To: Dr. Trevas

From: [Jacob Cryder, Erik Abraham, Tyson Spencer, Dylan Klemp, Suliman Alsinan, Austin Coyne]

Date: [2/26/2021]

Subject: [Implementation Memo]

The following memo will discuss in detail what team 20FB14 has been working on since the beginning of this project back in Fall of 2020, with a focus on the changes and milestones that have arisen the past seven weeks of the projects. This semester, the team has continued to pursue the "bicycle suspension project" with the same goals expressed last semester. This includes creating a mathematical model, testing the model with a bike, and creating a physical device that can adjust suspension settings while riding the bike. The mathematical model takes rider inputs such as weight and suspension sag in order to figure out the best suspension settings to use for certain terrain types. In order to test the bike, the team will measure suspension displacement over time in order to see how the bike reacts to different terrain types with suspension settings recommended by the mathematical model. For the physical device, the team would like to create a small device that mounts to the handlebars of a bike and can easily actuate the damping and lock out settings of the front and rear shocks.

Since last semester, there have been some major changes and milestones that have helped the team get closer and closer to the final project goals. Towards the end of last semester, Niner Bikes reached out to the team and offered to send the team a bike to test and create a proof-of-concept model for our design. Since receiving the bike, the team has been able to measure and record key components from the bike for the math model that would have otherwise been impossible to do without a bike. Having a bike has also made it easier to design a device that could possibly be used across a multitude of bikes. Another change that has happened this semester is the unofficial split of the team to work on two different aspects of the project at the same time. The team didn't see it necessary to have six people working on the mathematical model, so a decision was made to have three members of the group continue working on the math model while the three other team members could start on the physical design aspect of the project. The mathematical model team has been focusing on how to accurately measure data from the bike for testing with the use of Lidar sensors and linear potentiometers while the design team is going through an expedited version of the design process that all the other teams are following in order to create a proof-of-concept model. This break in the team only applies to the weekly work being done on the project. When it comes to big decisions, class assignments, and main client/stakeholder meetings, the whole team works together rather than the separate teams. The internal team groups were deemed necessary by the team because the great amount of work that needs to be done in a short amount of time this semester.

1 Customer Requirements (CRs)

When initially meeting with the team's client from W.L. Gore, a set of requirements were placed to ensure that the team would centralize within the constraints. With that said, the client stated the following: base research on current mathematical models, perform extensive research on bike systems, ensure that the average user can utilize the design, incorporate SolidWorks, create an Excel code, and validate with testing. To break that down further, the team created a mathematical model that met client's expectations, for the model is designed to input data based on the specs of the rider along with the trail grade conditions. The model was originally based on a Santa Cruz Heckler, however, after reaching out to various mountain bike companies, Niner bike provided a Niner RIP 9 RDO bike for testing. The mathematical model is now user friendly, for the primary software is used in Excel, and various dropdowns are provided to change the terrain settings along with other functions if needed. A rather new portion for this semester includes a design team, for this allowed the team to get hands on with designing components that are related to the mathematical model. The team was split up into two sections, one that focuses on the mathematical model while the other is generating designs. The design group has been using the D4P method, similar to what most teams went through last semester. SolidWorks designs are in the making and will soon be sent to the 3D printers for prototyping. This ties back into the validation testing, for the team has decided that the data collected from the mathematical model should then be applied to a real-life application with the suspension settings on a mountain bike. The design will incorporate and Arduino which involves coding to run functions such as stepper motors or linear potentiometer sensors. With that said, SolidWorks and MATLAB/Arduino are ranked a five, validation testing is ranked at four, user friendly/current systems is ranked at a three, and bike suspension research is ranked at a two. This ranking system has changed since the prelim report, for the design components are heavily focused on this semester, however, the client's requirements of having the mathematical model being user friendly was another concept to work on as well.

2 Engineering Requirements (ERs)

The Engineering Requirements that we as a team are required to follow can be seen in table 1 below.

