BAJA SAE: Building an Engineer

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Abstract

The desire for all employers is to hire an engineer with all of the necessary experience needed to perform the job with a high level of competence. Simulating this real-world experience in a classroom or lab becomes difficult when it has to be squeezed into a class like senior design. While for some, a good grade might be incentive enough to put forth the effort to properly gain these experiences, other things will likely become a larger priority. The SAE student design series introduces students to a competitive atmosphere that promotes extreme learning growth in a short period of time. Each portion of the competition has a specific aim that, when combined together, train a student into an engineer who is far more experienced and educated than one born from a traditional classroom. The opportunities that come from this competition, presented both to learn and grow more familiar with the real world environment of engineering are invaluable. It submerges students into an environment that encourages and promotes growth in every dimension.

Key Words: BAJA SAE, Front/Rear Suspension, Steering System, Engineer, Collegiate Design Series

1. Introduction

A professional engineer (PE) has a higher level of responsibility to provide an employer with his/her own hard-won achievement [1]. An ABET-accredited engineering program is one possible way to begin the process of becoming a PE. This goal can be achieved by regular curriculum as well as extra-curricular activities. The primary purpose of any form of education is to best prepare the student for what will be experienced in their field of study. The difficult part is simulating this real-world experience in a classroom or lab, due to the time constraints, as well as the missing incentive to be fully committed to the project if is done simply for a grade. While a grade might well be enough of an incentive for some, others will find that without the paycheck or reward at the end, other things will become a larger priority. But introduce a competition into the mix, and the dynamics completely change, hence, why collegiate sports are so huge. The Society of Automotive Engineers has created an atmosphere that promotes extreme learning growth in a short period of time, due to the increase in initiative, as well as time spent learning the subject. Each portion of the competition has a specific aim that, when combined together, train a student into a better engineer.

Since this will be the first year for UT Tyler to attend the BAJA SAE competition, the team needed a large amount of groundwork to be laid, including recruiting and training at every level. The university recognized all of the advantages that the competition brought to the school as well as to the students involved, so there were design projects available for seniors to receive credit for, while getting the BAJA program up and running. But more than getting the car designed and built, the group involved in getting the team established wanted there to be good engineering practice started from the very beginning. This meant that all decisions would be based on the BAJA SAE rules and the competition in which they would be competing.

The major activities for BAJA vehicle design at UT Tyler are introduced in brief in Section 2 and the lessons learned from this program are discussed in Section 3. Section 4 contains some closing remarks.

2. Major Activities at UT Tyler

An SAE BAJA vehicle is a small off-road vehicle used in a student competition against universities from all over the world recognized by Society of Automotive Engineering, built based on the 2018 BAJA SAE Rules [2]. The BAJA vehicle is composed of components that make up 5 main categories 1) chassis/frame, 2) drivetrain/braking, 3) steering and suspension, 4) powertrain, and 5) ergonomic systems. The chassis, gearbox, and front suspension systems have been completed in 2017 and other components are currently being built in 2018. In this section, major achievements for the current BAJA vehicle design will be introduced in brief.

2.1 Chassis and Suspension Systems

A chassis with front suspension systems is shown in Figure 1. The chassis is made from 4130 chromoly steel and is supported by Fox shocks combined with a suspension system that can withstand the variety of loads experienced at an SAE BAJA competition. The whole suspension system with the shocks could be marketed as a complete assembly.

The steering rack was placed in a lower rearward position, which allowed for a lower center of gravity of the entire system. The rearward position helped to accomplish the desired 100% Ackerman steering geometry, decreasing our turning radius and increasing the responsiveness of the steering system itself. It also moved the steering rack out of the way of the pedal box and moved the tie-rods out from in front of the A-arms where they would be susceptible to impacts from the course obstacles. Proper design practices were followed when designing the entirety of the steering system, making sure all joints were placed as to minimize bump steer throughout the entirety of suspension travel [3]. The scrub radius of 1in. was positioned so as to place the tie-rods and rod-ends in tension, rather than in compression, so that the components themselves could be smaller and lighter weight.

The spring-damper system was mounted on the lower control arm allowing for the use of the stiffness designed into tis member, using SOLIDWORKS finite element analysis, already needed for the lateral wheel loads seen on course. This also gave the team the opportunity to use a lighter shock with less travel, mounted mid-span of the lower arm reducing weight in both the shock and upper arm. The lower placement of the shock also contributed to a lower center of gravity, again, aiding the team in building a better handling vehicle.

The design of the rear suspension system is currently underway and is shown in Figure 2. Considering cost, weight, performing ability and system-level requirements, the trailing 3-link design was selected as a final design concept. Even though the double wishbone type might come in at a slightly lower weight, the trailing 3-link suspension shown offers better durability and easier manufacturability along with lower cost.

2.2 Gearbox

A single speed gearbox was designed to reduce the engine speed to driveline speed and is shown in Figure 3. The gearbox consists of single forward drive and single reverse drive manually shifted by the driver. The gear sizing and tooth pitch was chosen to reduce the maximum total gearbox weight to below 75lbs [4]. This final design was achieved by thermal expansion tests and finite element analysis on the internal components as well as the case, through the analysis tools in SOLIDWORKS.

