND	EXTREMELY DIFFICULT DBL. BLACK DIAMOND
TRAIL WIDTH	72" (1,800 mm) or more	36" (900 mm) or more	24" (600 mm) or more	12" (300 mm) or more	6" (150 mm) or more
TREAD SURFACE	Hardened or surfaced	Firm and stable	Mostly stable with some variability	Widely variable	Widely variable and unpredictable
AVERAGE TRAIL GRADE	Less than 5%	5% or less	10% or less	15% or less	20% or more
MAXIMUM TRAIL GRADE	Max 10%	Max 15%	Max 15% or greater	Max 15% or greater	Max 15% or greater
NATURAL OBSTACLES AND TECHNICAL TRAIL FEATURES (TTF)	None	Unavoidable obstacles 2" (50 mm) tall or less Avoidable obstacles may be present Unavoidable bridges 36" (900 mm) or wider	Unavoidable obstacles 8" (200 mm) tall or less Avoidable obstacles may be present Unavoidable bridges 24" (600 mm) or wider TTF's 24" (600 mm) high or less, width of deck is greater than 1/2 the height	Unavoidable obstacles 15" (380 mm) tall or less Avoidable obstacles may be present May include loose rocks Unavoidable bridges 24" (600 mm) or wider TTF's 48" (1,200 mm) high or less, width of deck is less than 1/2 the height Short sections may exceed criteria	Unavoidable obstacles 15" (380 mm) tall or less Avoidable obstacles may be present May include loose rocks Unavoidable bridges 24" (600 mm) or narrower TTF's 48" (1,200 mm) high or greater, width of deck is unpredictable Many sections may exceed criteria

Figure 5: IMBA Trail Rating System [11]

In terms of this project, obstacles and technical trail features (TTFs) may be modeled as an average amplitude and frequency for each trail difficulty. The team will determine these averages by measuring obstacle heights and frequencies on trails with IMBA ratings in the surrounding area.

Terrain quantification forms only the beginning of the mathematical model. Next, the platform for underlying suspension calculations must be chosen. Two different programs, LinkageX3 and MATLAB, seem ideal for this application.

LinkageX3 is a proprietary software that allows users to model a specific mountain bike geometry complete with suspension components and wheels. The user may then apply a rider weight, and the software will calculate shock forces and displacements in order to determine sag. This is important because the team can easily model whatever bike is acquired to test and use the outputs as initial values for further calculations involving different terrain types.

MATLAB is the best engine for calculating and displaying the results of the mathematical model. The

underlying math involves solving a second order differential equation with damping (c) and a forcing function (F(t)) particular to each terrain type. The equation is displayed below

$$mx'' + cx' + kx = F(t) \quad \text{[Equation 2]}$$

Where m is mass and k is the spring constant. The forcing function is best modeled as the Dirac Delta function $F(t) = d(t - c)$ where d is the damping ratio, t is time, and c is the damping coefficient. This function works well describing large impact forces that occur over small amounts of time, which is what happens often when riding a bike over bumps.

Now, several solving methods exist for this sort of differential equation. The team could use undetermined coefficients or Laplace Transforms to solve for a critically damped situation for each terrain type. MATLAB handles both methods easily enough, but using Laplace Transforms involves the frequency domain, which allows the team to use the amplitude and frequency measurements taken from physical trails. Laplace Transforms also turn a second order differential equation into a more easily solved quadratic equation.

Once critical damping coefficients are derived, the team can correlate them to physical suspension adjustments on the team's full suspension mountain bike through empirical testing. This will also help validate the mathematical model.

5 DESIGNS SELECTED – First Semester

Since this project is primarily analytical, the designs selected in this section are the software selected to use for this project. These software platforms are then compared to show the strengths with each one for each analysis type.

5.1 Technical Selection Criteria

The following stress and terrain analysis are critical to this project, for the team's primary customer requirements are to base research off current mathematical models and use preferred programs (SolidWorks & LinkageX3) to ensure the modeling is correct. This includes an open system of the rider, suspension system, bike frame geometry, damping, linkage systems, and terrain. With the given analyses, the engineering requirement also correlate with the project, for the spring and damping rate must be critically damped for all given terrain, and to validate mathematical models with other software models. Since the team is basing the design on stress and terrain damping analysis, the four-following programs of SolidWorks, Excel, LinkageX3, and MATLAB will be broken down to explain why one is preferred over the other.