Table 1: Engineering Requirements with units and target value

	Engineering Requirements	Unit	Target
1	Spring and Damping Rate Critical in all Cases	lbfs/in	critical/underdamped
2	Validate Mathematical Models with other Models	%diff	+-5%
3	Test Bike Compatibility (Clamp Diameter and Geometry)	mm	28
4	Minimize Weight Addition	g	<300
5	Compact Design to Fit on Handlebars	cm^3	7
6	Durability (Material Strength)	MPa	50

After getting a good idea of the goals of our project, we produced these six engineering requirements above. First, the dampening rate is one of the most critical factors in our project. Due to how much it affects the comfort of the user. without having the right damping coefficient, the oscillations are going to be too many or too few for a comfortable ride, it would be unsafe for the bike itself as well. As for the second requirement, it stands as the grounds of which we build our project on. If we are not able to validate our mathematical model, then there is no use for it in the real world. Comparing it with other similar models to discover trends that we should follow is the way we will validate the model. In case the difference in models comes up as larger than +- 5% then we will not consider the model to be valid. The third reequipment, which is the test bike compatibility, has already been met. Since the last semester we as a team were able to acquire a testing bike for this project that is provided by niner bikes free of charge. The main concern is for the bike to exceed the range needed for the clamp diameter and the mounting geometry, thankfully the test bike's dimensions are well within the tolerance of meeting this requirement. The next requirement talks about the limit for the device's weight. This requirement is intended to minimize strain adding the device adds on the user. We hope to achieve weights that are way below the requirement, but after getting a little further in the device development this weight is getting closer and closer. The fifth requirement limits the size of the device's control panel size. The goal is to be able to add the device to the front of the bike near the handlebars without making it harder to control or see for the user. Lastly, requirement number six limits the fragility of the device. As we all know bike rides can include a few impacts from the different road types, because the device is on the bike itself it needs to also be able to handle some of those bumpy roads.

3 Design Changes

The model sub team made a few critical changes to the mathematical model involving input variables and trail type specific outputs. They also switched the primary test apparatus from Arduino to a Motion Instruments linear potentiometer system. The design sub team has progressively moved from an electronic suspension adjustment device to a simple mechanical mechanism.

3.1 Design Iteration 1: Change in Mathematical Model Discussion

Originally, the mathematical model used input weight bias data for level ground only and was tailored to Dylan on his 2016 Santa Cruz Heckler. After receiving a 2020 Rip 9 29er from Niner Bikes in Colorado, the model was updated with the new bike's geometry and mass specifics. The team also obtained weight bias percentages for grades between 5% and 20% using Dylan as the rider, which correlate to the average steepness of each documented trail type of the International Mountain Bicycling Association (IMBA). Tyson added ascending and descending grade inputs to the model as dropdown menus, and Erik propagated the input data and shock displacement calculations/graphs into the sheets dedicated to each trail type (white circle through double black diamond). Old copies of the spreadsheet are not available, but an example of the updated sheets may be viewed below.

	A	B	C	D	E	F	G	H
2	**Initial Values**						Front Fork	Rear Spring
3	Bike Mass	bm	14.06	kg		Time (s)	Underdamped	Underdamped
4	Person Mass	pm	78.91	kg		0.01	0.048308708	0.021576667
5	Overall Mass	m	92.97	kg		0.02	0.058558061	0.025855014
6	Front sprung mass	mf	26.76	kg		0.03	0.066191943	0.029041292
7	Rear sprung mass	mr	66.21	kg		0.04	0.071603543	0.031313245
8	Front fork stiffness	kF	3600	N/m		0.05	0.075139992	0.03282377
9	Rear spring stiffness	kR	7600	N/m		0.06	0.077106708	0.033704136
10	Front damper value	λF	550	kg/s		0.07	0.077771435	0.034066798
11	Rear damper value	λR	1350	kg/s		0.08	0.077367988	0.034007865
12	Front damping coefficie	ςF	0.8860	Ns/m		0.09	0.076099719	0.033609259
13	Rear damping coefficien	ςR	0.9516	Ns/m		0.1	0.074142703	0.032940611
14	Front natural frequency	Fωn	11.5987	1/s		0.11	0.071648671	0.032060905
15	Rear natural frequency	Rωn	10.7138	1/s		0.12	0.068747687	0.031019931
16	Front Initial shock speed	v0	1.5	m/s		0.13	0.065550594	0.029859538
17	Front sag	x0f	0.035	m		0.14	0.06215124	0.028614738
18	Rear sag	x0r	0.016	m	29%	0.15	0.058628492	0.027314659
19	Rear initial shock speed	v0r	0.6303	m/s		0.16	0.055048067	0.025983383
20	Front damped frequenc	Fωd	5.3779	1/s		0.17	0.05146417	0.024640669
21	Rear damped frequency	Rωd	3.2942	1/s		0.18	0.047920979	0.023302583
22	Front Fork Travel	FT	0.15	m		0.19	0.044453971	0.021982044
23	Rear Shock Travel	RT	0.063	m		0.2	0.041091105	0.020689299
24	Leverage Ratio	LR	2.38	unitless		0.21	0.037853881	0.019432332
25	Grade direction	D	Ascending	unitless		0.22	0.034758279	0.018217216
26	Grade Rating	G	>10%			0.23	0.03181559	0.017048423
27	Front Bias	FB	28.78	%		0.24	0.029033148	0.015929082
28	Rear Bias	RB	71.22	%		0.25	0.026414981	0.014861209
29						0.26	0.023962371	0.0138459

