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Subject: [Implementation memo]

Our project has been assigned to be an analytical project. The Baja SAE vehicle is designed to withstand the harshest elements of rough terrain. There are many systems in this car that work simultaneously to make it possible for the car to run perfectly. The systems assigned to our team are the front brake, front suspension and dashboard. This is done by designing the systems in SolidWorks, and then the design is evaluated using the calculations and FEA. The dashboard design is based on the Arduino board. The design is evaluated on the basis of engineering requirements and modified accordingly to meet all of them.

1 Customer Requirements (CRs)

The Baja SAE vehicle is a single-seat, all-terrain vehicle. It should be light in weight and safe for the driver too. The comfort of the rider is a priority here, along with the ease of maintenance. The vehicle's stability, reliability, and durability contribute towards a successful design. The customer requirements, along with the weightage out of 5 presented below:

Sr.	Customer Requirement	Weightage
1	All-terrain Vehicle	4
2	Light Weight	3.6
3	Safe Design	4.5
4	Comfort for the rider	4.5
5	Ease of Maintenance	4
6	Short Stopping Distance	3.8
7	Steering should be accurate and easy to handle	4.2
8	Dimensional Stability	4
9	Reliable and Durable	4.5

2 Engineering Requirements (ERs)

The engineering requirements are a set of defined system parameters around which the design is developed, and the product is finalized. The engineering requirements for the systems assigned are deduced from the rules of Baja SAE. The track width defines the width of the wheelbase, while the weight of the car and driver provides the starting load on the system under static conditions. The shock absorber spring defines comfort and reliability on tough terrain. The steering of the car should be reliable and easy to operate. The dashboard should be able to detect vehicle data in real time and display it on the LCD or analog dashboard. The engineering requirements are presented as follows:

Sr.	Engineering requirement	Unit	Target value	Tolerance
1	Track Width	inch	62	±2
2	Able to carry driver weight	lb	130	±5
3	Weight of vehicle	lb	370	±5
4	Spring Compression	in	4.5	±0.5
5	Braking Distance @ $v = 12.169\ m/s$	meters	7	±0.5
6	Braking Time @ $v = 12.169\ m/s$	sec	< 5	-
7	Brakes Temperature	ºC	<100	-
8	Steering Effort	lb-inch	0.5	±0.05
9	Steering Degree	-	30	±5
10	Speed detection accuracy	km/h	< 5	-
11	Display delay	ms	< 25	±10

2.1 ER #1: Track Width

2.1.1 ER #1: Track Width - Target = 60 inch

The required track width was established by using the SAE Baja Rule book, The track width has a significant effect on the width of the Baja vehicle. Also, there was a change in the target value of track width from last semester, and it was 64 in to make 60 in. The vehicle's track width has a major impact on its overall performance. With a wider track, the Baja vehicle should be more stable and maneuverable.

2.1.2 ER #1: Track Width Tolerance = ±2

The track width tolerance is established by deciding that it should be as broad as feasible to enhance vehicle handling while remaining within the limitations given in the SAE BAJA Rule book. The stability and maneuverability of the vehicle are critical design considerations that must be addressed throughout the design process. As a result, the tolerance has been reduced to 2 in.

2.2 ER #2: Driver Weight

2.2.1 ER #2: Driver Weight - Target = 130 Ib

It was established early in the design process that the projected driver weight requirement would be 225 Ib. On the other hand, have changed it to 130 Ib. The engineering needs are predicted instantly. To get the most significant outcomes, it is essential to consider all of the criteria.

2.2.2 ER #2: Driver Weight - Tolerance = ±5

Because of the uncertainty involved in changing the driver's weight, a tolerance of 5lb was determined factors outside of his control influence the weight of the driver. Because no one's weight changes much over time, the team maintains a modest tolerance.

2.3 ER #3: Car Weight

2.3.1 ER #3: Car Weight - Target = 370 Ib

To better meet their needs, the requirement has lowered the maximum weight restriction of the vehicle from 450 to 370 Ib. The total weight of the car will be reduced, which will result in improved performance and stability.