5.2 Rationale for Design Selection

Stress Analysis:

As seen in chapter four, the pros and cons between Excel and SolidWorks did not vary by much. However, since SolidWorks provided more than location to apply specific loads on the geometry of the bike, the team preferred to use this program due to future studies at other desired locations. The program also allows a motion study that incorporates the rear floater shock when using the time lapse function. This small piece of information allows the model to absorb and distribute the load based on the desired setting on the damper when load is applied. Also, SolidWorks provides a full-scale model on the final Von Mises stress throughout the entire bike frame to display where other high and low stress may sit. With all the information that was needed for this study compiled into an individual and motion study, SolidWorks was the preferred program to use by the team, however, the Excel template will be used to check the mathematical model and potentially analyze specific moments and stresses.

Terrain Analysis:

Chapter 4 related the thought process for developing a mathematical model from various terrain inputs. In short, the team will measure trail obstacles and frequencies, and use LinkageX3 for initial values, which will then be plugged into a MATLAB program that uses Laplace Transforms and a Dirac Delta forcing function to output critically damped solutions. The team will then relate critical solutions to physical suspension adjustments on the relevant bike, validating the mathematical model through empirical testing.

CONCLUSION

In conclusion, the team is making steady progress to our end goal of a mathematical model of bike suspension as well as a physical product for mountain bikers. Through customer requirements and engineering requirements, the team was able to put together a black box model of basic functions of our final product. With much research into the world of mountain bike suspension, the team was able to put together benchmark findings as well as start to choose the best ways to carry on with certain sub sections of the bike suspension in concept generation.

6 REFERENCES

- [1] 2014 T. L. F. rduca January 21, "Use Solidworks in Stress Analysis - Measure Stresses, Strains and Displacements," *SOLIDWORKS Education Blog*, 21-Jan-2014. [Online]. Available: <https://blogs.solidworks.com/teacher/2014/01/use-solidworks-in-stress-analysis-measure-stresses-strains-and-displacements.html>. [Accessed: 18-Oct-2020].
- [2] M. Levy and G. Smith, "Effectiveness of vibration damping with bicycle suspension systems.", *Sports Engineering (International Sports Engineering Association)*, vol. 8, no. 2, pp. 99-106, 2005. DOI:10.1007/BF02844008.
- [3] M. Ahmadian, "Magneto-rheological suspensions for improving ground vehicle's ride comfort, stability, and handling", *Vehicle System Dynamics*, vol. 55, no. 10, pp. 1618-1642, 2017. DOI:10.1080/00423114.2017.1323106.
- [4] M. Rajkumar and R. Gandhinathan, "Conceptual Design of Shock Absorbing Bicycle Wheel.", *International Journal of Vehicle Structures & Systems (IJVSS)*, vol. 6, no. 4, pp. 115-119, 2014. DOI:10.4273/ijvss.6.4.06
- [5] W. Sun, D. Thompson and J. Zhou, "The influence of vehicle-track dynamic coupling on the fatigue failure of coil springs within the primary suspension of metro vehicles.", *Vehicle System Dynamics*, vol. 58, no. 11, pp. 1694-1710, 2020. DOI: 10.1080/00423114.2019.1643486
- [6] M. Orendruff, "The effect of mountain bicycle fork stiffness on impact acceleration", Masters dissertation, Dept. Exercise and Sport Science, Oregon State University, 1996.
- [7] Rosenberg and Karnopp, *Introduction to Physical System Dynamics*. New York, NY, USA: McGraw-Hill, 1983.
- [8] Specialized. The All-New Brain. <https://www.specialized.com/us/en/stories/brain-technology>. Accessed: 18 OcOcOcOctooober 2020
- [9] Fox. Live Valve. <https://www.ridefox.com/content.php?c=livevalve-bike>. Accessed: 18 October 2020
- [10] SRAM. Quarg Shockwiz. <https://www.sram.com/en/quarg/series/shockwiz>. Accessed: 18 October 2020
- [11] International Mountain Bicycling Association. Trail Difficulty Rating System. <https://www.imba.com/sites/default/files/content/resources/2018-10/IMBATrailDifficultyRatingSystem.jpg>. Accessed: 14 September 2020