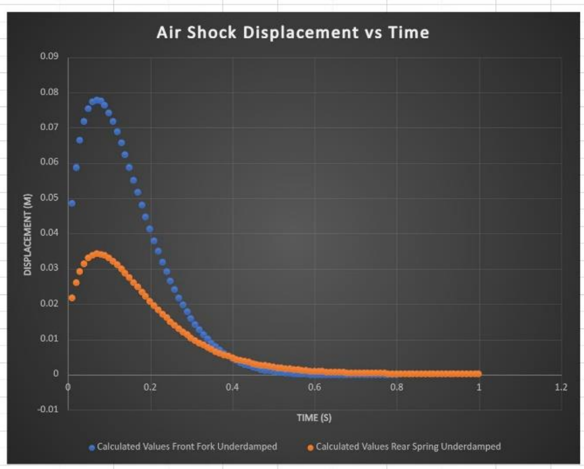

Figure 1: Math Model Inputs and Graph for Blue Square Trail Type [1]

The new weight bias data allows the calculations to model all the different trail types whether ascending or descending. A screenshot is below.

	A	B	C	D	E	F	G	H	I	J
1	Descending									
2	grade	angle	h (mm)	front (lbs)	rear (lbs)	front bias	rear bias %		kg	kg
3	0%	0	0	77.5	127.5	37.80	62.20		35.15	57.82
4	>5%	2.86	59.05	84.5	120.5	41.22	58.78		38.32	54.65
5	>10%	5.71	118.19	93	112	45.37	54.63		42.18	50.79
6	>15%	8.53	177.28	90.1	106.9	45.74	54.26		40.86	48.48
7	<20%	11.31	236.4	107	98	52.20	47.80		48.53	44.44
8										
9	Ascending									
10	grade	angle	h (mm)	front (lbs)	rear (lbs)	front bias	rear bias %		kg	kg
11	0%	0	0	77.5	127.5	37.80	62.20		35.15	57.82
12	>5%	2.86	59.05	68.5	136.5	33.41	66.59		31.07	61.9
13	>10%	5.71	118.19	59	146	28.78	71.22		26.76	66.21
14	>15%	8.53	177.28	52.5	152.5	25.61	74.39		23.81	69.16
15	<20%	11.31	236.4	49	156	23.90	76.10		22.22	70.75
16										

Figure 2: Math Model Weight Bias Data [1]

Physical testing of the Rip 9 mountain bike's suspension reactions will be used to validate current math model results. Eventually, the math model will output displacement curves and ideal suspension adjustments for our test bike. The model should give results for any rider weight and grade direction inputs.

3.2 Design Iteration 2: Testing Apparatus Changes

For much of this semester, the team planned to validate the math model with an Arduino Mega 2560 writing measurements from an Adafruit VL53l0x laser time of flight sensor to a micro-SD card breakout board. The sensor reads distances in the range of 30-1000 mm. Tyson designed and 3D printed a hardware box and brackets for the components. They allow the apparatus to be mounted near the front fork or rear shock for physical suspension testing. Pictures are below.