2.3.2 ER #3: Car Weight - Tolerance = ±5

According to the requirements specifications, the total weight of the vehicle cannot exceed 375 pounds. To account for any changes that may have occurred throughout the testing and trial stages, the team decided to retain the 375 Ib goal weight.

2.4 ER #4: Spring rate

2.4.1 ER #4: Spring Compression - Target = 4.5 in

The design team has established the spring's compression limit to be 4.5 inches. The spring and shock absorber is considered an essential part of the vehicle suspension. It provides stability and comfort for the driver. The rate of spring is considered designed to load and carry out the max compression.

2.4.2 ER #4: Spring Compression - Tolerance = ±0.5

The team decides on tolerance of 0.5 inches to account for weight distribution variations between the vehicle and the driver during testing. The force exerted on the spring increases according to the vehicle's weight. When large loads are applied, the 0.5 inch tolerance is eliminated.

2.5 ER #5: Braking Distance

2.5.1 ER #5: Braking Distance - Target = 7 m

The braking distance defines the performance of the vehicle at the specified speed. The engineering requirement for braking distance is determined using the Baja SAE rules. This engineering requirement is used in calculations for the thermal and structural performance of the brakes.

2.5.2 ER #5: Braking Distance - Tolerance = ±0.5

As the vehicle is an all-terrain vehicle, different ground conditions can cause the breaking difference to vary from the target value. For example, when there is rain, the braking distance might increase from the target value as there would be a slippage between the tire and ground.

2.6 ER #6: Braking Time

2.6.1 ER #6: Braking Time - Target < 5 s

The braking time is a critical thing while the vehicle is underused. The braking time is calculated using the braking distance and loadings on the vehicle.

2.6.2 ER #6: Braking Time – Tolerance = -

The tolerance value for braking time is not defined as any time below the target value is acceptable as long as the thermal loads on brakes are under the calculated limit.

2.7 ER #7: Brakes Temperature

2.7.1 ER #7: Brakes Temperature - Target < 100º C

When brakes are applied in any vehicle, the kinetic energy of the vehicle must be dissipated in the form of heat in the brakes. This friction power generation in the brakes raises the temperature of the brakes and must be under a safe limit. For a specific speed, the maximum temperature of the disk is defined as an engineering required to make the design safe and reliable.

2.7.2 ER #7: Brakes Temperature - Tolerance = -

The tolerance value for this engineering requirement is not defined as any value below than the target value is acceptable.

2.8 ER #8: Steering Effort

2.8.1 ER #8: Steering Effort - Target = 0.5 lb-in

The steering effort is the requirement needed to torque the vehicle's steering in such a certain direction. So, the target value for steering is set as 30 degrees, and the team decides to minimize the radius around to turn complete rotation. The steering effort should be adjusted to avoid the driver from becoming tired

2.8.2 ER #8: Steering Effort - Tolerance = ±0.05

Tolerances for steering effort are established to expand the diameter of the vehicle while keeping a constant need for steering force. A tolerance of 0.5 inches is sufficient since the steering diameter will not change considerably.

2.9 ER #9: Steering Degree

2.9.1 ER #9: Steering Degree - Target = 30º

The steering degree target for the vehicle has been set at 30 degrees. The steering degree will aid the team in identifying the lowest possible radius within which the whole car may be altered in any direction.

2.9.2 ER #9: Steering Degree - Tolerance = ±5

The design has 5 degrees steering tolerance to accommodate a quick turn over difficult terrain. Increasing the steering angle will assist the crew in stabilizing the vehicle. Also, the degree of steering can be changed during the speed turns or shocks. Differences in degrees can show the result of the value of the target, which is considered to be optimized.

2.10 ER #10: Speed detection accuracy

There are no specific requirements for the accuracy of the instrument panel in the SAE Baja manual. According to the requirements of the Chinese national automobile for the accuracy of the instrument panel, the minimum accuracy level is 2.5. Taking into account the mechanical error of the stepping motor, the accuracy is set to 5 units.