2.3 Drivetrain

The drivetrain systems of Baja SAE vehicles are subjected to extreme conditions and must be designed accordingly. Over the years, many university teams and large companies have attempted to create a drivetrain system that can withstand these extreme conditions. During these competitions, drivetrain systems are broken due to inefficient design or fundamental design flaws. To increase the reliability and sustainability of the system, the senior design team used an iterative design process to design all of the components. This insured a reliable performance when implemented on the car during competition.

2.4 Pedal Box

The pedal box is designed to create usable inputs for the driver to easily and safely operate the vehicle. Ergonomics, adjustability and brake performance were a priority because it is important that the driver be able to operate the vehicle for the full 4 hour endurance event with minimal fatigue. This is achieved by selecting, properly sized, dual master cylinders creating a fail-safe by separating the front and rear braking systems, as well as hinging pedals at the ankle so pressure can be applied to hold the drivers position under cornering and braking loads without applying inputs into the pedals.

A bias bar is used to quickly and accurately adjust brake bias depending on track conditions and driver [5], shown in Figure 4. The pedal box is frame mounted in the chassis and has adjustability to allow for different sized drivers to operate the vehicle accurately and comfortably.

2.5 Braking Systems

The rules state that the braking system must be capable of locking up all four wheels simultaneously [2]. But, more importantly, the system must be able to be accurately used by the driver, repeatedly throughout the endurance event. The braking system, although limited by the tires and surface conditions, sets the limits of the vehicle's capabilities to keep the vehicle under control and the driver safe. Thermal and force load simulations were carried out using the SOLIDWORKS analysis tools for proper sizing of the rotors and calipers as shown in Figure 5.

3. Discussion: Lessons Learned

3.1 Real World Environment

The SAE BAJA competition is made up of two parts, Static and Dynamic, each one designed to train the students involved to perform important engineering tasks at a premier level. This being a competition forces students to choose where their priorities lie in regard to the rules and the events and how those priorities have an effect on their design, budget, as well as their business plan. As in every profession, there are things that are part of every engineering project or task that is undertaken and are required for an exemplary execution of said task, and the ability to rank priorities is one of those things. Another is arranging and adhering to a hierarchy. When an engineer is hired on in the real world, a hierarchy is already established and the hire-ons have no question who they answer to or who they go through for approval. As they grow through the company, eventually they might be in charge of a group of engineers. This is one reason it is important that teams remain established in an institution for many years, so there is a growth through all ranks before graduation; therefore, students can gain experience in being at the bottom, as well as leading and managing other engineers at the top. This is much different from the way it is done in school where students are assigned a group, and they have a short time to choose positions while everyone still feels like peers. In this case, there is not the same respect or trust, and it is difficult to succeed. Since the competition season is one year long and ideally the teams are well established, there is not that wasted time of trying to learn the group members and assign positions, and the project is instantly off to a better start.

3.2 Design Decisions

As with any competition, in order to be competitive, all decisions should be evaluated through the lens of the rules and how to capitalize on what is allowed. To do this from an engineering perspective, a decision matrix was created that evaluated each parameter against the point values for each portion of the competition, and the priorities for each system were set accordingly. One of the first projects for UT Tyler was the front steering and suspension system. This was a difficult one because both steering and suspension, individually, have a large number of design parameters that need to all work together or be compromised to achieve a design that meets the global team design goals. It forced the members tasked with the project to research the effects each of these parameters had on the performance of the system and contact experts in industry to gain knowledge not in textbooks. These relationships and networking abilities were used throughout the entirety of the project and allowed the team to gain experience they would not have had otherwise. Once the initial parameters were selected and the system was formed, the system as a whole was evaluated by the professionals that were involved early on in the process, and the necessary changes were made. These changes come from a knowledge of the field or experience with this sort of problem solving, even if from a different field. In the end, the design team ended up with an SAE BAJA compliant front suspension and steering system that would not only handle well and be responsive, but also provide a large amount of travel and ground clearance to aid the driver in overcoming obstacles while supporting a chassis, powertrain, and driver. Various factors were taken into consideration that would ultimately affect the ability of the driver to be competitive. The technology and systems that can be used to accomplish these tasks already exists. But, the details of these systems are proprietary team information for the individual BAJA SAE teams around the world. This means that the design team started from nothing but the rule book, and created a particular solution for a particular problem, using parameters chosen to make the car behave the way the team wanted, based on the team goals.

3.3 Team Integration

Each project was only one system in a very dynamic project, which means that the learning experience did not stop there. Simultaneous to the steering and front suspension project, a BAJA SAE Gearbox project was also available for seniors to be a part of, as well as an extra-curricular project of designing and building the chassis and drivetrain available to all class levels. This forced each of the design teams to meet under the advisement of the SAE faculty advisor, as well as the team's Chief Engineer. This integration of different teams and systems added another dynamic that most in-school engineering projects do not have. The design defense required to prove that the chosen method of achieving a goal is the best one for the team pushes each of the members of the design teams to not just make a system that works, but one that works best in conjunction with the other systems, as well as best with the allotted time frame and budget. All of this combined creates an atmosphere very similar to that of a real-world design team. If a student were to be exposed to this sort of project environment for the entirety of their engineering education rather than only the traditional learning environment, then the student would be an engineer at the start of their career with a dramatically different skill set from a student that graduates without this experience.