Figure 3: 3D Printed Arduino Suspension Testing Box [2]

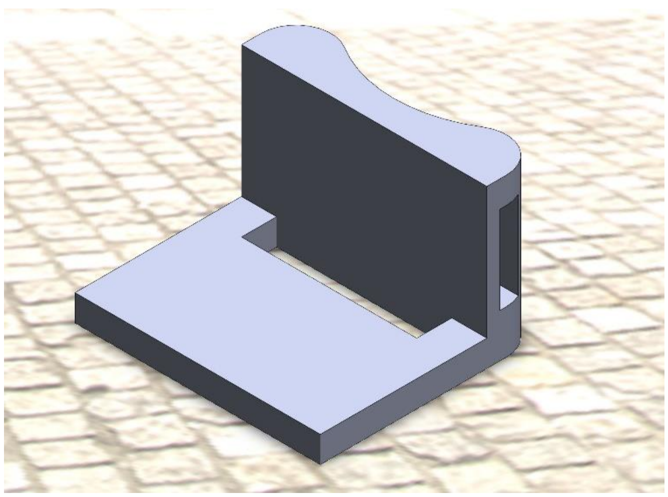

Figure 4: LIDAR Sensor Bracket [3]

Not only has implementation been difficult, analyzing the data will be tedious, and the Arduino Mega was fried on a metal table. It allows the VL53l0x to write to the Serial Monitor but will not support a micro-SD breakout board. Carrying a laptop on a moving bike is not ideal, so the serial monitor is not viable.

Of course, the team could obtain another Arduino Mega, but the overall system is tedious and inefficient. Motion Instruments, a recent startup company, has developed data acquisition systems specifically for full suspension mountain bikes which use highly accurate linear potentiometers and a proprietary iOS app. The team purchased one of these systems and hope to begin testing when it arrives next week. A stock photo may be viewed below.

Figure 5: Motion Instruments XC-Enduro Pro System [4]

This approach will streamline data analysis and math model validation, allowing the team to spend more energy finalizing the math model and prototyping a suspension adjustment device.

3.3 Design Iteration 3: Device Design Changes

This semester the team has made a key change in that there has been a split into two sub-teams: model and design. The design team began this semester by starting an expedited engineering design process for the physical device. Last semester the focus was solely on the model and thus splitting into sub teams allowed for quick and quality progress to be made on the design side as the model still had plenty of work needing to be addressed itself. The design team has performed various stages of concept generation, Pugh charting, and engineering problem solving. The primary focus thus far has been splitting the overall design into five design categories: Mounting to the bike, connecting to the mount, user input control, suspension dial adjustment, and design power source/mechanism. The team has a primary design concept comprising of a shim to mount to the bike, a modular plate to connect to the mount, a handlebar mounted dial for user input control, a fork clamp for suspension dial adjustment, and a wire for a mechanical power source. Other considerations included using a stepper motor rather than a mechanical wire however, the team has decided a wire system will be the better fit. At this stage the design sub team is planning for the composition of the wire drive system and CAD modelling each of the five design categories. The idea for the design is to have a lever system in which the user dial control will use wire tension and a spring to rotate the dial in one direction and release wire and spring tension to allow it to rotate the other way. The main challenge is that the suspension system has two suspension dials on the rear shock and one on the front fork, so a system that accurately adjusts each separately is crucial. The design team's next step is to begin creating the whole model in CAD followed by 3D printing and machine shop fabrication to create the prototype and solve potential tolerance issues. Overall, the design team is on track to accomplish the goal of a working prototype that utilizes the mathematical model’s outputs for accurate adjustment. Shown below are the current individual parts of our CAD model.