2.11 ER #10: Display delay

There are clear requirements for LCD display delay, which is generally less than 25MS. Taking into account the calculation and delay, the allowable delay is 25 ±10 ms. The picture display speed acceptable to humans is generally 24 frames per second. If the display speed is lower than this standard, people will obviously feel the picture pauses and discomfort. Calculated according to this index, the display time of each picture needs to be less than 40ms.

3 Design Changes

The vehicle design has remained mostly unchanged since SAE Baja vehicles were created. With a few minor modifications, maintenance has been simplified. After completing the final design, the team met to evaluate the benefits and compared them with the last ideas by using the decision matrix and having that discussed with the team, they reached the best solution. As a result of a few modifications to the suspension and brake were performed, as described below.

3.1 Design Iteration 1: Change in Brake Disk discussion

The original brake disk had a thickness of 0.1 inches. The disks of that minimum thickness could not meet the engineering requirements. Therefore, the thickness is increased to 0.2 inches, and FEA analysis is performed by the team. The accepted factor of safety is achieved, and hence the minimum thickness is finalized.

3.2 Design Iteration 2: Change in Front suspension

The original concept generation of the front suspension was the shock absorber connected and mounted to the lower arm throughout the linkage. However, to improve the ease of maintenance of the front suspension, the team made a decision to mount and attach the shock absorber to the upper arm. Therefore, the benefit of that is easy maintenance that can increase the performance of a car without affecting it.

3.3 Design Iteration 3: Change in dashboard

The chosen sensor is an IR sensor, which is included in the Arduino module. The infrared sensor includes an infrared LED and an infrared photodiode. It is called an infrared sensor because it detects radiation from IR transmitters. Infrared receivers take the form of photodiodes and phototransistors. When the infrared transmitter emits radiation, it will reach the object, and some of the radiation will be reflected back to the infrared receiver. However, the accuracy of this sensor is not high enough to identify every seam in the wheel. So I changed to LM393 speed sensor. The signal from the phototransistor is provided to the LM393 and depending on whether there is an object between the infrared LED and the phototransistor, the output of the LM393 IC will be high or low. The module can be used in association with a microcontroller for motor speed detection, pulse count, position limit, etc.

4 Future Work

The team will be responsible for developing and evaluating the SAE Baja vehicle components and identifying how each component's design parameters and size influence the system's overall performance. The focus will be on fulfilling client needs while also improving the system's overall performance. Additionally, the study will assist the team in determining whether the engineering criteria have been fulfilled.

4.1 Further Design

The following parts can show the details of analyzing the suspension, and brake system, and the dashboard. Given that all of the analysis has been done, the team will now focus on performing an in-depth assessment of the remaining components within the timeframe.

4.1.1 Completed Work

4.1.1.1 Front Suspension

This part concluded the vehicle's analysis. Any point in the vehicle's algebraic sum of force-moment cannot be higher than zero. In the section below, you'll discover formulas for calculating the vehicle's front and rear reaction forces.

$$\sum F_V = 0 \tag{1}$$

$$\sum M = 0 \tag{2}$$

By sub in equations (1) and (2) may be used to calculate the reaction forces acting on the vehicle's wheels. The reaction forces at each spin's front and back ends are estimated to be 97.5 lb and 146.5lb, respectively.

The reaction forces produced by the wheels will be received and transferred by the suspension system to the vehicle's arms. These forces will be transmitted to the coil spring of the shock absorber and positioned in the direction of the arm. For this coil spring, the equations (1) and (2) may be used to calculate the force acting on it. It is anticipated that the spring will exert a pressure of 129.6 Ib. Also, the team calculated the friction force that will effect on the arm and as a result of friction force is equal to 7.3 Ib and used this equation;

$$F_{frication} = \mu N \tag{3}$$

Hence, the team also has completed all the calculations and forces of both arms for the suspension that will affect them and used the simulation (FEA) for both arms to get the plots of the Von Mises Stress the FOS. Team used the same steps of analysis that is shown in above to apply the simulation in the upper and lower arms

The spring rate (k) of the coil spring at static condition

$$F_s = kx \tag{4}$$

Where x is the deflection in the coil spring.