3.4 Design Defense

One of the best parts of the SAE engineering competitions, as far as engineering education goes, is the design defense portion of the Static events. This is where the teams meet with a group of industry professionals and introduce and defend the design they brought to compete and why they made the decisions and compromises that they did. Not only does this give the team members the opportunity to show what they know, it also introduces them to difficult questions they had not thought of before that allow them to improve on their future designs. Design defense can also be an incredible networking tool, where the team members can create relationships with the industry professionals involved in hosting the competition and also have the opportunity to get recruited. If, at the end of the design defense portion, the team has shown superior knowledge and are selected to be in the top 10 teams, there is a more rigorous design defense. There are several judges, each involved in questioning about a specific topic, that go around and ask all of the teams questions, and then come together to decide which team exhibits the most knowledge and sound reasoning about their design choices. This pushes the teams to learn as much as they can about their area of expertise and make the best decisions early in their design phase.

4. Concluding Remarks

This competition replaces the incentive for students to make a commitment with the promise of a boosted resume and skill set, rather than just a grade. It moves the focus from completing a class to winning a competition, thus changing their mindset completely. When students are driven to win rather than just do "good enough," the outcome is a winner and not just a graduate. At that point, winning is not just the position your team places at competition, it is getting a better job because the students are better candidates than all of the others, and are better equipped when day one of their dream job comes around. This also benefits the school by having a high placement rate, as well as increasing the caliber of first-year engineers in the field. The graduating engineers also now have a connection to their school and want to support the program in the future when they become bosses, because they know the school did their best to provide the best education available. This education is available to all who are willing to devote the time and effort to start implementing these practices, whether it is through SAE BAJA, Formula SAE, Formula Student, or any of the other engineering competitions out there available to any school.

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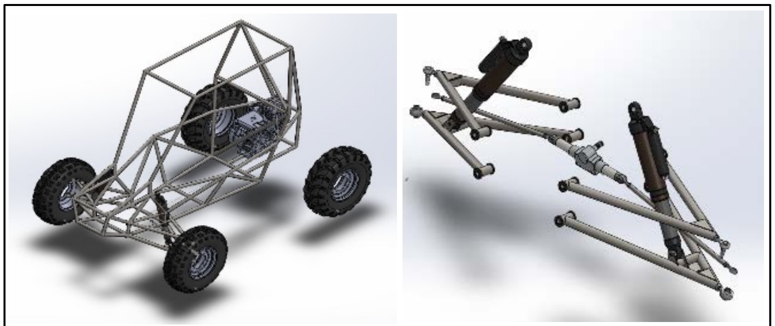

Figure 1. Chassis and front suspension system

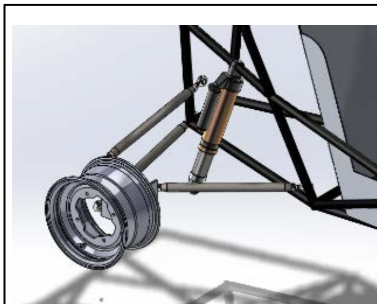

Figure 2. Trailing 3-link suspension system

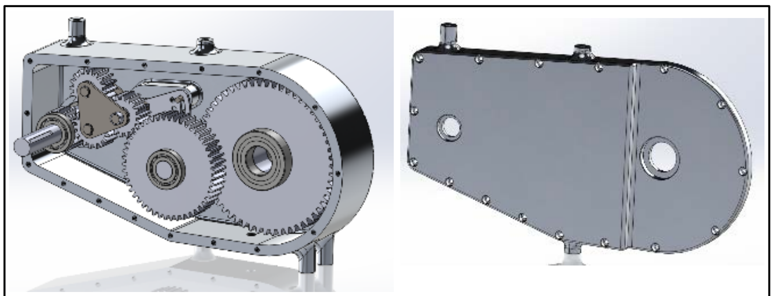

Figure 3. (a) Gearbox with assembled gear train and (b) its lid

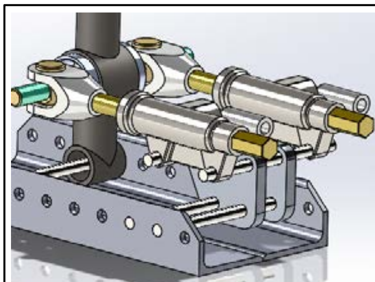

Figure 4. Pedal mounting plates with a bias bar

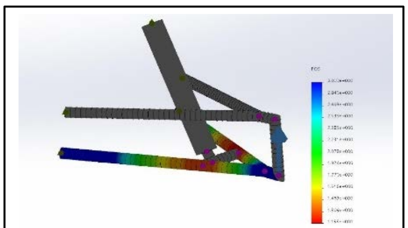

Figure 5. A FEA result of lower control arm showing the force gradient