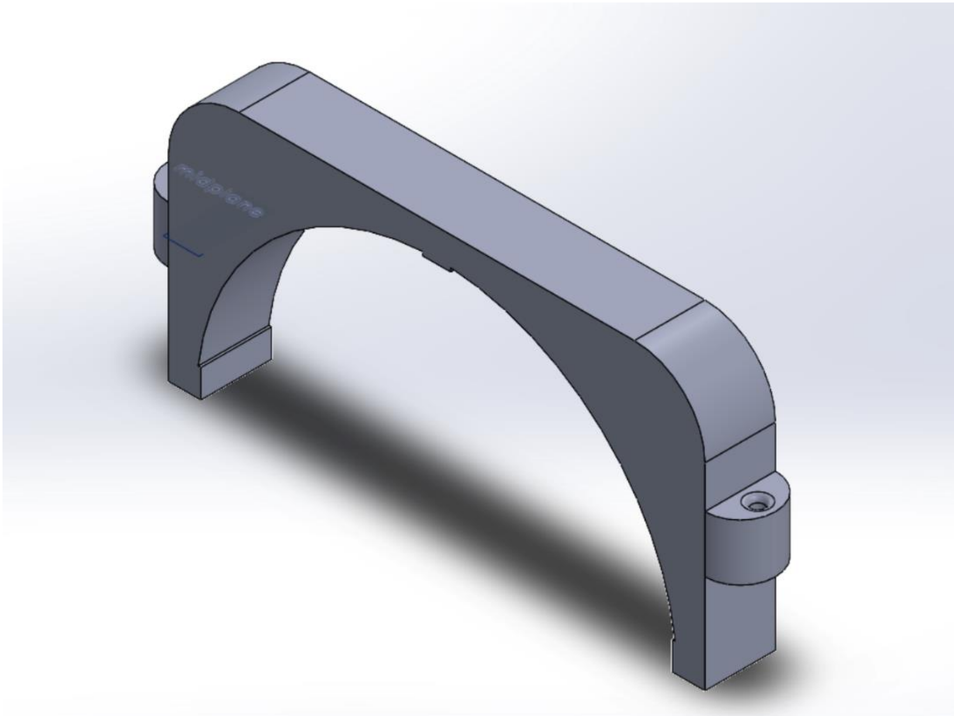

Figure 6: Suspension Adjustment – Knob Fork Clamp

This design will clamp around the suspension dials for rebound and compression. The tabs on either side will hold each side of a wire so that when tension is applied to one side the clamp will turn, pulling the dial in the desired direction as well.

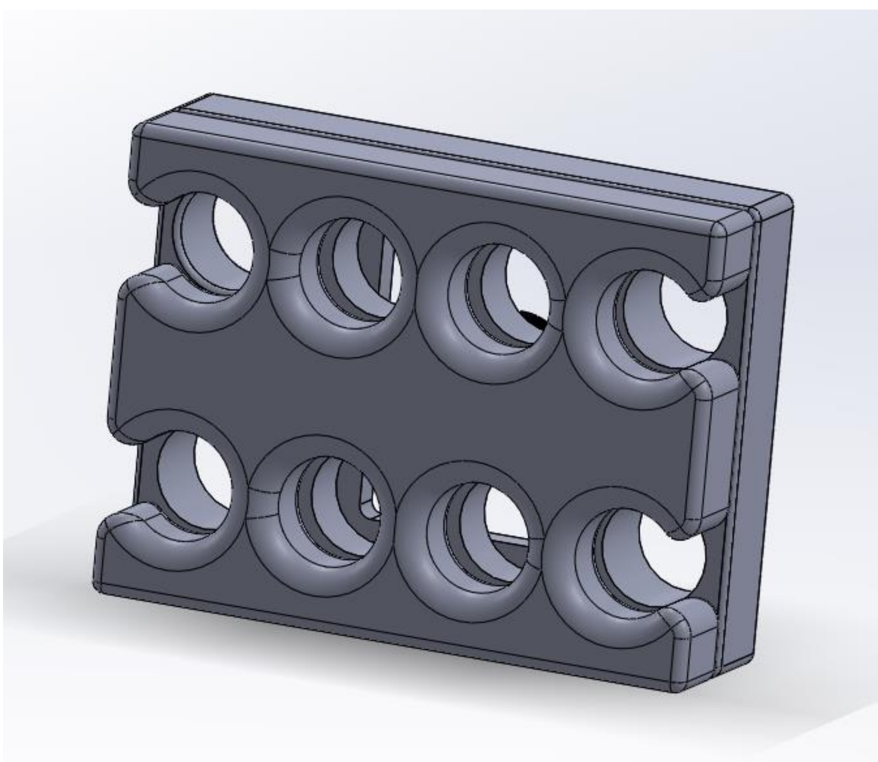

Figure 7: Mounting plate and Shim Mount

This design allows the motor to sit on the plate were Velcro or zip ties can be used to hold into place. The back plate will hold the shim design into place where the entire system will rest on.