As a result, the coil spring's spring rate per inch of compression will be full expended

Therefore, the team made assumptions about the spring rate at dynamic conditions for the stroke or deflection between the 1 in to 5 in and then the team took 2.5 in to calculate the rate of spring at this stroke and got 36.6 Ib/in.

4.1.1.2 Brakes

The complete suspension along with the brakes is designed using SolidWorks. The braking force and clamping force are calculated using the following equations.

$$F_b = \frac{m\left(v_f^{\ 2} - v_i^{\ 2}\right)}{8s} \tag{5}$$

$$F_b = 2\mu F_c \tag{6}$$

Equation 5 and 6 are used to find the forces on the brake disk. The power generated in the disk due to braking is calculated using the following equation 7.

$$P = \frac{1}{2nt} m v^2 \tag{7}$$

Where the time for the braking is calculated using equation 8 as given below.

$$v_f = v_i + \left(\frac{v_f^{\ 2} - v_i^{\ 2}}{2S}\right) t \tag{8}$$

Once the structural and thermal loads are calculated using the above equations, the brake disk is analyzed using FEA for thermal and structural performance. The results show that the engineering requirements are satisfied for the brake disk and the design is accepted.

4.1.1.3 Dashboard

At present, the instrument panel has realized the function of detecting the motor speed and displaying the speed and fulfilling the accuracy requirements. Here is the list of the required components: Arduino UNO, LM393 speed sensor module, 16×2 LCD display, 5V gear DC motor, Encoder wheel, Motor speed controller, Connection line, Breadboard. For the program of Arduino, it uses millis() function in Arduino to calculate the time of one revolution.

There will be a timer to keep timing, when a seam is detected, an interrupt will be generated, and the current time will be recorded, minus the time recorded in the previous time to get the time for a seam to pass. Multiply by the number of seams on the wheel, you can get the time for the wheel to make one revolution timetaken = current - prevent

rpm = (1000 / timetaken)*60 (1 sec = 1000 millis)

Get the speed according to rpm, then convert it from m/s to the commonly used km/s, and display it on the LCD.

Velocity = 2 * pi * rpm*R (m/s)

V_display = rpm * R * 0.3768 (Km/h)

4.1.2 Future Work

The team has updated all the modifications of the weight of car and driver by the client, and the team has updated these requirements on the calculation and simulations. Also, the team' s objective will focus on performing or analyzing the components of parts of the suspension system and the steering, brake system and dashboard.

The main goal of the team in upcoming weeks is to assemble the design by using SolidWorks and perform the motion study and analysis to visualize the performance of the system in actual working. Another target of the team is to complete the assembly by collecting all the parts and setting the fasteners, and the damper. Also, the knuckle will be redesigned to meet the requirement of the steering system.

For further analysis, the force that will be on the spring depends on the inclination angle θ. So, the force will be changed from 1 in to 5 in, because of that, the angle and the compression of the spring will be changed based on the stroke. So, the team has planned to calculate the force, compression of the spring rate and will be plotted.

Team has made a plan for the testing of the project since their project is analytical and it will be different and unique from the other groups. Therefore, the team will use the motion study of analyzing for each part of the steering, front suspension, and brakes system. The Motion Analysis of the steering system would further refine the system and provide a complete picture for the working of the steering system. Motion study for the brake system would further reaffirm the design dynamics as considered while designing the assembly. The suspension motions study would also be performed to verify that the engineering requirements for the suspension are fulfilled. For future work, the dashboard part will produce more functions on the basis of arduino. The dashboard will use stepping to design an analog dashboard. Use the detected rpm to control the rotation angle of the stepper motor, and use the pointer to correspond to the corresponding speed, just like the dashboard on a car.

4.2 Schedule Breakdown

This part provides a project timeline and an estimated completion date for the whole project.

The schedule breakdown of the future work is as presented in the following Gantt chart.

Task	October			November			
	2nd week	3rd week	4th week	1st week	2nd week	3rd week	4th week
Design Refinement	■	■					
Motion Analysis for Brakes			■	■			
Motion Analysis for Suspension				■	■	■	
Motion Analysis for Steering System					■	■	■
Final Submissions							■