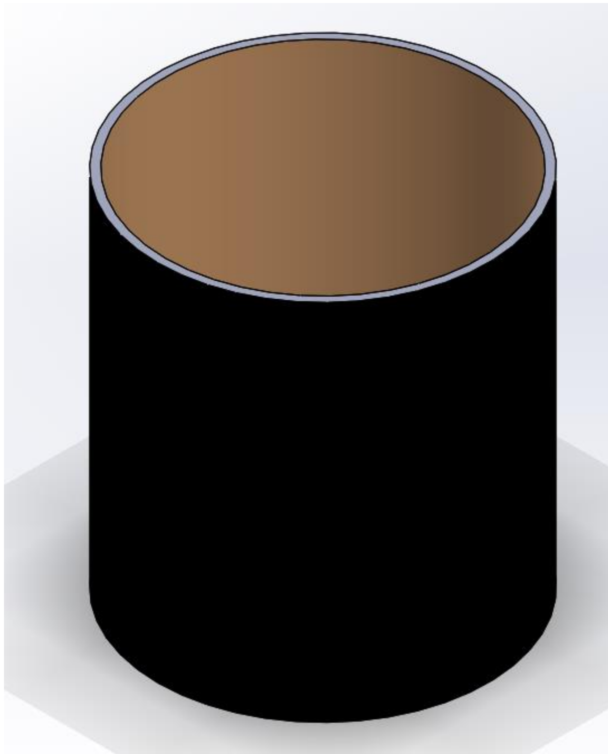

Figure 8: Basic Shim Design

This design is a rough concept of a shim that will be placed over the backflow on the floater shock. This will be placed over like a sleeve, where a clamp will be used to hold the design into place.

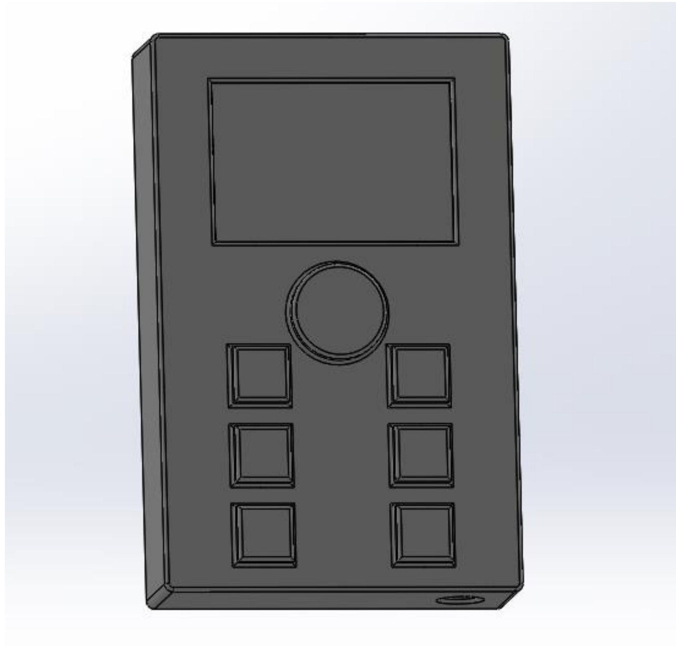

Figure 9: Control panel with buttons

This control panel will give the user more control options. It will also allow us to implement a screen if need and use a variety of buttons. It is a bit bigger than other designs, but it still fits with the size of the bike frame.

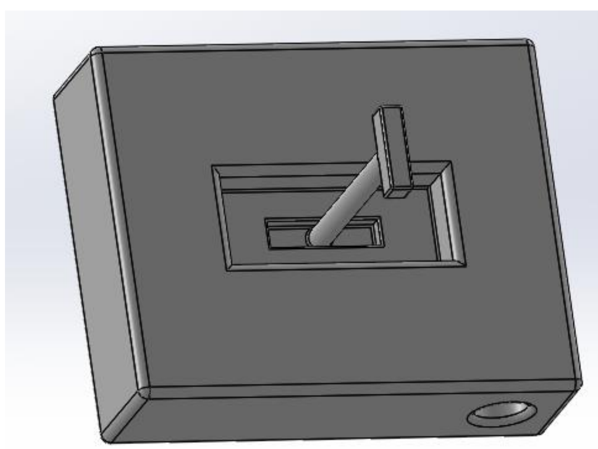

Figure 10: Control panel with a lever

This control panel is applying a simple approach to the problem. Instead of overwhelming the user with many control options, this design has one lever that takes inputs on the changes the user wants.

4 Future Work

Since there are two sub teams in the project, there are two different goals for this project: finish the mathematical model and create a device to adjust suspension settings on the fly. Finishing the mathematical model will require the team the team to turn the current model outputs into actual suspension adjustments. This task requires the team to analyze our data and decide on a correlation between the data and different adjustments. Next the team will be performing tests to validate the model and adjust as needed. For the design team, the goal is to get a prototype of the device that can adjust suspension settings on the fly. This prototype is expected to change the rebound and compression of the rear shock and adjust compression on the fork. It will be mounted on the handlebars and is currently going to be a mechanical system.

4.1 Further Design

Breaking down each portion further, the mathematical model team intends to analyze the current displacement graphs for each terrain type and ensure the damper flowrate is providing the best damping. For some terrain, the best damping might be a displacement curve that has three maximums meaning the shock will bounce before returning to a steady state. For different terrain, the team might want the shock to have one maximum where it is critically damped, thus absorbing all the shock and not rebounding. A linear potentiometer from Motion Instruments will be the testing device used to validate the model. Testing will include mounting the potentiometer on the bike and adjusting the suspension based on settings from the model. The linear potentiometer will allow the team to see real time data on suspension performance and what adjustments would benefit the rider. By seeing these adjustments, the team can then help incorporate the data into the model.

For the design team, each member is creating detailed CAD sketches for various parts of the design and will begin using rapid prototyping methods such as 3D printing to ensure each part works as needed. Members of the design team are working together to ensure each part is cohesive and are working towards a common goal of creating a device that perform the primary function of adjusting suspension setting on the fly. This part is expected to be a working prototype, but materials used will not be the same as if the product were to go to market.

4.2 Schedule Breakdown

The schedule, as seen in the Gantt chart in figure 11 below, shows the tasks the team is completing and the timeline for each task. Finishing CAD models will take about two weeks until the prototyping phase of the design, although CAD models will be adjusted based on prototypes and will go until the end of the semester. The mathematical model will be a work in progress until the end of the semester while the team uses testing to ensure the outputs are work well. Testing will begin next week once the linear potentiometer arrives.

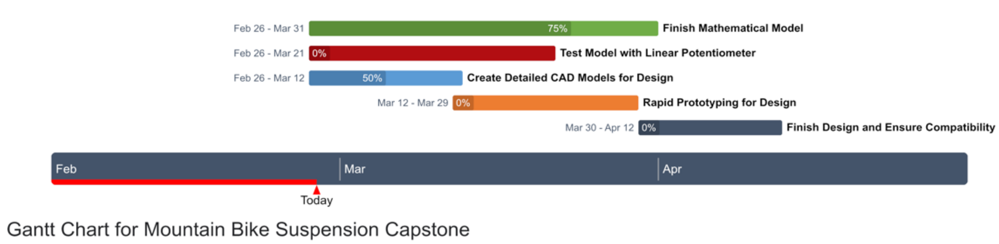

Figure 11: Gantt Chart for Major Tasks

5 References

Motion Instruments. (2020). XC-Enduro Pro.
Spencer, T. (2021). Arduino Pics. Flagstaff: Google Photos.
Spencer, T. (2021). Lidar Bracket. Flagstaff: Solidworks.
Tyson Spencer, E. A. (2021). Updated Math Model. Flagstaff: Microsoft Excel.